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ELECTRIC STORAGE BATTERIES

Lead-Acid Cells

Plates, Pasting and Forming, Separators, Containers,

Electrolyte, Specific Gravity, Hydrometers,

Chemical Action.

Battery Tests

Voltage Tests, Cadmium Tests, Hy-rate Discharge Tests

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Construction, Advantages, Principles

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ELECTRIC STORAGE BATTERIES

Storage batteries are used by the millions in automobiles, radios, telephone and telegraph systems, railway signal systems, electric trucks, train lighting, farm lighting plants, and for emergency power reserve in substations and power plants.

These batteries require charging, testing and care, and although they are very rugged in their construction, they require occasional repair due to the natural wear occurring on their elements by charging and discharging in normal use. So there are numerous opportunities for trained men in electric storage battery work.

It is also very easy for one to start a nice, profitable, small business of their own with very little capital in the repairing and servicing of automobile and radio batteries.

Fig. 1 shows a neat installation of storage batteries such as used for emergency lighting in public buildings, or with farm lighting plants.

Fig. 2 shows a single cell of a large power storage battery such as used in substations and power plants for supplying thousands of amperes during short periods.

You have already learned the principles of primary cells or batteries and how electric current can be produced by immersing unlike metals in an acid solution. It has also been explained previously that storage batteries are different from primary batteries in that they require charging before they are ready to supply electricity.

1. LEAD-ACID CELLS. PLANTÉ PLATES

One of the most common types of storage batteries is known as the **lead plate** battery. This is the type that is used almost exclusively in automobiles, for battery operated radio sets, and in large power plant batteries.

In 1860 a Frenchman named Gaston Planté discovered the principles of the lead plate storage cell. He found that if two strips of pure lead were immersed in an electrolyte of dilute sulphuric acid, a thin coating of **lead sulphate** would soon be formed on the surfaces of these plates.

He then discovered that by passing current through the cell the lead sulphate on the plate by which the current entered the solution would be changed to **lead peroxide**, or a compound of lead and oxygen. The lead sulphate on the other plate by which the current left the solution changed to **pure lead** in a spongy form. The term **sponge lead** is generally used in describing lead in this condition.

Thus the unlike materials required to produce the action in a cell were created by electrolytic action on lead plates which were formerly both alike.

After thus charging the cell, Planté found that it would give off current in the opposite direction. While discharging, the lead peroxide on one plate and the sponge lead on the other are again changed back to lead sulphate, and when all of the lead peroxide and sponge lead are changed back to lead sulphate, the plates are alike again and will not supply any more current.

However, if charged again by having current passed through them in the same direction as at first, the plates can again be made unlike and the cell brought back to charged condition, ready to produce current once more.

The lead peroxide plate from which the current flows during discharge is called **positive**, while the sponge lead plate at which the current enters during discharge is called **negative.**

From this we see that when charging a lead plate storage cell the **charging current does not store electricity in the cell** but merely makes the plates unlike by changing them chemically.

When a load or closed circuit is connected across the terminals of such a cell, current flows in the opposite direction to that in which the charging current flowed, and as the unlike material on the lead plates is gradually changed back to lead sulphate the voltage across the cell terminals becomes lower and lower, reaching zero when all of the material is reduced to lead sulphate and both plates are again the same.

The positive and negative plates for storage cells of the Planté type both consist of a sheet of pure lead, with grooves or corrugations on each side to increase the active area in contact with the electrolyte and thereby increase the capacity of the cell.

2. PASTED PLATES

One of the disadvantages of the Planté plate storage cell was in the fact that the lead plates being non-porous had to be charged and discharged a considerable number of times before the coating of active material was of sufficient thickness to give the required capacity. This charging and discharging process was known as **forming** and was too lengthy and costly a process to make batteries of this type commercially practical.

To overcome this difficulty another Frenchman named Camile Fauré produced battery plates of pasted construction in 1880, and these plates turned out to be so much more efficient that they are the type still used in modern lead plate storage batteries.

Pasted or Fauré plates consist of a grid or framework of **lead** and **antimony,** upon which is applied a paste of **lead oxide.** The antimony is used
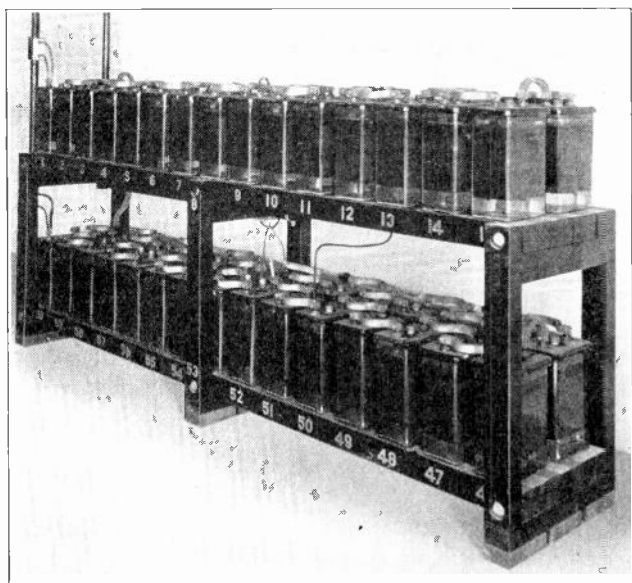
Fig. 1. This photo shows a large group of lead plate storage cells in glass jars. This battery installation is typical of those used for emergency lighting or farm lighting service, or for signal work. (Courtesy of Electric Storage Battery Co.)

with the lead to increase its mechanical strength and also to prevent the chemical action during charging and discharging from converting the grid into active material, as it would if pure lead only was used.

Fig. 3 shows a standard grid with a square mesh, and Fig. 4 shows a grid of the diamond type as used by one of the leading battery manufacturers.

The original Fauré plates had both positive and negatives pasted with **red lead.** In modern batteries **litharge** is also used with the red lead. The chemical term for red lead is: Pb_3O_4, and that for litharge is PbO.

The paste commonly used for positive plates contains a large percentage of red lead while that used for the negative plates contains a large percentage of litharge. **Lamp black** is often added to the negative plate to increase its porosity, as the negative plates tend to be rather dense on account of the large amount of litharge used in the paste.

The finished positive and negative plates are easily distinguishable by their difference in color, **the positives being of a dark brown color and the negatives dark gray in color.**

The upper part of Fig. 5 shows a positive plate on the left and a negative plate on the right. Note the difference in their color and also note the manner in which the paste is pressed into the grid flush with the surface so that both sides are smooth.

The lugs provided on the top corners of the plates are for attaching the terminals or group connectors to the cell.

In the lower part of Fig. 5 are shown a positive plate group and a negative plate group attached together by their connectors and terminal posts, and ready to place in the cells.

New battery plates for repairing worn out ones

are generally purchased from some battery supply company, as the plates can be made much cheaper in factories equipped for this work than they can in the average repair shop However, a general knowledge of plate construction and manufacture will be found interesting and possibly very valuable at some time or other; particularly if you should obtain a position in a battery manufacturing concern.

The following formula gives the materials commonly used in making the paste or active material for lead plates:

PLATE PASTE FORMULA
(Parts by weight)

POSITIVE	NEGATIVE
Red lead, 5 parts	Litharge, 5 parts
Litharge, 1 part	Red lead, 1 part
1.120 S. G. electrolyte, 1 part	1.150 S. G. electrolyte, 1 part
	1 ounce of lamp black per 100 lbs. of litharge.

As lead oxides are dry powders some liquid must be used to mix them into a paste so they can be applied to the grids. Dilute sulphuric acid is generally used for this purpose. When mixed with the lead oxides the sulphuric acid causes a chemical action to take place which changes part of the oxides to lead sulphate, causing the paste to harden rapidly, so that it is necessary to work fast when applying paste to the grids.

In making battery plates the paste can be applied either by hand or by special machines made for this
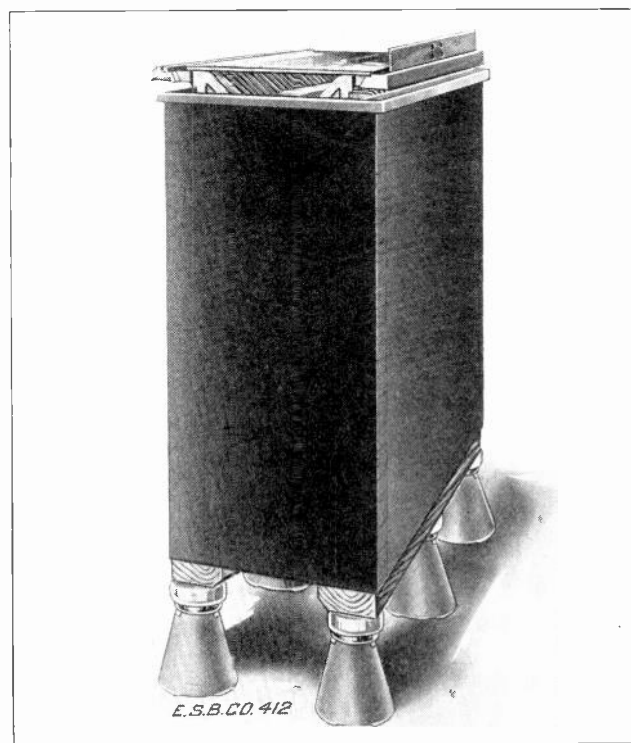

Fig. 2. Large lead plate storage cell in which the plates are supported inside of a lead lined wood tank which is in turn supported on insulators. Cells of this type are commonly used for emergency power and for D. C. control busses in power plants. (Courtesy of Electric Storage Battery Co.)
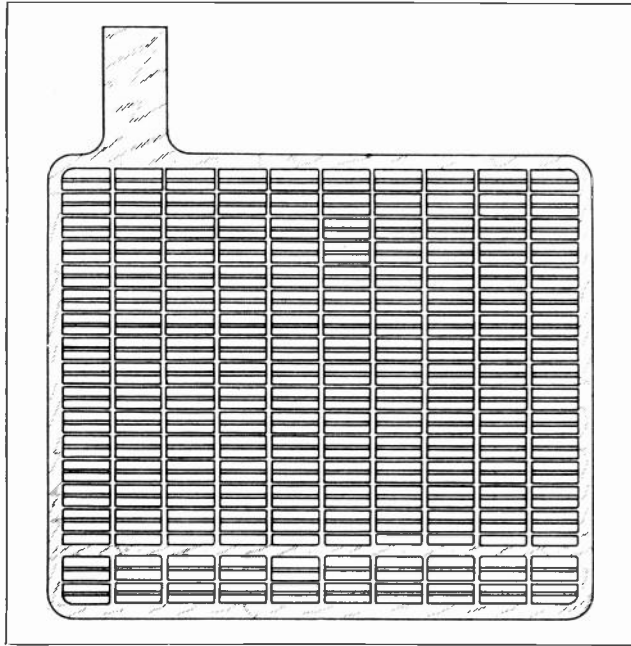
Fig. 3. The above drawing shows the construction of one common type of grid used for pasted plates. This drawing shows the grid before the paste has been applied.

work. When done by hand the pasting is generally done on a glass or marble covered table with sheets of blotting paper being placed between the grids and the table top. The paste is then applied to the grids from the top by means of a trowel, pressed firmly into the grid, and smoothed off flush with the surface.

After pasting, the plates are dried in a rack by circulating air over and around them at room temperature. The drying causes the paste to set and become hard and at the same time cements it firmly to the grid. As soon as the plates are dried they are ready for forming.

3. FORMING OF PLATES

We mentioned previously that it was necessary to form or condition lead plates of the Planté type by charging and discharging them. It is also necessary to form pasted plates by giving them one prolonged charge that changes the oxides of the paste into active material.

For forming the plates are assembled into groups, the positives together in one group and the negatives in another, and the plates separated far enough apart so that separators are not necessary between them.

These two groups are then placed in a tank filled with 1.150 specific gravity electrolyte, with the positive and negative plates in alternate positions, or one negative between each positive and the next, the same as they are arranged in the finished battery.

Direct current from a D. C. generator or line is then passed through the forming tank, being careful to connect the terminals so that the current flows into the tank at the positive plates and out at the

negative plates. In other words connect the positive terminal of the line or generator to the positive plate group.

The paste in the positive plates where the current enters will be changed to lead peroxide or PbO_2, while the paste on the negative group at which current leaves will be changed to sponge lead or Pb.

When the electrolyte begins to gas or bubble quite freely and the voltage between the positive and negative groups tests between 2.1 and 2.2, the plates are fully formed.

When the forming process is completed the plates are dried and are then ready for use in a battery.

4. STORAGE BATTERY CONSTRUCTION AND PARTS

So far we have discussed only the plates, which are the most important part of any storage battery. To complete the battery, however, requires a number of additional parts, such as container, jars, separators, connector straps, terminals, cell covers, etc.
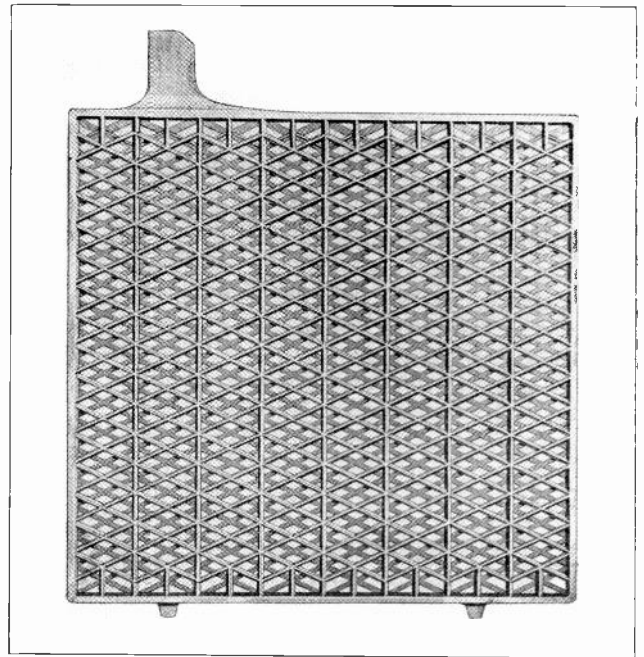

Fig. 4. Photo of another type of grid of the diamond type construction. The lead bars serve both as a frame to hold the paste or active material and as conductor to carry the current from the active material to the plate lug. (Courtesy of Philadelphia Battery Co.)

Fig. 6 shows a number of these parts required for a complete battery. On the extreme left and in the background is a complete cell and in front of this and to the right are shown two more positive and negative groups assembled together. In the center is shown a wood battery box or case and in front of it a stack of wood separators and two cell connector straps. On the right are shown two empty cell containers or jars with their covers and vent caps.

In constructing a storage battery of the lead plate type a number of positive plates are connected together by burning or welding them to a lead con-

nector strap equipped with a terminal post, as shown in the lower left view of Fig. 5.

The number of plates selected depends on the size and capacity of the cell to be built. The greater the number or total area of the plates the greater will be the capacity of the cell.

A group of negative plates consisting of one more than the number of positives is then fastened together in the same manner and the positive and negative groups meshed together, as shown in the left foreground of Fig. 6.

The reason for always having one more plate in the negative group of a cell than in the positive group is because the capacity of cells is rated and determined according to the number and size of positive plates, and in order to work both sides of the positives it is necessary to have a negative plate on each outer side of the positive group, and this requires one additional negative in each cell.

The voltage of any single cell or group of positive and negative plates is slightly over 2 volts in the ordinary lead plate battery when fully charged. The standard automobile battery consists of three such cells connected in series, and develops 6 volts. Twelve-volt batteries have been used to some extent for automotive work but are rapidly becoming obsolete, because of the tendency of car manufacturers to standardize on six-volt starting and lighting systems.

Fig. 7 shows three groups of positive and negative plates assembled together for a three-cell battery. Such positive and negative groups are called **elements**.

Fig. 6. This view shows the more important parts of a lead plate storage battery for automotive use. Note carefully these various parts when reading the accompanying paragraphs. (Courtesy of Universal Battery Co.)

5. SEPARATORS

After the positive and negative groups are fitted together as explained the positives must be insulated from the negatives by inserting thin wood or rubber **separators** between them.

These separators are used to keep the plates from touching each other and thereby forming internal short circuits. The separators must be porous so the electrolyte can pass through them and so that they will offer the least resistance to the passage of current. They must also be designed to allow free circulation of electrolyte over the surface of the positive plates.

Although separators are made of both wood and rubber the wood separator is most generally used. Cedar and cypress separators are generally used because of their porosity which reduces the internal resistance of the cell, and because of their ability to resist the action of the acid in the electrolyte.
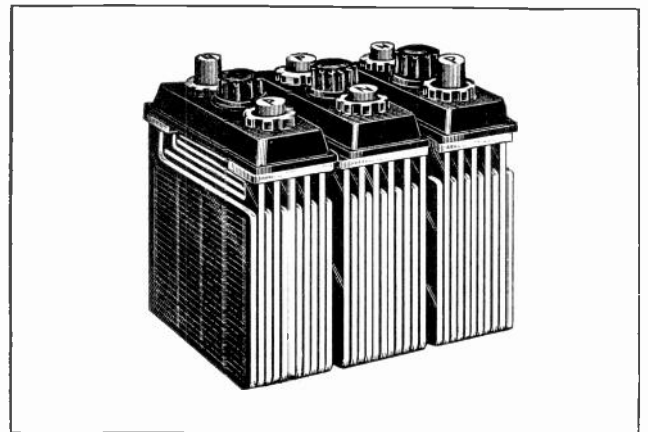
Fig. 7. Above are shown three groups of positive and negative plates assembled together and ready for separators before being placed in the cells of a battery.

Separators made of basswood and of hardwood are also sometimes used.

Separators are provided with grooves on one side and when inserted between the plates they should always be placed with the grooved side next to the positive plates and with the grooves running vertically, or up and down, so as to provide free circulation of the electrolyte.

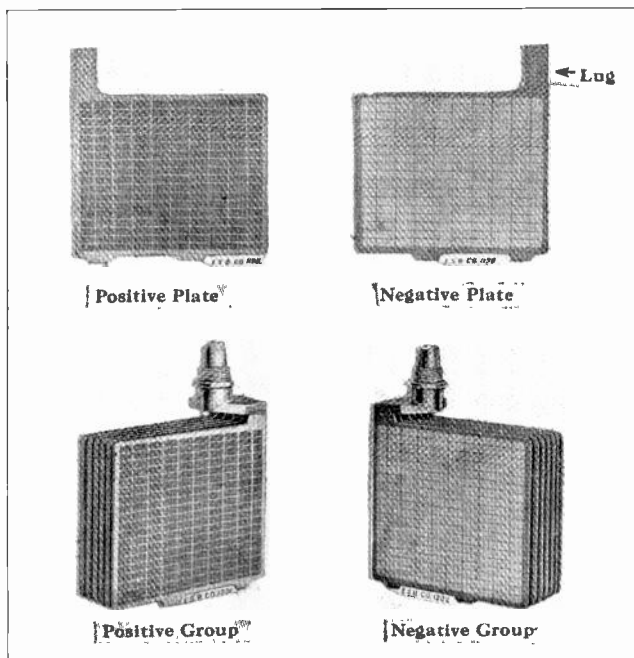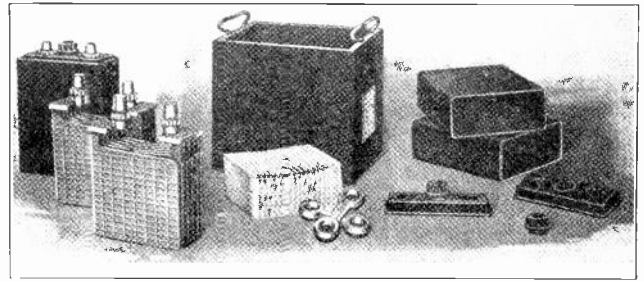After being sawed and grooved, cedar and cypress

Fig. 5. The above views show completed or pasted plates of both positive and negative types. Single plates are shown above, and below the plates are shown grouped or connected together to the cell terminals. (Courtesy of Electric Storage Battery Co.)

separators are always treated in a hot alkaline solution and then washed thoroughly. The purpose of this treatment is to remove certain substances from the wood which would otherwise form acetic acid if not removed. Acetic acid interferes with proper chemical action in the battery and may also damage the battery as it tends to corrode the lead. Sometimes plate lugs are so weakened and corroded due to presence of this acid that the plates drop off the lugs. The treatment also tends to increase the porosity of the separators and thereby reduce their resistance to the passage of current through the cell.

As the separators are treated at the factory where made they are shipped wet or damp and **must be kept damp until they are** put into service. If they are kept in water a small quantity of sulphuric acid should be put in the water to prevent the separators from becoming slimy or moldy.

Fig. 8 shows several different styles of wood separators with grooves of different sizes and various spacings.
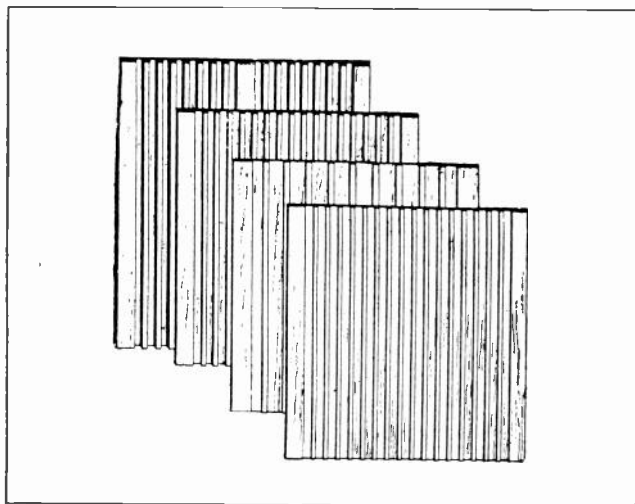

Fig. 8. Several different sizes of wood separators with different types of grooves. These separators are used to insulate the positive and negative plates from each other and prevent them from short circuiting within the cells.

When separators are fitted between the positive and negative plates they should be trimmed and set so that their tops will come at least 3/16 or ¼ of an inch above the tops of the plates, in order to prevent short circuits that might otherwise be caused by foreign material dropping in the cell through the vent opening when the vent plugs are removed.

Special cutters or separator trimmers can be obtained for trimming wood separators to proper size. A separator trimmer consists of a flat board with a knife attached to its edge by a hinge, so that separator edges can be sheared off by placing them on the board under the knife.

Another type of separator developed by the Willard Storage Battery Company is known as the **threaded rubber** separator. This separator is made of a thin sheet of hard rubber which has a large number of short threads placed crosswise through the

rubber when the separator is molded. These threads number over 6000 to the square inch and serve as wicks to allow the electrolyte to circulate through the separator, and also to afford a path for the passage of current through the acid soaked threads.

The threaded rubber separator has ribs or corrugations on one side which correspond to the grooves on wood separators. When installed between the plates the ribbed side of the rubber separators must be placed next to the positive plates with the ribs running vertically, or up and down.

6. RETAINERS AND ISOLATORS

Some battery makers use thin perforated sheets of hard rubber about 1/64 of an inch thick, which are placed between the ribbed side of the wood separator and the positive plates. These thin rubber sheets are called **retainers** and are used to prevent the active material from shedding or falling out of the grid of the positive plates.

These retainers, however, have the disadvantage of a tendency to clog up, and thus increase the internal resistance of the cell.

One large battery manufacturing company uses additional notched strips of hard rubber which are fitted into slots cut in the edges of the grids. These strips are called **Isolators** and are for the purpose of locking the edges of the plates rigidly in position to prevent warping and distortion of the plates with age or severe use.

The use of these isolators doesn't eliminate the necessity for separators but the isolators give a great deal of added strength and rigidity to the plate groups, and prevent the plates buckling and cutting
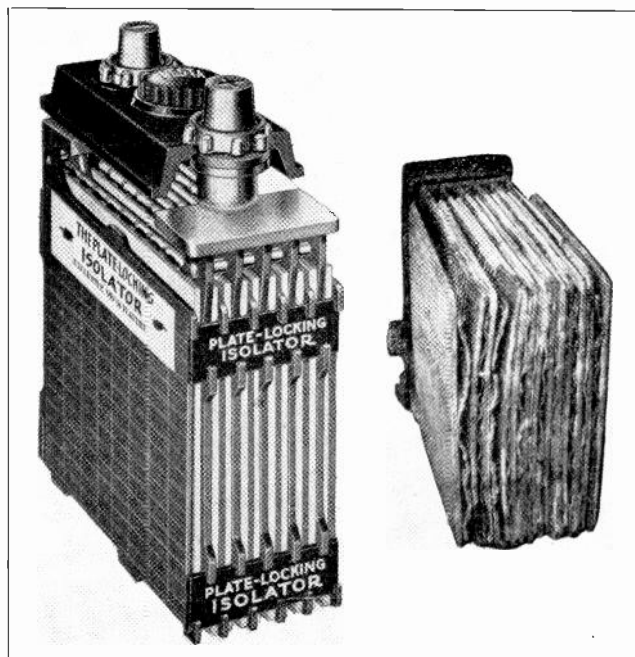

Fig. 8A. This photo shows on the left an excellent view of a cell element equipped with isolators for holding the plates in position and preventing warping or buckling; and on the right is shown a group of badly warped plates which were not equipped with isolators of this type. (Courtesy of Vesta Battery Co.)

through the separators where the plate corners would otherwise become warped against them.

When a separator becomes worn through by pressure from warped plates it allows the plates to short circuit and puts the cell out of commission.

The view on the left in Fig. 8-A shows an element or group of positive and negative plates equipped with isolators, and on the right in this same figure is a group of badly warped plates showing what may happen to a plate group that is not equipped with isolators.

The position of the wood separators and the manner in which their tops are allowed to project slightly above the plate tops are also shown in the left view of Fig. 8-A.

Isolators were formerly made from celluloid, but the disadvantage of this material was its tendency to melt or dissolve at high temperatures, so hard rubber is the material now used.

7. CELL CONTAINERS AND BATTERY CASES

After an element or group of positive and negative plates has been assembled with separators it is ready to be placed in the cell container. Each cell must, of course, be insulated and separated from the other cells in the battery, and the containers used for this purpose must be acid-resistant and able to withstand a certain amount of mechanical abuse and vibration.

Hard rubber meets this condition very well as it resists the action of the acid and is fairly tough and strong. Glass is also acid resisting and can be used in the construction of batteries for stationary use where they are not subjected to any mechanical abuse or severe vibration.

Fig. 9 shows a hard rubber jar or cell container on the left and a rubber jar cover on the right. Ribs or ridges about one inch high are provided in the bottoms of these jars to strengthen them and also to keep the plates up off the bottom of the cell, and prevent their being shorted by any active material which may shed from the plates during use and settle to the bottom on the container. The ribs in the jar bottoms form spaces in which this loosened active material settles and prevent it from reaching the lower edges of the plates.
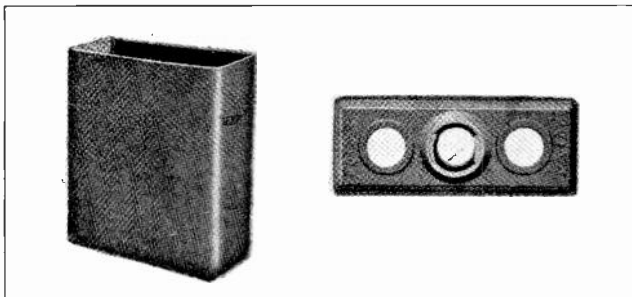
Until recent years automotive battery cell groups

Fig. 9. This view shows a common type of hard rubber cell jar and cover such as used in automobile batteries with wood cases.
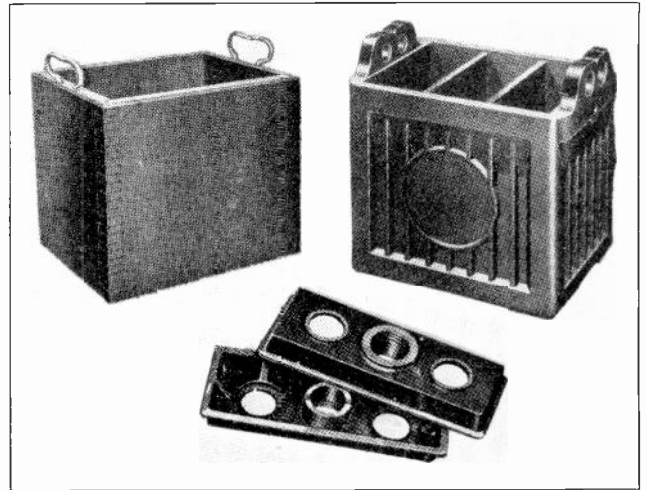

Fig. 10 Above are shown two types of cases commonly used with automobile batteries. The one on the left is made of wood and the one on the right is made of molded hard rubber. Two-cell covers are shown beneath the cases.

or elements were all placed in individual jars of this type and the three or six jars, or complete cells, then mounted in a wood box such as shown in the left in Fig. 10.

Wood battery cases have the disadvantage of being subject to rotting and rapid deterioration due to the action of the acid fumes or any acid spilled upon them. Their life can be greatly prolonged by coating the wood with acid-proof paint, but even then wood cases are not very satisfactory for automotive batteries or other uses where they receive rough treatment.

A much better battery case which has come into very general use for automotive and radio batteries in the last few years is the hard rubber case, such as shown on the right in Fig. 10. These cases are not affected by acid and, therefore, last much longer than wood cases and they are very strong and compact.

You will note that the cell partitions of hard rubber are built right into these cases so they do not require separate cell jars but are complete when fitted with rubber cell covers, such as shown beneath the cases in Fig. 10. These covers are used to close the tops of the cells and keep out dirt, water, etc., and to prevent spilling of the electrolyte.

The covers are each provided with three openings. One in the center for the vent and filler cap and one near each end for the terminal posts of the plate groups to project out to the connectors. The sides of the covers are so shaped that when they are installed in a jar or case a V-shaped space or groove is formed all around their edges between the cover and the side of the battery. Into this groove is poured hot sealing compound which hardens as it cools and forms an acid-resistant seal between the cover and container.

Fig. 11 shows two complete automobile batteries. The one above being built in a wood case and the one below in a rubber case.
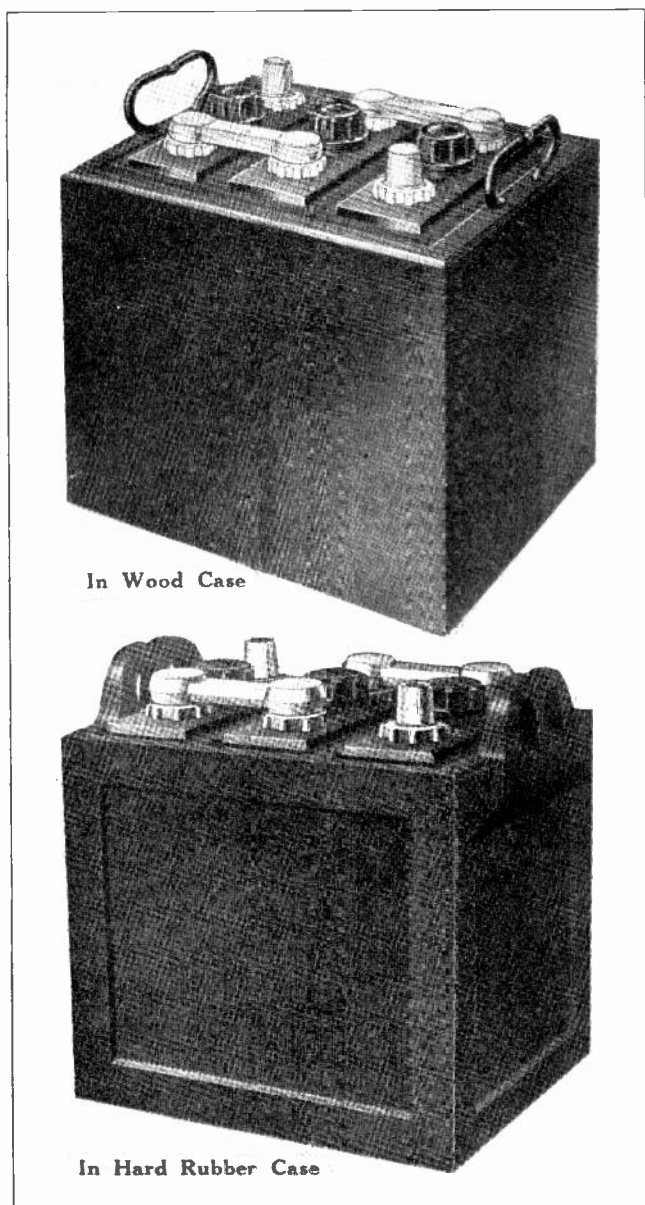
In Wood Case

In Hard Rubber Case

Fig. 11. Top view shows a completed wood case battery of the 3-cell, 6-volt type, and below is shown a complete battery of the same type but in a rubber case.

8. ELECTROLYTE

After a new battery is completed or an old one repaired each cell must be filled with electrolyte, and the level of this electrolyte should always be kept from ⅜ to ½ inch above the tops of the plates.

The electrolyte used in lead plate storage batteries consists of chemically pure sulphuric acid (H_2SO_4) and distilled water. A commercial grade of acid should never be used, as it contains certain impurities which may cause local action and rapid deterioration of the battery plates even when the battery is not in use. For the same reason distilled water only should be used, as ordinary well water or water from a faucet contains chemicals that are detrimental to battery action and life. You will recall from an earlier article on primary cells that local action is caused by impurities in the plates or electrolyte,

setting up local short circuits or small active cells at various spots on the plate surface wherever the impurities lodge or collect.

9. SPECIFIC GRAVITY

The term **specific gravity** has already been mentioned and is one with which we should become thoroughly familiar at this point. Specific gravity refers to specific weight of any liquid or substance compared to the weight of an equal volume of pure water, or, in other words, the ratio of the weight of the substance to the weight of an equal volume of water.

The specific gravity (S. G.) of pure water is assumed to be 1, usually written 1.000, and is used as a standard for comparing the weights of similar volumes of other materials and thus establishing their specific gravity.

One pint of water weighs approximately one pound and one pint of sulphuric acid weighs 1.835 pounds. So we say the specific gravity (S. G.) of sulphuric acid is 1.835. This shows us the acid is about 1.8 times heavier than water.

10. HYDROMETERS

The specific gravity of any liquid can be easily and quickly determined by means of a device called a **hydrometer.**

Fig. 12 shows a hydrometer on the left, and in the view on the right one of these devices is shown in use to test the specific gravity of the electrolyte in a battery.

A hydrometer consists of a glass tube syringe containing a small float inside of the glass tube as shown in Fig. 12. The float is weighted at the bottom end so that it will float upright when the outer
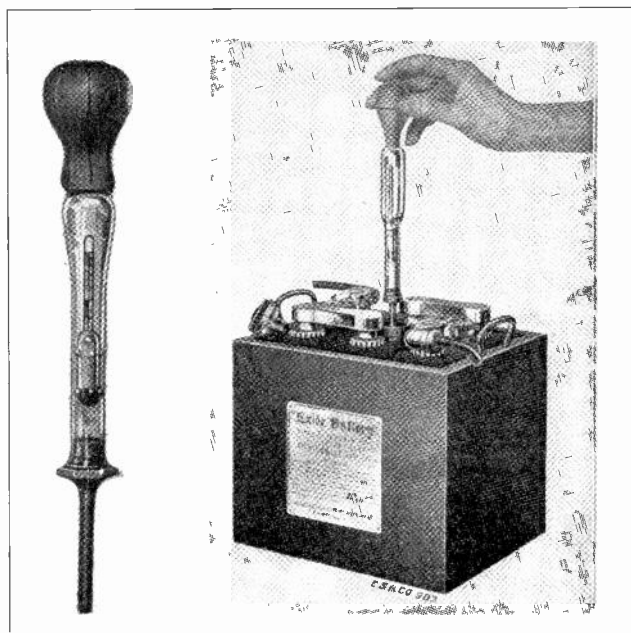

Fig. 12. On the left is shown a common battery hydrometer. Note the small float within the glass barrel of the hydrometer and also the rubber bulb on the top for drawing in the electrolyte. The view on the right shows the method of using a hydrometer for testing the electrolyte of a battery.

tube is filled with liquid which has been drawn in by the rubber bulb. The upper end of the float is marked with a graduated scale from 1.100 to 1.300 for ordinary automotive battery testing.

In speaking of specific gravity or hydrometer readings taken of battery electrolyte, instead of stating the figure in full as a fraction, we generally drop the decimal and shorten the expression. For example the reading 1.200 would be called twelve hundred, and the reading 1,275 called twelve seventy-five, etc. The decimal is also commonly left out of the figures marked on the scales of battery hydrometers.

In order to indicate the specific gravity of the liquid which is drawn into the hydrometer tube, the float is weighted just the right amount so that it would float in water with the mark 1 just at the surface of the water. Sulphuric acid being heavier than water the float will not sink as far in the acid but will float higher, and the specific gravity of the acid can be read at the float mark which is at the surface of the acid.

In using a hydrometer the bulb is depressed and the syringe tip immersed in the liquid to be tested. Releasing the bulb then draws the large glass tube partly full of liquid and causes the float to rise. Care should be taken to see that the float doesn't stick to the glass tube but rises freely in the liquid. If too much liquid is drawn into the hydrometer the top of the float may be held against the top of the syringe tube or up in the bulb, and some of the liquid should be forced out so that the float will ride freely at a convenient level for reading.

As the amount of acid in the electrolyte of a storage battery varies during charge and discharge and thereby varies the gravity of the electrolyte, hydrometer readings are a good indication of the state of charge. This method of testing will be explained later.

11. PREPARATION OF ELECTROLYTE

In preparing electrolyte for lead plate storage batteries for automobile use sufficient water is mixed with the sulphuric acid to bring its specific gravity to about 1.280 or 1.300 according to the strength desired. Sulphuric acid can be obtained in the concentrated form (1.835 specific gravity) but is more generally supplied partly diluted to 1.400 specific gravity for use in preparing battery electrolyte.

When mixing concentrated or 1.835 S. G. sulphuric acid and distilled water **always add the acid to the water slowly, and stir the solution continuously while adding.**

If the water is added to the acid the mixture will heat so violently that it may break the container and injure the operator, or the violent boiling may splash acid in one's eyes.

Sulphuric acid even in its diluted form in battery electrolyte is very injurious to clothing and will burn the skin of the hands if not immediately

washed off. Strong sulphuric acid is very dangerous if carelessly handled and allowed to splash into the eyes or on the face and hands of the operator. Ammonia and strong soda water are good neutralizers for this acid, and should always be on hand and immediately used to wash off any acid from the flesh or clothing in case of an accident.

Mixing of electrolyte should be done in an acid-proof container of hard rubber, glass, earthenware, or lead. A wooden paddle or glass rod should be used to stir the solution. Don't use metals for this purpose.

The electrolyte should be allowed to cool below 90° F. before being put in battery cells.

When preparing electrolyte with prediluted sulphuric acid of 1.400 S. G. and distilled water it doesn't matter which one is poured into the other,

MIXING ELECTROLYTE BY VOLUME		
WATER	DILUTED ACID	Sp. Gr. OF ELECTROLYTE
ADD 3½ PINTS OF DISTILLED WATER	TO 1 GAL. OF 1.400 ACID	FOR 1.300 ELECTROLYTE
" 4½ " " " "	" 1 " " " "	" 1.280 "
" 5 " " " "	" 1 " " " "	" 1.275 "
" 5½ " " " "	" 1 " " " "	" 1.260 "

Fig. 13. This convenient small table shows the amount, by volume, of water and acid to be mixed together to produce battery electrolyte of four different strengths.

but care should be used not to mix large quantities too fast and it is well to stir the solution while mixing.

A convenient table for preparing battery electrolyte from 1.400 S. G. acid is shown in Fig. 13. This table shows the number of pints of distilled water to be added to each gallon of 1.400 acid to produce electrolyte ranging from 1.300 to 1.260 S. G.

Another convenient table for mixing electrolyte ranging from 1.120 S. G. to 1.400 S. G. from concentrated acid of 1.835 S. G. is shown in Fig. 14. This table gives the amounts of water both by volume and by weight so that either method of measuring can be used according to which is most convenient. The table also gives in the last column the percentage of sulphuric acid in the electrolyte solution.

12. TEMPERATURE CORRECTION

You will note that in the table in Fig. 14 the temperature of both the acid and electrolyte is speci-

MIXING TABLE			
SPICIFIC GRAVITY OF SOLUTION OR ELECTROLYTE AT 70° F.	PARTS OF WATER TO 1 PART OF C. P. SULPHURIC ACID 1.835 SP. GR. AT 70° F.		PERCENTAGE OF SULPHURIC ACID IN SOLUTION
	BY VOLUME	BY WEIGHT	
1.120	8.00	4.40	17.40
1.150	6.15	3.35	21.40
1.180	4.95	2.70	25.20
1.200	4.33	2.36	27.70
1.220	3.84	2.09	30.20
1.250	3.22	1.76	33.70
1.270	2.90	1.57	36.10
1.280	2.75	1.49	37.30
1.300	2.47	1.34	39.65
1.350	1.95	1.06	45.20
1.400	1.56	0.84	50.50

Fig. 14. This table shows the amounts, both by volume and by weight, of water and full strength acid which should be mixed together to produce electrolytes of different specific gravities.

fied to be 70° F. This temperature is mentioned because all hydrometer readings are based on an electrolyte temperature of 70° F., due to the fact that at other temperatures the readings will change, because the liquid expands and becomes lighter for a given volume when heated and contracts and becomes heavier when cooled.

As the weight or density of the liquid determines the height at which the hydrometer float will rest in the liquid and the reading which will be obtained, we can readily see that the temperature of the electrolyte will affect the hydrometer readings.

This is a very important point to remember when making hydrometer tests on electrolyte during mixing, or on the electrolyte of batteries that may have become overheated during use or charging, or that may be extremely cold or warm due to climatic conditions.

For correcting hydrometer readings according to the temperature of the electrolyte a device called a **correction thermometer** is commonly used. Fig. 15 shows a thermometer of this type which can be inserted in the electrolyte when mixing or into the electrolyte of the battery through the vent opening.

This correction thermometer has two scales. The scale on one side being used for the temperature readings and the one on the opposite side is the correction scale.

The reading on the correction scale at the point where the thermometer indicator line rests will give the number to add to or subtract from the hydrometer readings to get the corrected reading. The scale also shows by a + or − sign before each figure whether the number should be added to or subtracted from the hydrometer reading.

A convenient rule to use in making temperature corrections when a correction thermometer is not available but the temperature of the battery or electrolyte is known is as follows:

For every three degrees above 70° F. one point is added to the hydrometer reading, and for every three degrees below 70° F. one point is subtracted from the hydrometer reading.

For example, if we have electrolyte at a temperature of 100° F. and the hydrometer shows a reading of 1.270, then the electrolyte temperature being 100°, or 30° above 70°, we will divide 30 by 3 and find that 10 points must be added for correction of the hydrometer reading. Then 1.270 plus 10 = 1.280 or the correct gravity reading.

13.   CHEMICAL ACTION IN CELLS DURING CHARGE AND DISCHARGE

In order that you may more fully understand some of the tests used with storage batteries and be able to recognize certain trouble symptoms and give the batteries the proper care, it will be well at this point to consider the action that takes place within the cells while they are charging and discharging.

It is also particularly valuable to know the condition of the plates and electrolyte both in charged and discharged condition. Let us start first with a new battery that is fully charged and consider the action that takes place during discharge.

When a lead plate battery is **fully charged** the active material in the positive plates is in the form of **lead peroxide** and is brown in color. In the negative plates the active material is in the form of **sponge lead** which is gray in color. The electrolyte will be at **maximum density** which is **between 1.280 and 1.300 S. G.** for automotive batteries.

With the battery in this condition the **open circuit voltage** of each cell will be **between 2.1 and 2.2 volts.** Now if the cell is connected in a closed electrical circuit current will flow due to this voltage or pressure, from the positive terminal of the cell through the circuit, and back to the negative terminal.

As the cell discharges certain chemical changes take place within it. **The acid in the electrolyte is gradually absorbed by the plates** in the process of changing the lead peroxide and sponge lead into lead sulphate. Thus the plates which were unlike when the cell was charged tend to become alike on discharge, or both change to lead sulphate.

The specific gravity or density of the remaining electrolyte decreases in proportion to the acid absorbed by the plates, so as the discharge progresses the electrolyte becomes weaker and weaker. When
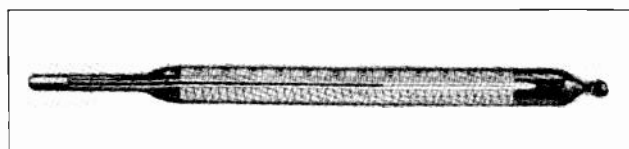

Fig. 15. Convenient type of battery thermometer for making corrections in hydrometer readings according to temperature of electrolyte.

the specific gravity shown by the hydrometer reading drops to 1.150 if we test the cell voltage with a voltmeter you will find that it is down to about 1.7 or 1.8 volts, and we then consider the cell discharged.

So we find that in a discharged cell we have two conditions to observe. First, the active material on both plates has been changed to lead sulphate. Second, the density or specific gravity of the electrolyte is very little above that of pure water. It is, of course, possible to obtain considerable current from a battery after the cell voltage has dropped below 1.7, but it is generally not considered practical and is not good for the battery to discharge it much below this point. So when the voltage drops this low and the hydrometer readings show about 1.150 the batteries should be recharged.

During charging a reverse action to that which occurred during discharge takes place. To charge a cell direct current is sent through it in a direction opposite to the flow of current when the cell was

discharging. This causes the sulphuric acid to be driven out of the plates back into the electrolyte, thus raising the density or specific gravity again. At the same time the lead sulphate in the positive plates is changed back into lead peroxide and the lead sulphate on the negative plates changed back into sponge lead.

When practically all of the acid has been driven out of the plates and the lead sulphate converted into lead peroxide and sponge lead the cell is said to be fully charged, and should show a specific gravity reading of between 1.280 and 1.300 and a cell voltage of 2.1 and 2.2 on open circuit test.

When the cells are fully charged some bubbling or "gassing" of the electrolyte will be noticed. This is due to the fact that when the charging current has no more lead sulphate to work on, it will convert the water in the electrolyte into hydrogen and oxygen gas which will come to the surface of the electrolyte in the form of small bubbles, thus indicating that the cell is about fully charged.

## 14. CHEMICAL TERMS AND FORMULAS OF BATTERY ACTION

While it is of no great importance to the average battery service man to know the exact chemical reaction that takes place within the batteries during charge and discharge, it is often very interesting to know this action as described in chemical terms.

The chemical reaction which takes place in the cell during charge and discharge can be described as follows:

We know that the electrolyte is composed of sulphuric acid and water, or H_2SO_4, the H_2 representing two parts of hydrogen gas, S one part of sulphur, and O_4 four parts of oxygen. The lead peroxide on the positive plates consists of PbO_2, in which Pb represents one part of lead and O_2 represents two parts of oxygen. The sponge lead on the negatives can be represented by the chemical symbol Pb which is one part of lead.

The lead sulphate which is formed on both positives and negatives during discharge is designated by the symbol $PbSO_4$, in which Pb represents one part of lead, S one part of sulphur, and O_4 four parts of oxygen.

The action which takes place in the positive plate during discharge, or the uniting of the lead peroxide with hydrogen and sulphuric acid from the electrolyte, can be chemically explained as follows:

$$PbO_2 + H_2 + H_2SO_4 = PbSO_4 + 2 H_2O.$$
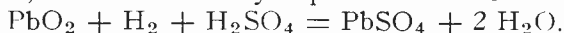
The action on the negative plates during discharge, or the uniting of sponge lead with sulphuric acid to form lead sulphate, is described as follows:

$$Pb + SO_4 = PbSO_4.$$
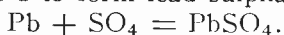
The action on the positive plate during charging and when current is sent backwards through the solution and plates, causing the chemical elements to reunite into their original form, is as follows:

$$PbSO_4 + H_2O + O = PbO_2 + H_2SO_4.$$
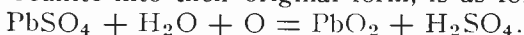
The action on the negative plate during charge is $PbSO_4 + H_2 = Pb + H_2SO_4.$

As previously stated no particular effort needs to be made to study these chemical formulas, and they are given here only for convenient reference in case special questions arise regarding them.

15. BATTERY TESTS

There are a number of different tests which can be made easily with hydrometer, voltmeter, ammeter, etc., to determine quite accurately the condition of lead plate storage batteries. These are of particular value for the practical battery service man to know.

This Section should be carefully studied until you are sure you are thoroughly familiar with methods of making each test and the battery conditions indicated by them.

One of the most commonly used tests on storage batteries is the gravity test which is made with a hydrometer as previously described. In the preceding article we found that the specific gravity of the electrolyte in a battery changes considerably as the battery charges or discharges.

The gravity increases as the acid is driven out of the plates and into the solution during charge, and decreases as the acid is absorbed from the electrolyte by the plates during discharge. So we can readily see that a hydrometer reading taken at any time will indicate the approximate condition of charge or discharge.

Automotive batteries are commonly made so that when they are fully charged the specific gravity of the electrolyte will be 1.280 to 1.300, and when the gravity drops to 1.150 they are considered to be practically discharged and should be put on charge immediately as it is very harmful for a battery to stand in a discharged condition.

Automotive batteries built for use in tropical climates are made so that they are fully charged at about 1.200 S. G. The reason for this is that in such climates there is no danger of freezing, and the electrolyte being always warm is more active.

Furthermore electrolyte of the same acid strength will give a lower gravity reading because of its expanded and less dense condition at the warm temperatures.

The convenient chart in Fig. 16 shows the conditions indicated by various gravity readings. Fig. 16-A shows the position of a hydrometer float in

BATTERY CONDITIONS INDICATED BY GRAVITY TESTS		
1.150 Sp. Gr.------------DEAD	AUTO BATTERIES IN TEMPERATE CLIMATES	ELECTROLYTE TEMPERATURE AT 70°F.
1.215 Sp.Gr.----------½ CHARGE		
1.280-1300 Sp.Gr.-----FULL "		
1.200 Sp. Gr.-------FULL CHARGE	AUTO BATTERIES IN TROPICS	
1.225 Sp.Gr.-------- " "	STATIONARY AND VEHICLE BATTERIES	

Fig. 16. Chart showing conditions of charge indicated by various hydrometer readings on lead plate storage batteries in different climates.
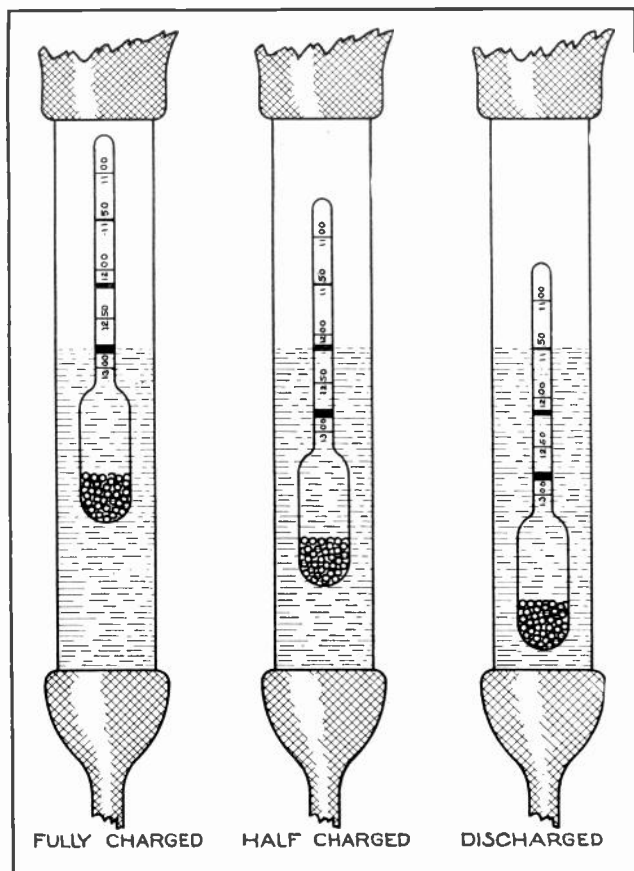
FULLY CHARGED   HALF CHARGED   DISCHARGED

Fig. 16A. This drawing clearly shows how to read an ordinary battery hydrometer. Study each of the three views very carefully while reading the accompanying explanation.

three samples of electrolyte taken from charged, half charged, and discharged batteries. Careful observation of the hydrometer sketches in this figure will be of great assistance in learning to properly read these devices.

16. VOLTAGE TEST

While the hydrometer test must be used to determine the condition of the electrolyte and is generally a rather good indication of the state of charge of a battery, it is not altogether reliable for this latter purpose.

We know that there should always be a definite relation between the voltage of a cell and the specific gravity of its electrolyte, but in some cases the gravity of the electrolyte may have been altered by adding strong acid or by replacing a large quantity of spilled electrolyte with distilled water.

In either of these cases a gravity reading would not be an accurate indication of the true condition of the cell. So a voltage test made by connecting the terminals of a low-reading voltmeter across a cell or battery is a more reliable means of determining whether the battery is fully charged or not, and whether the positive and negative plates have been made as unlike as possible by the charging current; because it is only when the active material of these plates is fully converted back to its original charged

state that the voltage between the positive and negative terminals will be at maximum.

Comparing such a voltmeter reading with the hydrometer reading will also indicate whether the electrolyte is overrich or weak. For example, if the electrolyte shows a S. G. of 1.280 or 1.300 and a voltmeter only shows a reading of 1.8 volts per cell, this indicates that the electrolyte is too rich in acid and should be diluted with distilled water.

On the other hand if the voltmeter indicates a cell voltage of 2.2 and the hydrometer reading shows the gravity of the electrolyte to be only 1.230, this indicates that the electrolyte is too weak and should be slightly strengthened by adding more acid.

17. ON-THE-LINE VOLTAGE TEST

Voltmeter readings obtained when testing a battery will vary somewhat according to whether the battery is charging, is open-circuited and disconnected from the charging line, or is discharging under load.

The **on-the-line** voltage test is made while the battery is connected **in the charging line and charging.** At the end of the charge or when the cell is about fully charged the maximum cell voltage on this test will be about 2.5 volts. This voltage indicates a complete chemical change of the material in the plates. Old batteries often do not rise above 2.3 volts per cell on this test due to the negative plates retaining some of their lead sulphate.

Once the voltage of the cell reaches 2.5 volts there can be no further rise of gravity since the plates are free from lead sulphate. If the gravity is below or above the full charge specific gravity of the cell it should be corrected by adding acid or water accordingly.
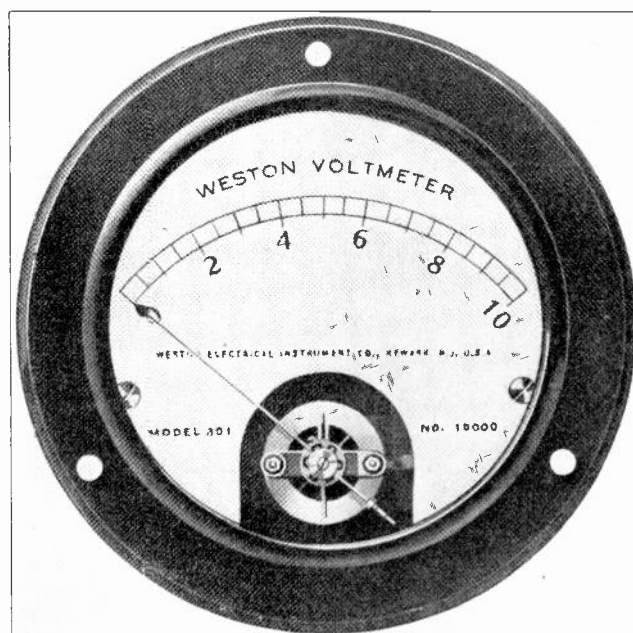

Fig. 17. Popular type of low reading voltmeter which can be mounted on a bench, panel, or portable test panel, and used for testing the voltage of storage cells or batteries. (Photo courtesy of Weston Electrical Instrument Co.)

It is not advisable to attempt to correct the density or gravity of the electrolyte before bringing the voltage up to maximum by charging.

18. OPEN CIRCUIT VOLTAGE TEST

As soon as a battery is removed from the charging line the cell voltage drops rapidly until it reaches 2.1 volts in from 2 to 3 minutes. This is caused by a thin layer of lead sulphate forming on the surface of the negative plates and between the grid and lead peroxide of the positive plate, due to a slight chemical or discharge action which occurs within the cell as soon as the charging circuit is broken.

Once this thin layer of lead sulphate is formed the rapid voltage drop ceases due to the resistance of the lead sulphate film. This discharge or local action doesn't cease entirely, however, and a lead plate cell will not stay charged indefinitely but will gradually become discharged even though not connected to any circuit or load. An idle lead plate battery will become discharged in about 100 days of idleness if not charged during the idle period.

During discharge of the battery, lead sulphate is formed on both groups of plates and causes the open circuit voltage to drop. Theoretically a cell can be discharged to zero voltage, but for all practical purposes the discharge should be stopped when the
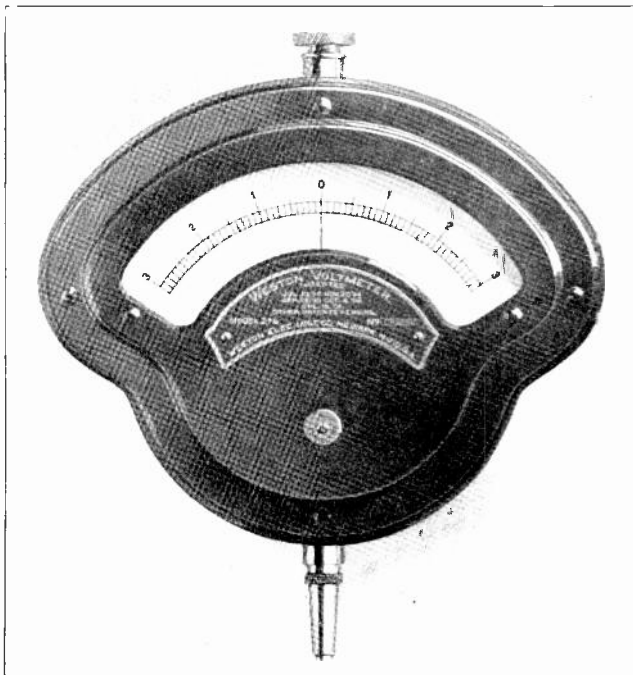

Fig. 18. Convenient type of portable voltmeter for testing the voltage of single cells. (Courtesy of Weston Electrical Instrument Co.)

cell voltage drops to 1.7 volts on the open circuit test or voltmeter test made with the battery discharging at a very low rate.

If the discharge is carried beyond this point, so much of the active material will be converted into lead sulphate that the plates will be almost useless. The plates are then said to be **sulphated**. Plates

which have been allowed to get into this condition require a long slow charge to free them of all the lead sulphate.

Fig. 17 shows a D. C. voltmeter of the type which can be conveniently used for testing storage batteries. You will note that this meter has a low reading scale so that quite accurate tests can be made on one cell or on several cells of a complete three-cell battery. This meter can be equipped with flexible test leads and points and either mounted on a wall or bench, or carried to a car to make tests on the battery before removing it. A portable meter in a wood case is also very convenient for testing batteries while in the car.

Fig. 18 shows another type of battery voltmeter particularly adapted for portable use. This instrument has a test point or prod directly attached to its lower side and forming one terminal of the meter.
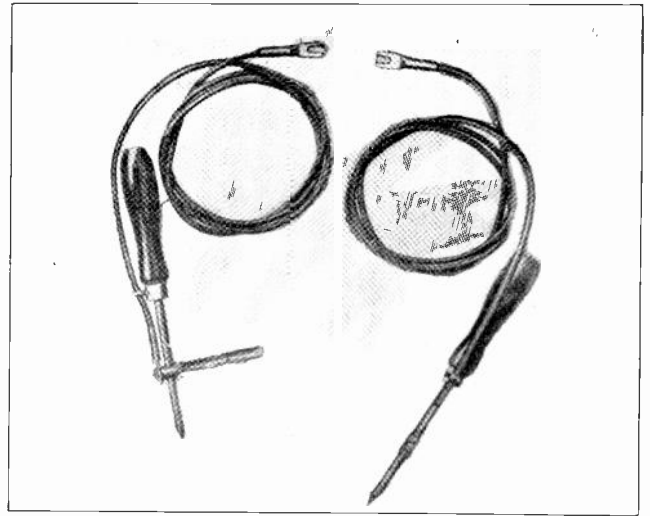

Fig. 19. This view shows a pair of test leads, one of which is equipped with a Cadmium stick for making Cadmium tests on storage batteries.

The other terminal on top of the case can be fitted with a flexible lead and test point. This meter has a scale which will allow the needle to read in either direction and only up to a maximum of 3 volts, thus giving very accurate readings on the low voltage of single cells.

19. CADMIUM TEST

The Cadmium method of testing a battery is very reliable as it reveals the actual condition of the plates better than any other test does. With the Cadmium test we can determine two important facts regarding the condition of the battery.

1. Whether or not the capacity of both positive and negatives are equal.
2. Whether the battery is charged or discharged.

This test also serves as a check on both the voltage and specific gravity. The Cadmium test derives its name from the fact that a stick of cadmium metal is used in place of the usual negative voltmeter test point.
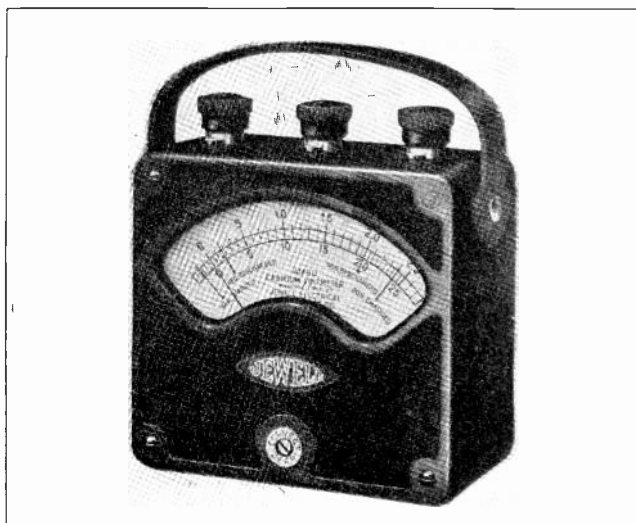
Fig. 20. Convenient portable voltmeter with special scale for making Cadmium test on lead plate battery. (Courtesy of Jewel Electrical Instrument Co.)

Fig. 19 shows a pair of voltmeter leads and test points for use in making cadmium tests. You will note the small round rod or stick of cadmium metal attached to the test point on the left.

This cadmium is a metallic element and not a mixture or alloy, and convenient small rods or cadmium sticks can be purchased from any battery material supply house.

When the cadmium stick is placed in the electrolyte of a cell with a voltmeter connected between the stick and one of the cell terminals, a definite voltage will be set up due to the difference in chemical action of the acid on the cadmium stick and the battery plates.

If the **voltmeter is connected between the cadmium stick and the negative plates or terminal** the voltage reading will vary according to the condition of the plates. If the plates are pure sponge lead or **fully charged the voltage will be about .1 volt,** the cadmium stick being positive and the plates negative in polarity. In this case the **reading will be to the left side of zero** on the voltmeter scale.

If the **voltmeter is connected between the cadmium stick and the positive plates or terminals** a different reading will be obtained. If the plates are pure lead peroxide or **fully charged the voltage reading will be 2.4 volts** and the cadmium stick will now be negative to the lead peroxide or positive plate.

When the cadmium stick is used in combination with lead sulphate or discharged plates a still different voltage will be obtained, all depending on the amount of lead sulphate on the plates tested.

Fig. 20 shows a voltmeter with a specially marked scale for cadmium tests, and Fig. 21 shows an enlarged drawing of the scale of a meter of this type.

Voltmeters for this work should be of high resistance for cadmium tests and should have a scale calibrated from 0 to 2.7 volts to the right of zero,

and .3 volt to the left of zero. These same voltmeters can also be used to make all ordinary battery voltage tests, but they should never be connected across more than one cell because their voltage capacity is low.

Cadmium tests should only be made with the battery on charge at the regular charging rate. **The test lead to which the cadmium stick is attached should always be connected to the negative terminal of the voltmeter,** while the plain test lead to be used on the cell terminals is to be connected to the positive terminal of the meter.

With the battery on charge the cadmium stick is inserted through the vent hole of the cell cover until it makes good contact with the electrolyte. The cadmium stick must not touch the plates and for this reason many of these sticks are equipped with insulating tips or with a perforated rubber tube over their ends.
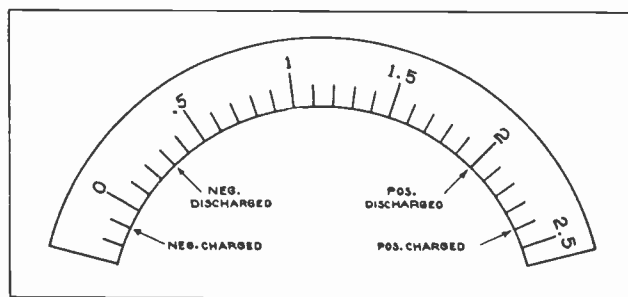
The cadmium should remain in the electrolyte

Fig. 21. Diagram showing the scale of a Cadmium test meter with the important test readings marked.

for a minute or two before taking the readings so that a thin coating of cadmium sulphate will form on the stick. The other test point can then be shifted between the positive and negative cell terminals to make the various tests.

By attaching it to the negative terminal the condition of the negative plates can be determined, and when it is in contact with the positive terminal the condition of the positive plates can be determined by the voltmeter readings.

With the battery on charge the voltage reading between the cadmium stick and the positive terminal will be about 2.4 volts if the positive plates are pure lead peroxide or fully charged.

With the free test point on the negative terminal a reading of .1 volt to the left of zero will be obtained if the negative plates are pure sponge lead or fully charged.

If these two readings are added together their sum should equal the reading of a voltage test taken from positive to negative terminals. These voltages would indicate that both positive and negative plates are fully charged and in good condition.

If when making such a test the positive reading was 2.4 volts and the negative reading to the right of zero, the voltage of the cell would be obtained by subtracting the negative reading from the posi-

tive reading. Such a test would indicate that the negative plates are in bad condition since they are not charged while the positives are.

The cadmium test is the most reliable test that can be made and determines if both the positives and negatives are at the same state of charge, as they should be if both groups of plates are in good condition.

20. HY-RATE DISCHARGE TEST

The hy-rate discharge test is made on storage batteries by taking voltmeter readings across the individual cells while the battery is discharging at a heavy rate.

This test is particularly valuable in determining the condition of the various cells of a battery and is very commonly used in testing automobile batteries, as these batteries must maintain their voltage without excessive voltage drop while operating the starting motor which, as we have already learned, may draw several hundred amperes during starting of the engine.

For making this test some form of high rate discharge test set is generally used. These sets consist of a variable resistance, generally of the carbon pile type, an ammeter of sufficient capacity, and a voltmeter.

On some of these test sets three voltmeters are used, one being connected across each cell to eliminate the necessity of shifting the meter terminals from one cell to the next.

Fig. 22 shows three types of high rate discharge testers. The one above has a long tube filled with carbon disks and equipped with a knob and threaded rod at the right hand end to vary the pressure applied to these disks, and thereby vary their resistance and the rate of discharge of the battery connected to the set. The ammeter and voltmeter are also mounted on the base with the variable resistor.

On the lower left in Fig. 22 is shown another type of high rate discharge set with the meters and rheostat handle located on a vertical panel and equipped with both heavy-duty terminal clips and test prongs.

On the lower right in Fig. 22 is shown a convenient portable test device for making high rate discharge tests on individual cells. This device consists of a pair of heavy test prongs with a resistance element shunted across them, and the meter also connected across the prongs to read the voltage during the test.

This tester is conveniently portable and can be used right at the battery either on the charging bench or in the car, by merely pressing the sharpened test points down against the terminals or straps of the cell to be tested.

The discharge rate for making these tests is based on the number of plates per cell, the usual rate being 20 to 25 **amperes per positive plate**, figuring only the positive plates in one cell.

For example an 11-plate battery having eleven

plates per cell would have 6 negatives and 5 positives in each cell. As the discharge rate is based on the number of positives the high rate discharge current for testing such cells would be 5×20, or 5×25, or 100 to 125 amperes.

While the battery is discharging at this rate the voltage of each cell is measured separately, and if the battery is in good condition and fully charged the voltage should not drop below 1.75 or 1.78 volts per cell during the test. This voltage drop is caused by the heavy current flowing through the internal resistance of the cell.

If the cell's internal resistance is normal the voltage drop will not be excessive but if the cell is in bad condition the voltage drop will be much higher than usual.

The internal resistance of a cell is due to the resistance of the several parts and materials in the internal circuit of the cell. When the cell is discharging through some load the discharge current
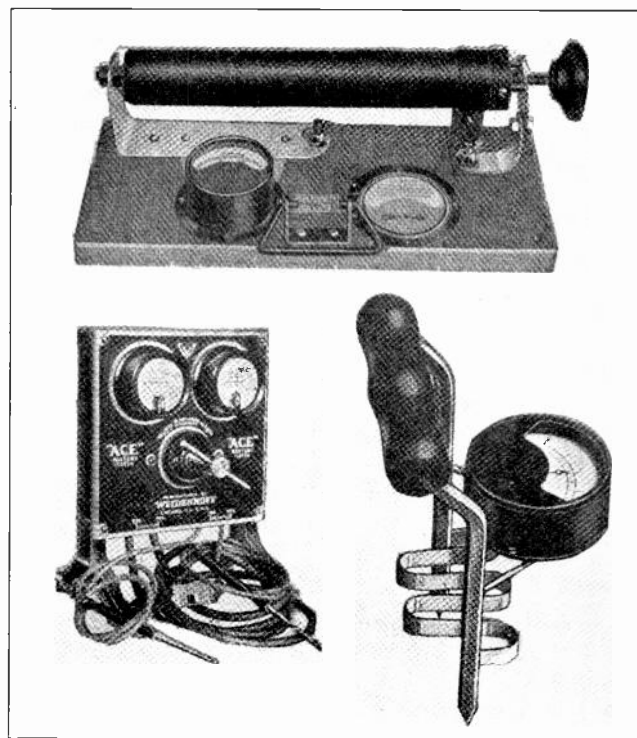

Fig. 22. Several styles of hy-rate discharge test sets. The one above is for either portable or bench use. The one at the lower left for bench use, and the one at lower right for portable use for testing individual cells.

also flows through the internal circuit and must pass through the plates, separators, and electrolyte; so the resistance of these materials determines the internal resistance of the cell.

Excessive voltage drop may be due to several causes such as spongy or worn out plates, clogged separators, or wrong specific gravity of the electrolyte.

Thin and worn separators may also be the cause of large voltage drop by allowing the plates to be short circuited during heavy discharge tests. A

high rate discharge can be used to very good advantage to locate defective cells in batteries that are being brought in to a shop to be charged.

The exact readings obtained on this test are not as important as the difference in readings between the several cells. A cell that gives a reading of more than .1 volt less than the other cells is generally defective and should be opened and examined.

Sometimes a high rate discharge test will cause one cell to give a reverse reading which indicates that the cell is dead.

21. STORAGE BATTERY CAPACITY

The capacity of storage batteries or individual cells is rated in **ampere-hours.** This term refers to the product of the discharge current multiplied by the number of hours that the discharge can be maintained.

Capacity ratings for storage batteries of the automotive type are based on a discharge started from a fully charged condition, and continued until the battery reaches normal discharged condition with its voltage down to 1.7 volts per cell.

The discharge rate for capacity tests on automobile batteries is generally based on an eight-hour discharge period. For example, a battery rated at 80 ampere hours should be able to deliver 10 amperes for eight hours. The capacities of stationary batteries and those for use in electric vehicles is generally figured on a five-hour discharge rate.

One of the characteristics of storage batteries which it is very important to remember is that their capacity is affected by the rate of discharge, the capacity in ampere hours decreasing as the rate of discharge is increased.

For example, an 80 ampere-hour battery will not discharge at the rate of 80 amperes for one hour, but will deliver 4 amperes after considerably more than 20 hours. In other words, they will deliver more energy and show a higher efficiency at low rates of discharge than at high discharge rates.

The ampere-hour capacity of the storage battery depends upon several factors among which are: (a) plate area (b) porosity of active material (c) strength of electrolyte.

For all practical purposes the plate area is the most important factor, and principally controls the capacity of the battery. Therefore, all capacity formulas are based on plate area.

The chemical activity of a battery is always greatest at or near the surfaces of the plates where the active material and the acid are in contact with each other. This is particularly true during high rates of discharge when the acid is being used up very rapidly. So by increasing the plate surface exposed to the electrolyte we increase the amount of active material in contact with the acid, and thereby increase the capacity of the cell.

A simple formula for determining the approximate ampere-hour capacity of storage batteries according to the plate area is as follows:

$$\frac{W \times L \times 2 \times P.P.}{144} \times 50 = \text{ampere hour (A.H.) capacity.}$$

In which: W = width of the plates
L = length of plates
2 = number of sides on each plate
P. P. = number of positive plates in one cell
144 = square inches in 1 sq. ft.

The average positive plate for use in automobile batteries is approximately $4\frac{1}{2} \times 5\frac{1}{2}$ inches. So if we apply this formula to an ordinary 11-plate, 3-cell automobile battery the problem would be as follows:

$$\frac{4.5 \times 5.5 \times 2 \times 5}{144} \times 50, \text{ or approximately 85.5 A.H.}$$

This battery would be rated in round figures as an 80 ampere-hour battery, allowing the slight excess capacity for reduction in efficiency with age.

The thickness of battery plates has very little effect on the ampere-hour capacity of the battery as under normal conditions a plate doesn't discharge actively clear through the plate, but discharges mainly on and near the surface. This is due to the fact that the pores in the active material soon become clogged and choked with lead sulphate.

When a battery is discharged down to the normal discharged condition it is very seldom that more than 25% of the active material is used, and that is largely at the surfaces of the plate.

While the plate thickness doesn't materially affect the ampere-hour capacity it does affect the discharge capacity or rate in amperes at which a cell or battery can be discharged.

Surprising as it may seem, thin plates always have a higher discharge capacity in amperes than thick plates. This is due to the fact that the electrolyte will diffuse through the thin plates much more rapidly and will quickly replace the acid used up by the active material during the discharge action of the plates.

Plates for automobile batteries are made in slightly different sizes in order to fit different styles of battery cases and to provide more or less capacity, according to the requirements of the car. This is well to remember when ordering plates for repairing various batteries and a good plan is to carefully measure or check the size of those removed when ordering the new ones to replace them.

Three common plate sizes are as follows:

Type	Symbol	Dimensions
Small	S	$4\frac{1}{2}''$ high $\times$ $5\frac{5}{8}''$ wide
Medium	M	$4\frac{3}{4}''$ to $5\frac{1}{4}''$ high $\times$ $5\frac{5}{8}''$ wide
Large	B	$6''$ high $\times$ $5\frac{5}{8}''$ wide

These plates can also be had in three different thicknesses as follows:

Type	Symbol		
Thin	T	3/32″	thick
Regular	R	⅛″	"
Thick	T.T.	5/32″	"

22. CAPACITY TESTS

The purpose of a capacity test on a battery is to determine the amount of work that it is capable of doing before its voltage drops to 1.7 volts per cell, or the normal discharged condition.

While formulas give us a theoretical idea or approximate knowledge of what the rated capacity of a battery should be, the actual capacity can be much more accurately determined by a test.

This test is performed by charging the battery fully and then discharging it through a variable resistance and ammeter until the battery reaches the normal discharged condition.

In order to obtain accurate results from a capacity test of this kind the following two factors must be carefully watched and checked:

1. Discharge rate must be maintained constant from start to finish.
2. The time required for the battery to reach normal discharged condition must be noted.

In order to maintain a constant rate of discharge throughout the entire test period an ammeter and some form of variable resistance are necessary; the ammeter to check the amount of current flow and the rheostat to keep it adjusted to a constant value.

When the battery is first put on test its voltage is high but as the test progresses the voltage gradually drops and the discharge rate would tend to decrease. It is, therefore, necessary to cut out a little resistance about every 15 minutes in order to keep the discharge rate in amperes constant.
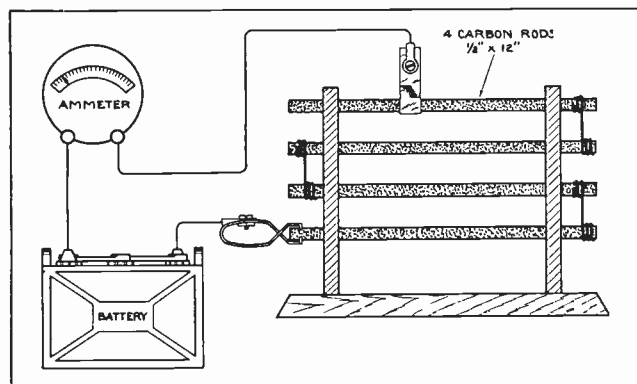

Fig. 23. Diagram showing construction and connections of a simple capacity test discharge resistance, which can be easily and cheaply made of carbon rods supported in an insulating frame of heat resisting material.

Fig. 23 shows a diagram of a simple capacity test arrangement, the equipment for which is very low in cost and simple to set up for any battery shop. The battery is connected in series with an ordinary ammeter of the proper capacity and several carbon rods such as ordinary arc carbons.

These round carbon rods can be mounted in strips of heat-resisting material of an insulating nature, such as asbestos, marble, or slate with their ends securely connected together in series as shown. A heavy test clip can then be used to vary the resistance in the circuit by sliding the clip along the rods or moving it from one rod to another.

Convenient carbon pile rheostats can also be obtained for this work but are, of course, a little more expensive than the simple shop tester shown in Fig. 23.

The discharge rate at which to start a capacity test on an automobile battery can be determined by dividing the assumed or approximate ampere-hour capacity of the battery by 8, because as previously stated these tests are generally made at the 8-hour discharge rate.

For example, if we wish to run a capacity test on an automotive battery which we assume from the number of plates used is an 80 ampere-hour battery, the discharge rate would be obtained by dividing 80 ampere-hours by 8 hours, or $80 \div 8 = 10$ amperes discharge rate.

If this battery when placed on capacity test can maintain a discharge rate of 10 amperes for 8 hours or more before the voltage drops to 1.7 volts per cell, and the gravity drops to 1.150, then the capacity is actually known to be 80 ampere-hours or more.

For example, if it required 8½ hours at the 10 ampere rate to bring the voltage and gravity down to the above mentioned figures then the capacity would be 8½ × 10, or 85 ampere-hours.

The ampere-hour efficiency of a storage battery can be determined by dividing the discharge in ampere-hours by the charge in ampere-hours required to bring it back to the same state of charge as the test was started from. This efficiency of ordinary lead plate batteries often runs as high as 90% or over.

23. CYCLING STORAGE BATTERIES

Before putting into service a new lead plate battery or one that has been recharged and has had some of the old plates replaced with new ones the battery should be cycled, or charged and discharged several times.

This process more completely forms the new plates and greatly improves their condition and efficiency by more completely converting the paste into active material.

New batteries are generally cycled two or three times at the factory before being shipped out and this considerably increases their capacity and serviceability.

The original forming process described in an earlier article doesn't always change all of the paste into active material, and unless a new battery or one in which new repair plates have been installed is cycled, it will not deliver its rated capacity and may give trouble when first put in service.

A battery that has been neglected and allowed to become sulphated by standing for long periods in a discharged state will often fail to come up to full gravity and voltage when charged, due to the fact that one ordinary charging cannot convert all of the lead sulphate back into active material. Such a battery if given only the ordinary charge will not deliver its full rated capacity in ampere-hours and its performance will be rather poor.

Cycling a sulphated battery will convert more of the lead sulphate back into active material, thereby increasing the capacity and improving the performance of the battery. The rate of charge or discharge for cycling a battery should be at about the ordinary 8-hour rate, or a little slower generally, so that the battery can be discharged during the day and put back on the charging line throughout the evening.

As a rule the rate of discharge for cycling is between 2 and 3 amperes per positive plate in each cell. For example an 11-plate battery having 5 positive plates per cell would be discharged at about 10 to 15 amperes.

The same rheostat and ammeter used for making capacity tests can also be used along with a battery charger for cycling. However, as it is not necessary to keep the discharge rate constantly at the same value when cycling, a very simple and low cost discharge resistance can be made up from several automobile lamps connected in parallel and an ordinary automobile dash ammeter in series with them, as shown in Fig. 24.

If desired several small switches can be arranged to quickly connect more or less lamps in parallel, to vary the discharge rate for cycling different sized batteries.
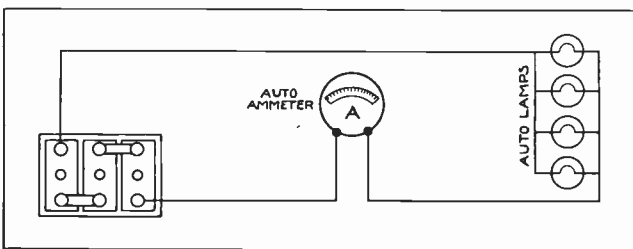

Fig. 24. This sketch shows the connections for using an ammeter and a group of automobile lamps for discharging a storage battery during a cycling process.

24. BATTERY CHARGING

As previously stated whenever the voltage of a lead plate storage battery drops down to 1.7 volts per cell the battery must be recharged. For charging storage batteries direct current is required because, in order to convert the lead sulphate back into active material on the plates and drive the acid from the plates back into the electrolyte, we **must** pass current constantly in one direction opposite to that of the discharge current.

This means that when connecting a storage battery for charging, the positive battery terminal **must** be connected to the positive side of the charging line or direct current source, so that the charging current will be forced into the battery at the positive terminal and out at the negative.

If there is any doubt about the polarity of the charging line wires, a simple test can be made by immersing the wire ends in a small glass of water to which has been added a small amount of acid. When the wire ends are held about an inch apart bubbles will rise from each, and the wire at which the most bubbles are formed is the negative. Some resistance, such as a 100-watt lamp or similar devices which will limit the current to about 1 ampere should be connected in series with the line when making this test.

The polarity can also be determined by a compass test with current flowing in the line, as explained in an earlier section.

Where only alternating current is supplied it can be rectified or changed to direct current for battery charging purposes, by means of bulb type rectifiers or motor-generators. If 110-volt D. C. is available all that is required is suitable resistance connected in series with the battery to reduce the voltage of the line and regulate the charging current.

There are two general methods in use for charging batteries, one known as the **constant current** method and the other as the **constant potential** method.

The constant current method is sometimes known as series charging, because all of the batteries are connected in series and are all charged at the same current rate regardless of their size or condition. With this system about the same charging rate in amperes is maintained from start to finish of the charging period.

Constant potential charging systems generally use a motor-generator set for changing A. C. to D. C., and all of the batteries are connected in parallel directly across the low voltage D. C. generator bus bars. This system is sometimes called **parallel charging**, as the batteries are all connected in parallel and each battery forms an individual or separate circuit between the positive and negative busses.

The motor-generator consists of either an A. C. or D. C. motor, according to the available current supply, driving a low-voltage D. C. generator which connects to the charging busses, and supplies a constant potential of about 7.5 volts for charging 6-volt batteries or 15 volts for charging 12-volt batteries.

With the batteries connected across the bus bars in parallel and a constant voltage maintained by the generator, the current through each battery will be governed by the voltage and condition of that battery.

If a completely discharged battery is connected across the bus bars the charging current through that battery will be quite high at the start, since the voltage of the battery is very low and offers very

little opposition in addition to the internal resistance of the battery, to the current flow from the generator.

As the battery becomes charged its voltage gradually increases and opposes the voltage of the generator, thereby causing the charging rate to decrease or taper off.

Constant potential charging is also often referred to as 8-hour charging, because the rather high rate of charge used with these systems generally charges the average battery in about 8 hours.

25. CHARGING RATES

Charging rates depend largely on the size of the battery and the type of equipment used. In commercial charging it is not always practical to regulate the current to suit each individual battery and in cases of this kind a rate is used that best suits the average battery.

Where the charging current can be regulated a good rule to determine the charging rate for any certain battery is to start charging at ⅛ of its rated capacity in ampere hours, and when it is a little over one-half charged reduce this rate to one-half the starting rate.

For example, if the capacity of a battery is 80 ampere-hours, the charging rate at the start would be ⅛ of 80, or 10 amperes and the finishing rate about 5 amperes. The reason for reducing the charging rate toward the finish of the charge is to prevent overheating of the plates, as the amount of lead sulphate and acid in the plates and being worked upon by the charging current is gradually being reduced, and the heavy charging current would develop too much heat.

In constant current or series charging it is not possible to regulate the current to suit individual batteries, since they are all connected in series and the same amount of current flows through each.

A commercial charging line may have connected to it batteries of different capacities, ranging from 80 to 120 ampere hours. In addition to having different ampere-hour capacities these batteries will probably vary a great deal as to their state of charge, so it is necessary to select a rate suitable for the group.

26. ELECTRON BULB CHARGERS

A very popular type of battery charger used for rectifying or changing A. C. to D. C. and for charging batteries on constant current systems is the **electron bulb rectifier**, also commonly known as the **Tungar bulb charger.**

Due to the low current capacity of ordinary electron bulbs these chargers are used only with constant current or series charging systems. Bulb type chargers are made in two types known as **half wave** and **full wave** chargers.

A half wave charger is equipped with one bulb and has a maximum current output of 6 amperes of
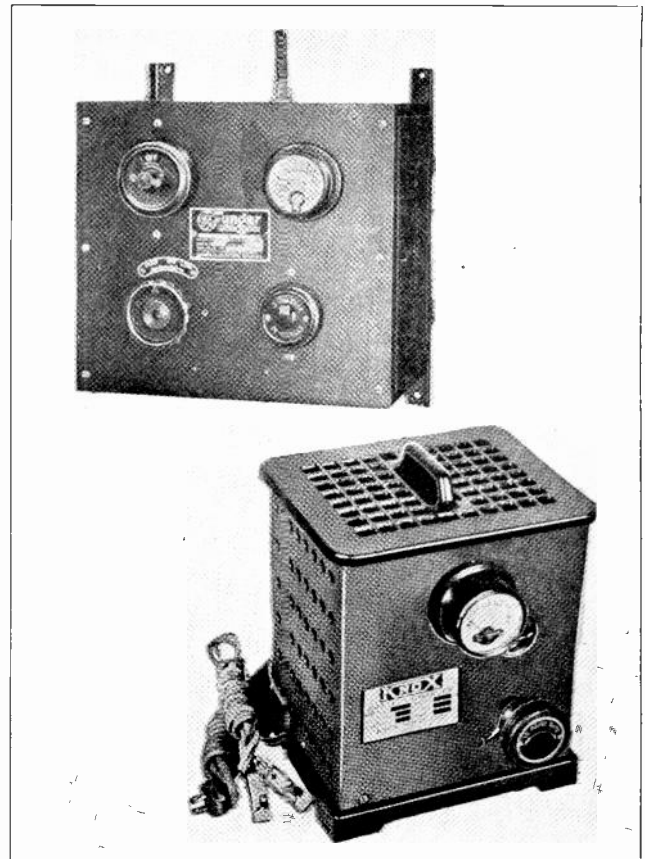

Fig. 25. Above are shown two common makes of bulb type rectifiers or battery chargers. The one above is a full-wave type. while the one below is a half-wave type.

pulsating D. C. from one-half of the A. C. wave, or every other alternation only.

Although the current output is low the voltage on the D. C. side of these chargers can be raised high enough to charge from 10 to 15 six-volt batteries in series. The voltage is regulated by means of a tap changing control which increases or decreases the number of turns in the winding of an auto transformer.

Full wave Tungar chargers use two rectifier bulbs and rectify both sides of the A. C. wave. The current output of these units is double that of the single wave chargers or about 12 amperes maximum. The voltage is controlled in the same manner as with single wave type. These chargers can, of course, be made to deliver more than the above mentioned amounts of current for short periods, but this will shorten the life of the rectifier bulbs much below their rated life which is between 800 to 1000 hours of operation.

For this reason their rated current capacity should not be exceeded. Vibration of the charger will also tend to reduce the life of the bulbs so these units should be mounted where they are free from excessive mechanical vibration. The efficiency of a well designed Tungar rectifier on full load is about 75%.

Fig. 25 shows two types of electron bulb chargers, the one at the upper left being the larger size full

wave type for wall mounting, and the one below is a smaller charger of the single wave type for shelf mounting or portable use. Note the ammeters for indicating the charging rate and the knob controls for adjusting the transformer taps to vary the charging rate.

A complete description of the operating principles and circuits of Tungar rectifiers was given in Section Six on Alternating Current, and it would be very well for you to review this material at this point.

27. OPERATION OF BULB TYPE CHARGERS

While these rectifiers are very simple in design and easy to operate, there are a few rules that must be observed to secure best results with them. Half wave rectifiers may be equipped with one or two control dials, but full wave rectifiers are generally equipped with four controls, two for each bulb.

Where two controls are used for each bulb one is used to raise or lower the voltage in large steps while the other is used to regulate the voltage in smaller steps. The regulation of the voltage, of course, regulates the charging current sent through the battery or batteries.

The following simple rule should be followed when starting Tungar chargers.

First be sure all controls are turned back to zero, then turn on the starting switch and observe the bulb to see if it lights or burns. Now with the batteries properly connected turn the lower or close-regulating dial clockwise until the proper current value is shown on the ammeter. If the ammeter fails to show a reading turn this dial back to zero and try the upper or coarse-regulating dial. Bring the charging rate as close as possible to the proper value with this coarse dial, and then use the lower dial for final adjustment.
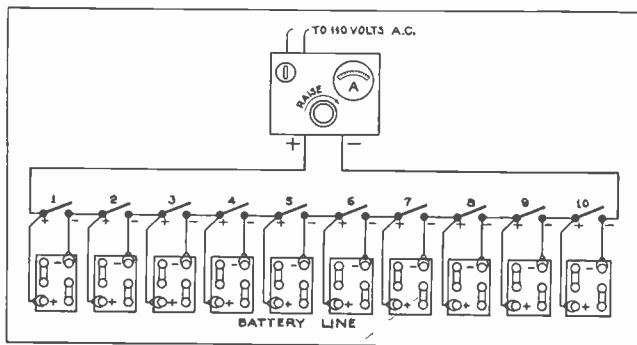

Fig. 26. Diagram showing the connections for charging up to ten batteries in series by means of a bulb type rectifier or the constant current system.

As more batteries are added to the line the charging rate drops so it will be necessary to readjust the controls to maintain the same current value. If a battery is accidentally connected backwards on a constant current charging circuit the charging rate will increase instead of decrease.
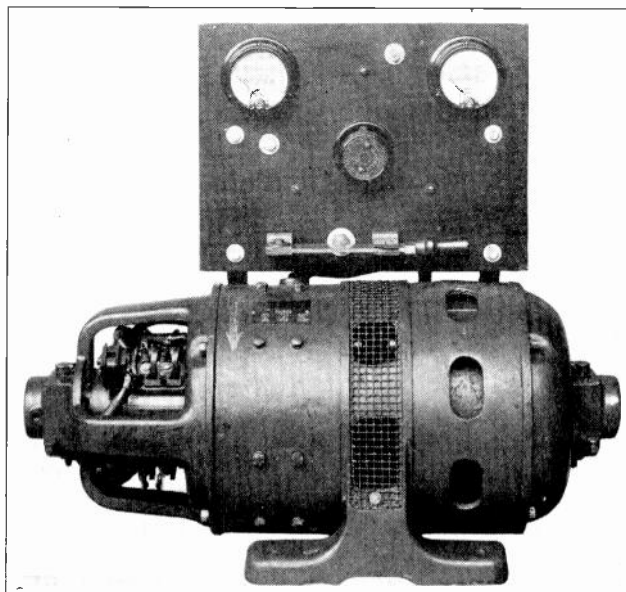

Fig. 27. This photo shows a neat, compact type of motor generator with its control and panel, for use in charging batteries by the constant potential method. (Courtesy of Roth Bros. Manufacturing Co.)

When part of the batteries are removed from the line the charging rate will automatically increase and if the controls are not readjusted the fuses will be blown. If the fuses are not of the proper size the bulb may be burned out instead. Ten-ampere fuses will generally give the proper protection.

If the Tungar charger fails to operate you can look for the following common troubles:

1. Examine supply line fuses.
2. Bulb filament may be open or burned out. Test bulb for open circuit or try a new bulb.
3. Make sure that the bulb is screwed tight in its socket.
4. If points of contact on bulb or in socket are dirty, clean them with sandpaper.
5. If the bulb glows but the ammeter fails to register examine the battery connections. Most troubles or interruptions with chargers of this type are caused by poor connections at the batteries.
6. Some chargers are provided with one fuse in series with the battery and if this fuse is blown no charging current will flow even though the bulb is glowing.
7. The rectifier bulb may fail to operate due to a slow leak in the glass having destroyed its vacuum, or due to a badly sagged filament.
8. Control contacts may be loose or dirty and not making proper connection in the circuit.

28. CONSTANT POTENTIAL CHARGERS

As already explained a constant potential charger consists of a motor-generator set, the motor being either D. C. or A. C. and designed for 110 or 220 volts, according to the available supply, and the generator producing direct current at 7½ volts for charging 6-volt batteries, or 15 volts for charging 12-volt batteries.

Fig. 27 shows a compact motor-generator charger of this type; the motor and generator units both being built into one frame. This machine is equipped with a panel on which are mounted the voltmeter and ammeter, voltage-regulating rheostat by which the charging rate is controlled, and a knife switch for closing the circuit to the bus bars and batteries.

Fig. 28 shows a neat charging bench equipped with a constant potential charger and the bus bars and batteries can be clearly seen in this view.

You will note that the batteries are all connected to the bus bars in parallel by means of flexible leads and battery clips, and the small knife switches are provided for disconnecting individual batteries.

Constant potential charging differs considerably from constant current or series charging in that with constant potential charging each battery regulates its own charging rate to quite an extent by its voltage and condition.
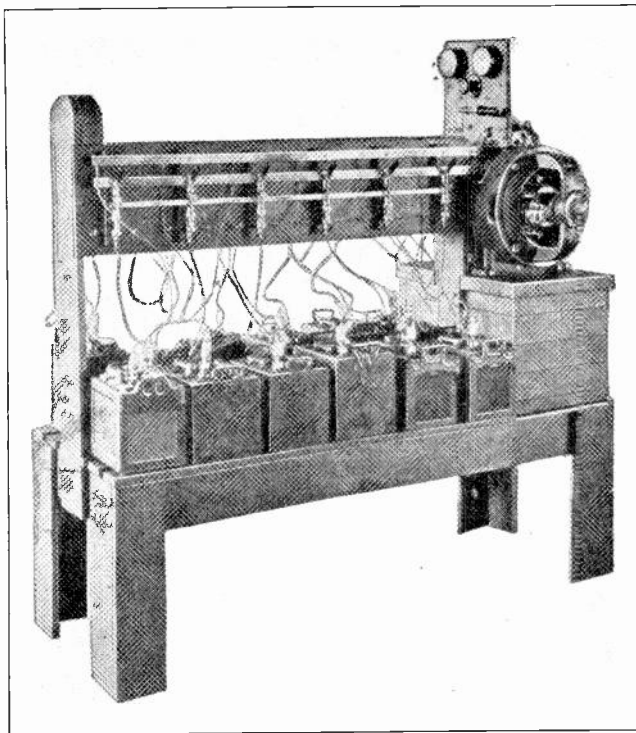

Fig. 28. Neat type of charging bench equipped with constant potential motor generator charger and convenient busses and switching arrangement for connecting and disconnecting the various batteries.

When a battery is first connected across the bus bars it charges at a very high rate due to its voltage being low, but this charging rate gradually decreases or tapers off as the voltage comes up to full charge.

When a completely discharged battery is placed on a constant potential system the charging current at the start may be as great as 20 amperes but will rapidly taper off as the battery voltage increases, dropping down to as low as 2 or 3 amperes when the battery becomes fully charged. Because of this

action this form of charging is sometimes called a tapering charge. It is also very often referred to as "eight-hour charging service."

From this we can see that it is possible to have a number of batteries connected in parallel to one of these chargers and each of the batteries charging at a different rate, according to their state of charge and condition.

The charging rate is limited only by excessive heating, and when any battery overheats the charging rate should be reduced by connecting a resistance in series with one of the leads to that particular battery. Convenient small resistance units equipped with a clip at the lower end for attaching direct to the battery terminal are obtainable for this use.

The temperature of the batteries should never be allowed to exceed 110° F. during charging and temperature tests should always be made on a cell in the center of the battery, as these cells tend to heat more than the outer ones because of poor ventilation, due to the fact that they are between the outer cells.

Where both 6 and 12-volt batteries are to be charged two 7.5-volt generators can be connected together in series and their terminals connected to three bus bars, as shown in Fig. 29.

This makes it possible to obtain two different voltages from the bus bars, 7½ volts between the center bus and either of the outside ones and 15 volts across the two outside busses. Six-volt or twelve-volt batteries can be connected as shown in the diagram and both types charged at the same time.

29. OPERATION OF CONSTANT POTENTIAL CHARGERS

When operating constant potential battery chargers the following simple rules would be well to keep in mind:

1. Batteries must be connected in parallel across the bus bars, with the positive terminal of each battery connected to the positive bus and negative terminals to negative bus. When the generator is idle the main switch on the control panel must be opened before connecting batteries.
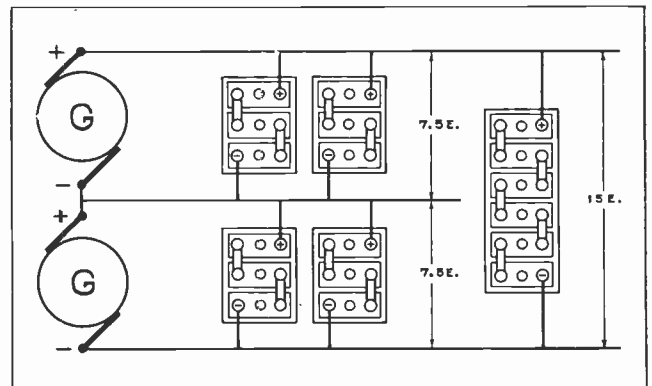

Fig. 29. This sketch shows the method of connecting two low voltage D. C. generators for charging both 6E and 12E batteries at the same time.

2. When starting the machine the motor of the M-G set is first started and allowed to come up to speed. The voltage is then regulated by means of the generator rheostat and is set at 7.5 volts for charging 6-volt batteries. This voltage adjustment is very important and must not be neglected.

3. When the voltmeter registers 7.5 volts the main switch on the control panel can be closed, completing the charging circuit and starting the batteries to charge.

4. If it is necessary to stop the set for any reason, first open the main switch on the control panel in order to prevent the batteries from feeding current back through the idle armature of the generator. It is also advisable to disconnect the battery leads or open the individual battery switches when provided, and thus disconnect the batteries from the bus bars, or otherwise current will circulate between the batteries. This is caused by the ones which are of higher voltage or nearer to full charge discharging through the ones that are of lower voltage or have not been on charge as long.

The ammeter on the control panel will indicate the total charging current passing through all batteries. Each battery will take current according to its state of charge and condition, and if it is desired to know the charging current of any individual battery this can be obtained by connecting a small ammeter in series with one of the leads to that battery.

Fig. 30. Diagram showing the connections for using a lamp bank to charge from one to twelve six-volt batteries directly from a 110-Volt D. C. line.

Caution: Be very careful never to accidentally connect a charging lead across the bus bars or from positive to negative bus, as this short-circuits the D. C. generator and you may receive a severe burn due to the heavy rush of current.

30. CHARGING DIRECT FROM D. C. LINES WITH RHEOSTATS

We have already mentioned that when a supply of 110-volt direct current is available, batteries can be charged directly from such a line by connecting a proper resistance in series with them. For charging in this manner the batteries are all connected in series, as with the constant current or Tungar charger systems.

Very economical charging resistances in the form of lamp banks, consisting of a number of lamps in parallel, can be made for this use or a simple water rheostat can be used. Adjustable factory-made rheostats can also be purchased for this use.

Fig. 30 shows a diagram of the connections for charging several automotive batteries with a lamp bank.

Any ordinary 110-volt incandescent lamps can be used for such lamp banks but it is quite common practice to use 32-candle-power, carbon filament lamps as they are very rugged and low in cost. A 32-C.P. lamp offers 110 ohms resistance and will allow 1 ampere to pass through it when connected directly across a 110-volt line.

However, when these lamps are used in a lamp bank and a string of batteries connected in series with them, the current through each lamp will naturally be a little less than 1 ampere due to the counter voltage and internal resistance of the batteries.

It is, therefore, necessary to use a number of lamps in parallel in order to obtain the desirable charging rate. The charging rate can be easily regulated by turning on or off one or more of the lamps by means of switches placed in series with them. With a lamp bank adjusted for a charging rate of 6 amperes the average automotive battery will be fully charged in 24 hours.

The diagram in Fig. 30 shows a sufficient number of lamps in the charging bank to enable a line of 10 or 12 batteries to be charged at a fairly good rate. It is, of course, not necessary to use all of these lamps when only charging a few batteries. The knife switches shown can be used to turn on or off complete groups of lamps, and the small snap switches shown in series with each of the lamps in the right-hand group can be used to turn on or off individual lamps of this group for final regulation of the charging rate.

The upper view in Fig. 31 shows a method of connecting a rheostat in series with a group of batteries for charging them directly from a 110-volt line, and the lower sketch in this figure illustrates the use of a water rheostat for the same purpose.

A simple water rheostat is a very convenient device for occasional charging of batteries, and can be made from a large earthen jar filled with water to which a small amount of sulphuric acid or salt has been added, to increase its conductivity and reduce its resistance.

The electrodes can be made of a couple of old battery plates or most any flat pieces of metal, and the charging rate can be varied by raising or lowering one or both of the electrodes in the solution.
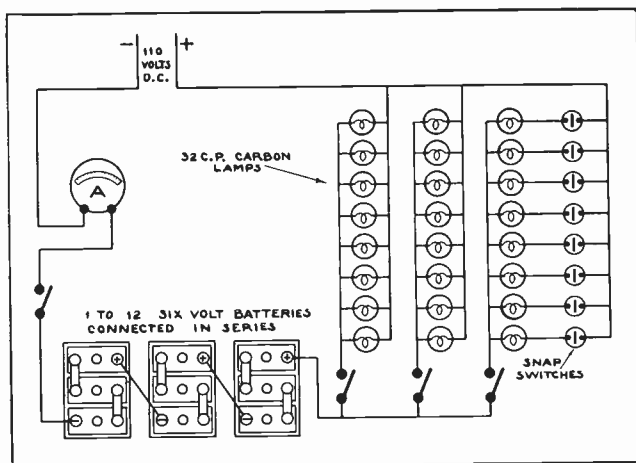
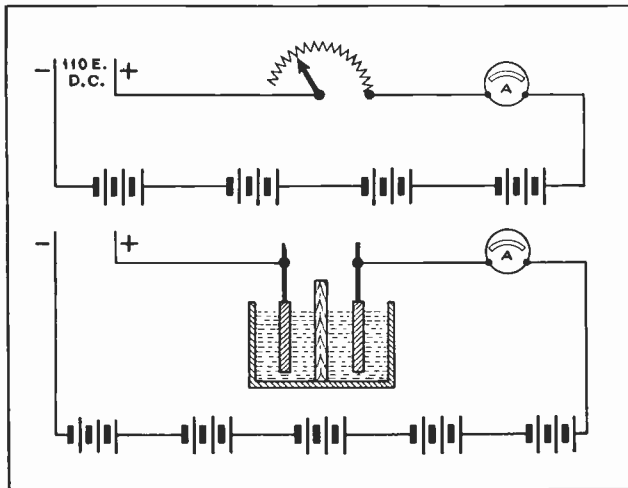Care must be taken with a water rheostat to see

Fig. 31. The above sketch shows method of using an ordinary factory made rheostat and ammeter for charging batteries from 110-volt D. C. line. The sketch below shows a home made water rheostat used in place of the commercial rheostat.

that the liquid doesn't over-heat or boil away. It is a good plan to place a strip of wood or some other porous insulating material between the electrodes of a water rheostat to prevent them from accidentally becoming shorted together. Be careful to see that the insulator does not form a complete barrier and tend to prevent current flow from one electrode to the other.

The advantage of a water rheostat is that it can be quickly and easily made up from ordinary parts around a battery shop and used for emergency charging from 110-volt D. C. lines. In general, however, the lamp bank or commercial form of rheostat will be found more dependable and will require less attention.

31. BATTERY TROUBLES AND REMEDIES

Because of the very severe conditions under which the average automobile battery operates they require frequent inspection and occasional repairs. Automotive batteries are subjected to severe vibration, very heavy discharge rates, and very often excessive charging rates, and they are also quite generally subjected to neglect on the part of the car owner. These things will tend to shorten the life of a battery and to cause it to give unsatisfactory service, unless some battery service man who knows how is frequently inspecting the battery and making the necessary repairs from time to time.

If given proper care, which simply means keeping it well charged, filled, and cleaned, a good grade of battery should ordinarily last from 2 to 3 years. On the other hand, a very good battery can be ruined or put in bad condition within a few months by abuse and improper care.

One of the most common abuses to which the average automobile battery is subjected is low electrolyte level caused by neglecting to inspect and refill at proper intervals. Many car owners forget that the water in their battery electrolyte is con-

stantly evaporating and thereby lowering the electrolyte level. This evaporation is particularly rapid during hot weather and the battery should be inspected and refilled with distilled water at least every 2 weeks in Summer and 4 weeks in Winter, or oftener in case of heavy use.

Another common abuse of automotive batteries is operating them in a semi-discharged condition, which causes the plates to sulphate and the battery to give poor service. This can be prevented by simply removing the battery from the car and having it fully charged in the shop, or by slightly increasing the charging rate of the car generator.

In many cases batteries are also damaged by maintaining an excessive charging rate which causes gassing and overheating. This can be avoided by simply adjusting the charging rate of the automobile generator. Some of the more common battery troubles with their symptoms and remedies are given in the following paragraphs.

When a **battery will not hold a charge** but runs down immediately after being fully charged this is generally due to broken down insulation caused by failure of the separators between the plates. Or, in some cases, it is caused by high sediment in the bottom of the jars due to the shedding of active material from old or abused plates.

In either case the cells will have to be opened and either new separators installed or the sediment removed.

Separator troubles or failure may be due to a number of causes such as wearing thin or completely through due to normal wear or buckled plates; carbonizing of the wood due to strong electrolyte, or overheating; cracks sometimes caused by low electrolyte exposing the upper portion of the separators to the air; poor quality of wood used in the separators. The only remedy for any of these faults is to replace the old separators with new ones.

When the **battery appears weak** and fails to operate the starter or lights properly the trouble may be either in the battery itself or in its connections. It may be that the battery is not fully charged due to too low a charging rate, or to excessive use of lights and starting motor. The trouble may be due to low electrolyte which allows only part of the plate surface to be active, or it may be due to worn out plates or broken plate connections. It may also be due to loose or corroded terminals or to the battery being too small in capacity for the load of drain placed upon it by the electrical equipment of the car.

Sulphation is quite a common cause of battery trouble. This condition occurs when the lead sulphate on the plates has had a chance to harden into a white crystal formation, which is a very poor conductor of electricity and tends to clog or seal the pores of the plates, reducing their porosity and activity.

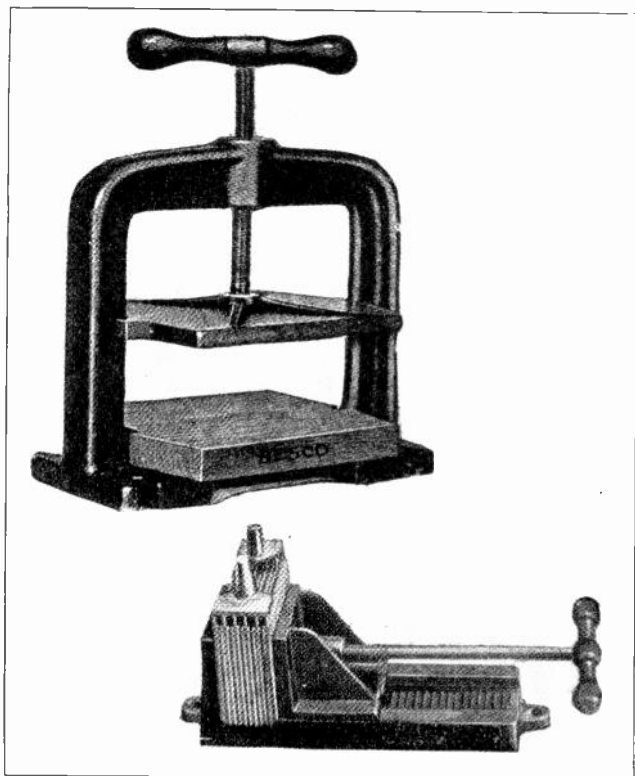Sulphated plates will not take a charge properly and even though the charging rate may be normal

Fig. 32. Two types of plate presses used for straightening negative plates which have been warped or buckled out of shape, but are otherwise in fair condition.

the battery constantly appears weak and low in voltage. Sulphation may be caused by allowing the electrolyte to evaporate to a very low level. It may also be caused by the battery never having been fully charged or by overrich electrolyte.

Sulphation tends to reduce the ampere-hour capacity of the battery and in many cases causes the plates to warp or buckle. The only remedy for a sulphated battery is a prolonged charge at a low rate of between two to six amperes after which it should be cycled or discharged and recharged a couple of times as explained in a previous article.

32. BUCKLED PLATES

Buckled plates are quite often the cause of separator failure and defective battery operation. Warping or buckling of the plates may be due to overheating, over-discharging, or allowing the battery to stand a long time in a discharged condition.

When the plates warp or buckle in this manner their corners exert excessive pressure on the separators and, due to the vibration of the battery in the car, will soon wear completely through the separator and short circuit the cell.

If the negative plates are in good condition otherwise except for being warped they may be straightened by pressing them in a plate press, and put back into service. To straighten plates in this manner the positive and negative groups are separated and thin boards inserted between the plates of the group that is to be pressed.

This whole assembly is then placed in the plate press and pressure applied very gradually until plates are again straight and flat. Positive plates cannot be straightened successfully by pressing, as the active material cracks and drops from grids.

Fig. 32 shows two styles of plate presses which are commonly used in battery shops for this work.

Another trouble that is often caused by allowing batteries to become overheated is known as **granular plates**. When the temperature of batteries is allowed to become higher than 110° F. the plates gradually become soft, the positives loosening or shedding their active material and the negatives tending to swell up and become spongy or sandy appearing. The only remedy for granular plates is to replace them with new ones.

Lead plate batteries will freeze in cold weather if the electrolyte is allowed to become too low in specific gravity by operating the battery in a nearly discharged condition. Frozen plates can be readily detected when the plate groups are separated as the active material will fall off the positive plates in hard flakes, having been forced loose from the grid by the expansion of the electrolyte when it froze.

Frozen plates are always an indication that the battery was not fully charged, because it requires a temperature of 94° F. below zero to freeze electrolyte at 1.300 specific gravity.

The only remedy for frozen plates is, of course, to replace them with new ones.

Sometimes a battery will develop a cracked case or jars due to vibration, buckled plates, or freezing. The indication of a cracked case or jar is excessive loss of electrolyte in one cell, making it necessary to fill this cell more frequently than the others to keep the electrolyte at the proper level.

Where a rubber case is used electrolyte will also be noticed on the outside of the case if it is cracked. Where rubber jars are used in a wood box the bottom of the box will be wet with electrolyte and if the condition has existed for some time the wood may be badly rotted and softened by the action of the acid.

Fig. 33 shows how to test single battery jars or rubber battery cases for leaks. The method shown in the upper sketch is used for testing a rubber jar, by filling the jar with weak electrolyte and immersing it in electrolyte as shown. A pair of metal electrodes connected in series with a 10-watt lamp and to a 110-volt D.C. or A.C. line are then placed as shown, one in the electrolyte within the jar and the other in the electrolyte around the jar.

If the jar is cracked the lamp will light, but if the jar is good the lamp will remain dark. In making this test be sure to keep the upper edges of the jar slightly out of the electrolyte so that the whole jar is not immersed.

For testing rubber battery cases, as shown in the lower sketch in Fig. 33, each of the cell compart-

ments is filled nearly to the top with weak electrolyte and tests made with the electrodes on each side of both partitions.

The lamp will indicate a leak in either partition by lighting when the electrodes are placed on opposite sides of the cracked rubber wall.

33. BATTERY CARE

A few general rules that can be followed by the battery repair man and also by the car owner to avoid many of the common battery troubles are as follows:

1. Keep the battery well charged and frequently test the voltage and gravity. Also keep the electrolyte one-fourth inch or more above the tops of the plates at all times.
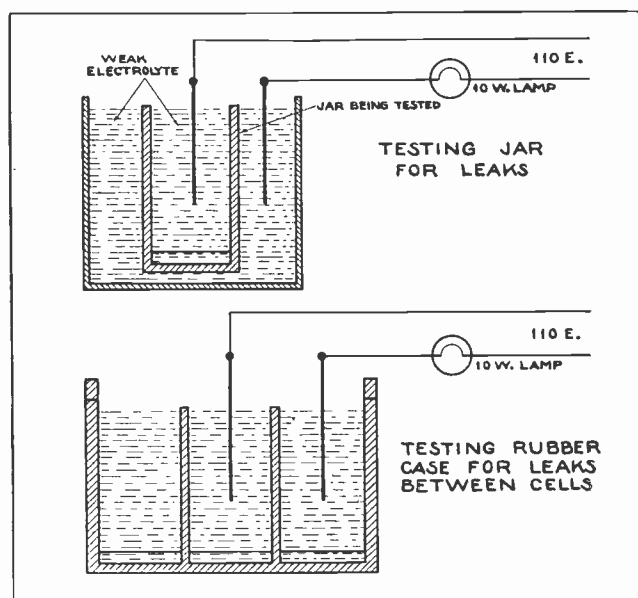

Fig. 33. The above two sketches illustrate the method of testing single cell jars or complete rubber battery cases for possible cracks or leaks.

2. Use only pure distilled water for refilling the battery and replacing evaporated water from the electrolyte.

3. In cold weather be particularly careful to keep the battery fully charged to prevent its freezing.

4. Inspect the battery every two or three weeks during the Winter and weekly in the Summer. Several times a week is not too often during long, fast trips in hot weather.

5. Do not allow the battery to overheat by excessive charging but instead reduce the charging rate either by adjusting the generator third brush or by burning the headlights while driving.

6. Do not overload the battery by using too many extra electrical accessories or light bulbs that are too large.

7. Do not use the starter excessively.

8. Keep the battery terminals tight and free from corrosion. Clean off any corrosion that may have
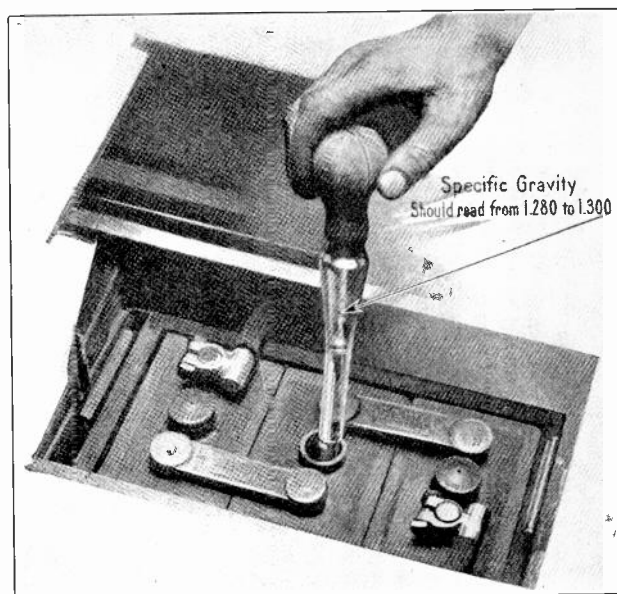

Fig. 33A. This view shows the use of a hydrometer for testing the gravity of a battery right on the car. This test is very important and should never be neglected when inspecting a customer's battery.

formed by wiping terminals with a cloth soaked in ammonia or strong soda water, and prevent further corrosion by coating terminals with vaseline.

9. See that the generator charges at the proper rate to keep the battery well charged but not high enough to overheat it.

10. If the gravity fails to come up to full charge reading when the car is in service, check the generator charging rate and increase it if necessary.

11. Keep the top of the battery dry and clean at all times.

12. Always remember to switch off the ignition even though the engine may have stopped due to stalling, and also remember to turn the light switch to the parking position when the car is idle at night, and thus prevent excessive drain on the battery.

34. STORAGE BATTERY REPAIRS AND SHOP METHODS

In working in an automotive battery service station or operating a shop of your own, there are a number of common repairs and service operations which are most frequently performed. Some of the most common of these jobs and the methods of performing them are explained in the following paragraphs.

The battery service man is frequently called upon to inspect batteries on the cars, to determine the level of the electrolyte, and refill the battery with distilled water if necessary. This is an extremely simple operation but one which should be carefully done in order to be sure that all three cells of the battery are properly filled.

As previously explained the level of the electrolyte should be brought up to between $\frac{1}{4}$ and $\frac{1}{2}$ inch above the tops of the plates, but care should be taken not to fill the cells too full, so that the electrolyte will not be up to the tops of the filler open-

ings where it will leak or splash out through the small openings in the filler or vent caps.

Water or acid spilled on the top of an automobile battery tend to collect dust and create a muddy condition, and also tend to cause the battery terminals and connections to corrode.

Fig. 34 shows a convenient form of battery filler outfit consisting of an inverted one gallon glass bottle mounted in a carrier frame and stand which
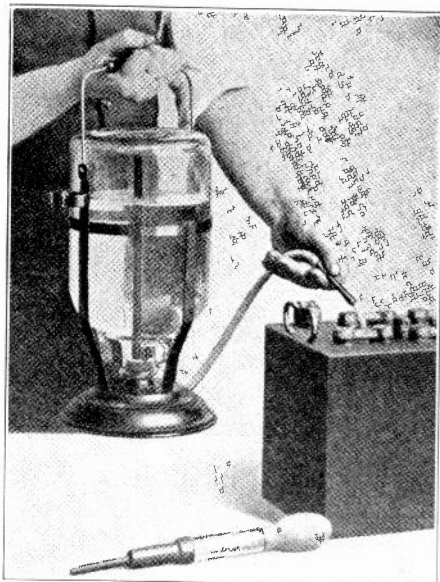

Fig. 34. Above is shown a very convenient type of battery filler used for adding distilled water to the cells of lead plate batteries for automotive or radio use.

has a cork to fit the neck of the bottle, and a flexible rubber tube for running the water into the cell openings.

These devices provide a small stream with which it is easy to fill the cells and yet easy to avoid spilling the water. They also permit the operator to see the level of the electrolyte inside the cell, which cannot be done if a funnel is used. When the cell is filled to the proper level the water can be immediately shut off by merely pinching the rubber tube. If a cell is too full some of the electrolyte can be removed by sucking it out with a hydrometer, or with a regular syringe made for this purpose and having a large rubber bulb and a slender rubber stem.

The operator in a battery shop should always encourage his customers and local automobile owners to come in regularly for this inspection and service on their battery, as the small amount of time required will be much more than repaid by the longer and more satisfactory service obtained from a battery that is kept properly filled.

A small charge can be made for this service if desired, or in many cases giving this service free will bring in a great deal of profitable battery business in the form of other repairs from customers whose good will and regular patronage has been obtained through this free service.

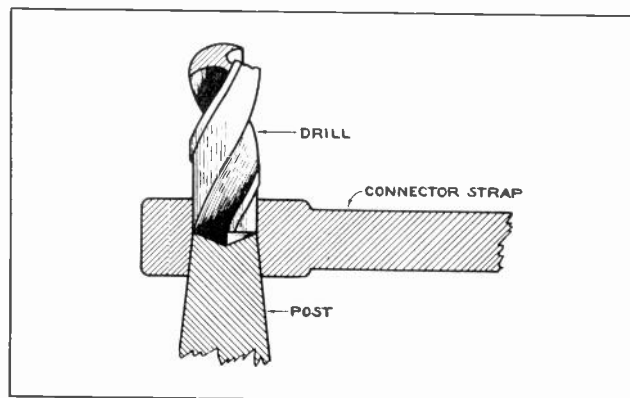Another test that is commonly made on the bat-

Fig. 35. Diagram showing the method of drilling out the tops of posts to remove connector straps when taking a battery apart.

teries while in the cars is the test of the battery voltage and of the specific gravity of the electrolyte. This test is also very easy to make with a portable voltmeter and a battery hydrometer.

In many cases the car owner's battery may be giving fairly good service in the operation of the lights and starter, and yet be getting very close to the discharged condition, where it will fail him just at some time when he most needs it.

This can be avoided by testing the voltage and gravity regularly and keeping the generator charging rate adjusted so that it will keep the battery well charged. In the Winter time these tests are particularly useful in avoiding frozen batteries, as frozen batteries are always due to having allowed the batteries to operate in a nearly discharged condition.

Leaky cells and cells with shorted plates or other defects can also be detected by these tests in time to correct the trouble before all the plates of the cell are ruined by sulphation, due to low electrolyte, or badly damaged by short circuiting.

35. OPENING AND DISASSEMBLING STORAGE BATTERIES

When a battery needs to be removed from the car and taken into the shop for repairs one of the first problems in the shop is to properly open the battery with the least loss of time, and without damaging any of its parts. There are three operations neces-
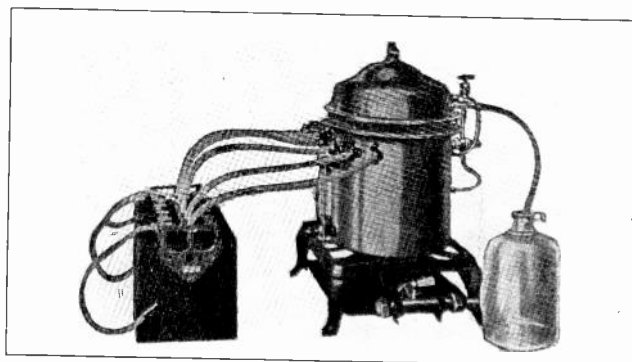

Fig. 35A. Common and convenient type of battery still and steamer, used both for steaming and softening compound when disassembling batteries, and for supplying distilled water for use in mixing electrolyte for refilling battery cells.

sary to open any automotive battery and these are as follows:—

1. Cell connectors or straps must be removed.

2. The sealing compound and cell covers must be softened and removed.

3. The elements or plate groups must be drawn from the cells.

The cell connectors or straps can be removed from the terminal posts by means of a large drill of about the same diameter as the top of the post. First mark the exact center of the posts and connectors, and then using a ½", ⅝", or ¾" diameter drill, depending on the size of the post, drill about half way through the welded or burned-on portion of the strap and post connection, as illustrated in Fig. 35.

The connector straps can then be easily removed by means of a heavy pair of gas pliers.

Another way in which these connector straps are often removed is by using a lead burning torch to melt or soften the top of the strap directly over the
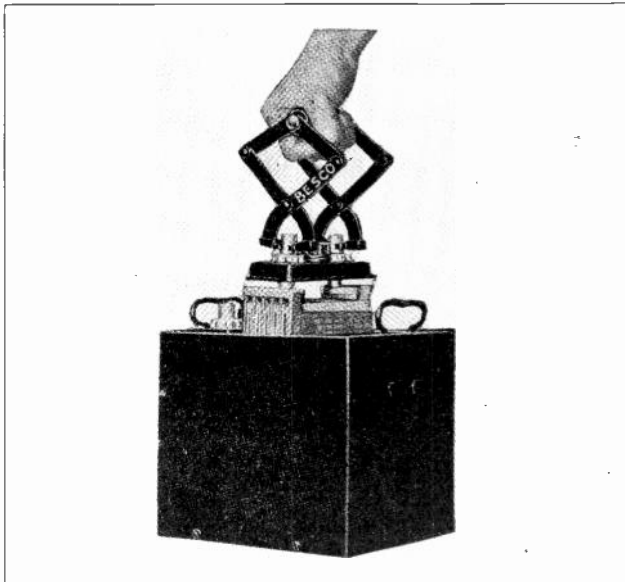

Fig. 36. This view shows a convenient type of cell puller used for lifting plate groups or elements from cell jars when taking down a battery for repairs.

post connection, while keeping an upward pressure exerted on the strap by prying from underneath with a screw driver.

As soon as the top of the strap has become melted or softened about half way through it will release from the post and pry upward.

The sealing compound and covers can be softened and loosened by heating or steaming. This is usually done by means of a regular battery steamer, such as shown in Fig. 35-A, and which supplies steam under low pressure through several rubber tubes which can be inserted into the cells through the vent openings.

This method requires from five to ten minutes to soften the compound so that the cell covers can be removed and the elements taken out. The device

shown in Fig. 35-A is a combination steamer and still.

By boiling water in this container placed over the gas flame, pure distilled water can be obtained from the hose on the right, which is shown placed in the top of the glass jar, and the unit also supplies steam from the tubes on the left for opening batteries.

When not in use for opening a battery these steam tubes can be shut off by means of small cocks or valves, and the steam allowed to condense in the upper part of the still and drip from the right hand tube into the jar in the form of distilled water.

The compound can also be softened by lightly playing a soft torch flame over the top of the battery in case no steamer is available.

When opening a battery it is not necessary to remove all of the electrolyte from the cells, but it is advisable to drain it down to the top of the separators by means of a filler syringe or hydrometer, as the steam process will add some distilled water to the cell and might cause it to overflow if the electrolyte level was high.

After softening the compound the elements including the covers are removed by taking hold of the cell posts with two pairs of pliers or with a regular cell group puller, such as shown in Fig. 36, and pulling upward. The elements can then be left setting in a slanting position on top of the jars, to permit them to drain and allow the electrolyte which runs from them to drip back into the jars.

After draining all compound should be carefully cleaned off from the covers and jar tops by means of a heated putty knife or scraper, both of which are shown in Fig. 37.
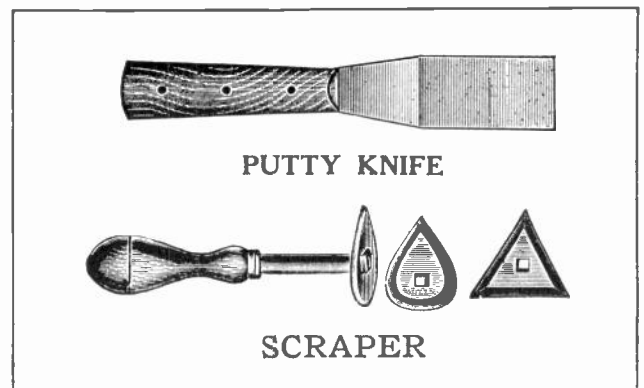

PUTTY KNIFE

SCRAPER

Fig. 37. A putty knife and scraping tool such as shown above are very convenient tools for removing or trimming sealing compound on storage batteries.

36. REPLACING DEFECTIVE PLATES AND SEPARATORS

After the elements are removed and the positive and negative plate groups separated, it is easy to tell by examining them and the separators what repairs are necessary.

If the separators are cracked, worn thin, or punctured they should be replaced with new ones, and if both sets of plates are in good condition they may not need to be renewed.

When either set of plates are badly worn or have lost considerable of their active material they should be replaced with new plates. Badly warped negative plates should either be straightened in a plate press or replaced with new ones. Granular plates or badly sulphated plates should also be replaced, unless perhaps in the case of sulphated plates the sulphation is not so bad but that it can be corrected by a prolonged charge and cycling.

The positive plates usually wear out somewhat faster than the negatives do and, in some cases where the positive plates are in very bad condition, and the negatives still comparatively good, a new set of positives may be used with the old negatives and considerable service obtained from a battery rebuilt in this manner.

However, a battery which has had all of the plates replaced will be likely to give much more dependable and considerably longer service. A good point to remember in this connection is that it seldom pays to put back any parts into a battery if their life or service would be questionable, because even if your work is well done on the part which you repaired and some other part fails very shortly after the battery is back in service the customer is likely to blame your work for the failure.

In many cases, where all the plates are in bad condition, it is just about as cheap for the customer and much more profitable for the battery man to sell a new battery. This is particularly true where labor costs and wages are rather high and where factory made batteries can be obtained at low cost.

In other cases, however, where labor costs are low it may pay to replace the plates and rebuild the battery, using the case or jars and covers over again.

Where a new battery is sold to the customer the best of the used plates can be saved and used in rebuilt batteries for loan service. A small allowance can be made to the customer on his purchase of a new battery if the parts from the old one are worth it.

Very often the only thing wrong with a battery or the cell will be the separators, in which case they should all be replaced with new ones, and the cost of this repair job is low enough to be very practical.

37. REASSEMBLING REPAIRED BATTERIES

After repairs have been made on a battery it can be reassembled in the following manner. First assemble the positive and negative groups with the separators between the plates. Then place the groups in the jars or cell compartments of the battery case, taking care to arrange them according to polarity, or so that positive and negative terminals are in the proper position for conveniently connecting the cells in series for the battery.

When replacing the covers if there is any difficulty in forcing them onto the cells the covers should be steamed or heated until slightly softened, after which they will go in place very readily.

After the elements and covers are all in place the cells must be sealed with hot compound, the sealing compound being heated in a small pot over a gas flame, or in an electrically heated dipper which can be obtained for this purpose.

Before pouring the compound make sure that the covers fit snugly all around so that no compound will be allowed to run into the cell and also make sure that all surfaces are dry, as compound will not stick to wet spots.

The cover channels can be dried out by passing a soft-flame torch quickly and lightly over them.

After the battery is sealed the freshly poured compound can be given a much neater and better finished appearance by passing the torch flame lightly back and forth over it.
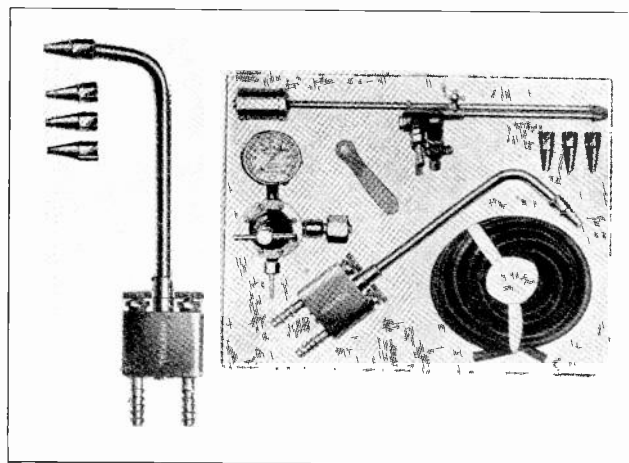

Fig. 38. On the right is shown a complete lead burning outfit, with the exception of the gas cylinder, and on the left is shown a larger view of the torch with its adjusting screws and extra tips for obtaining various sized flames.

38. LEAD BURNING

After the cells are back in place and the covers sealed, the next step is to connect the cells together in series by means of connector straps running from the positive post of one cell to the negative of the next, attaching these straps to the terminal posts by a process known as **lead burning.**

This is not really a burning process but merely refers to the melting or welding the lead of the straps and posts together, to make a very rugged and low-resistance joint that will carry the heavy battery currents at low voltage.

Connections that are properly made in this manner are mechanically strong and will not become loosened by vibration. They will also resist corrosion much better than bolted connections would.

For lead burning a small and intensely hot flame is required. These flames are generally obtained by a combination of two gases such as oxygen and acetylene, oxygen and hydrogen, or oxygen and illuminating gas.

Compressed air instead of oxygen is sometimes used with illuminating gas or acetylene.

Where regular city gas or illuminating gas is available, oxygen can be purchased in steel cylin-

ders and used with this gas. In other cases both oxygen and acetylene can be purchased in cylinders, and the two gases used together by means of a mixing valve and light weight torch, such as shown on the left in Fig. 38.

On the right in this figure is shown a complete lead burning outfit with the exception of the gas cylinder. This outfit consists of the torch and mixing valve. pressure-regulating valve and gage, a trap and valve for the city gas line, extra tips for the torch, and a length of small flexible rubber tubing for connecting the torch to the gas cylinder and gas line.

Both of the torches shown in Fig. 38 have the gas mixing valves with their adjusting screws attached directly to the torch. Mixing valves can also be obtained for mounting on the bench so that one tube will carry the mixed gases to the torch, thus providing a little more flexibility in handling the torch.

Fig. 39 shows a torch of slightly different type, with one of its tubes connected to the water trap on the gas line and the other tube connected to the pressure-regulating valve on the oxygen cylinder.
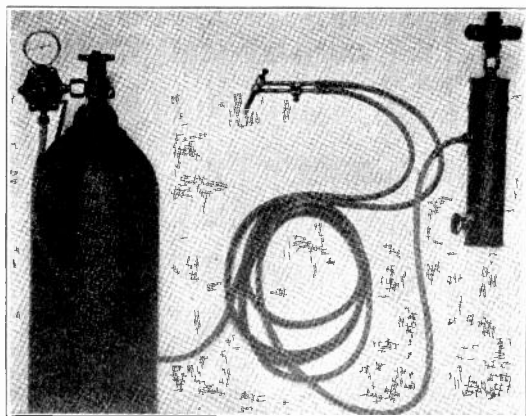

Fig. 39. This view shows the method of connecting a lead burning torch to the gas cylinder and piping, and also shows the mounting of the pressure regulating valve on the gas cylinder.

39. ADJUSTING THE LEAD BURNING TORCH

In order to do a good job of lead burning it is very important to have the correct pressures and mixtures of the different gases. The gases which are obtained in steel cylinders are stored in these cylinders under very high pressure, and this is the reason for the necessity of the pressure-regulating valve. shown in Figs. 38 and 39.

This valve when properly adjusted allows the gas to escape very slowly from the cylinder, and keeps it supplied at the proper pressure to the mixing valve and torch. When oxygen and hydrogen, or oxygen and acetylene are used each gas should be at a pressure of about 2 lbs. per square inch. When using oxygen and illuminating gas the oxygen should be at about 10 lbs. pressure and the illuminating gas at whatever pressure it is supplied, which is generally about 8 ounces.
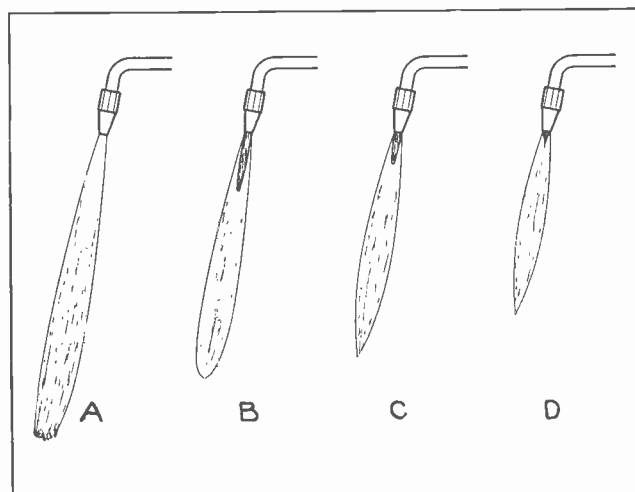

Fig. 40. The above sketch clearly shows the various steps in adjusting a lead burning torch. Examine each of these views very carefully while reading the accompanying explanation.

With these pressures right it is a comparatively simple matter to mix the gases in the right proportions with a mixing valve. This adjustment, however, is of the greatest importance in obtaining the proper kind of a flame for a good job of lead burning.

If too hot a flame is used the lead will oxidize rapidly on the surface and make the welding or uniting of the strap and post very difficult or next to impossible. If the flame is not hot enough the work is very slow and before melting temperature is obtained at the desired points, the entire terminal may be heated too much by the spread of heat and may melt down and run on to the battery.

The illuminating or acetylene gas is used to supply the body of the flame, and the oxygen is used to increase the heat of the flame. If too much gas or too little oxygen is used the flame will be yellow and will tend to carbonize and blacken the surface of the lead, making the burning or welding job very difficult. A plain gas flame doesn't give sufficient heat for this work.

If too much oxygen is used the flame will be too hot and the excessive heat and excess of oxygen will tend to oxidize the surface of the lead, giving it a yellow or sort of rainbow color, and producing a wrinkled and rather tough skin on the surface.

When a torch is first lighted with only the gas turned on, the flame will be long and yellow, with a soft brushy tip shaped as shown at "A" in Fig. 40. Then when the oxygen is first admitted, by means of the mixing valve, a slender blue flame will appear within the yellow flame near the tip of the torch, as shown at "B" in Fig. 40. This greatly increases the heat of the flame but doesn't yet produce sufficient heat for satisfactory lead burning.

As the proportion of oxygen is increased the blue flame gets shorter and hotter, forming a small blue cone which will be shaped as shown at "C" in Fig. 40. With the ordinary lead burning torch the oxygen should be adjusted until this blue flame is from

⅜ to ½ inch in length, with its tapered sides fairly straight or slightly full, and its tip very slightly rounded.

If too much oxygen is admitted the blue flame becomes very small and sharp-pointed as shown at "D" in Fig. 40, and the flame will be too hot and will tend to oxidize the lead. Admitting still more oxygen will often cause the flame to blow completely out on the ordinary small lead burning torch.

When the flame is correctly adjusted as at "C" in Fig. 40, it is then ready to use for lead burning.

The hottest part of the flame from a torch of this kind lies just beyond the tip of the blue cone, so the flame should be held in such a position that the blue cone almost touches the surface of the lead to be melted. Experience and practice will soon show the correct position for holding this flame.

It is very important to remember that to perform a good lead burning job all of the lead surfaces that are to be welded together must be absolutely clean and free from dirt, scum, or grease of any kind.

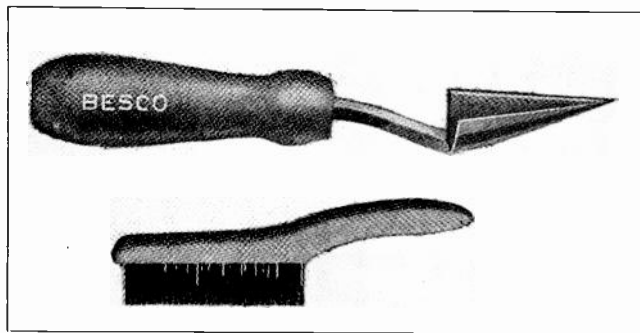The inner surface of the openings in the connector straps can be cleaned and also reamed to fit the

Fig. 41. Above is shown a convenient type of combination lead scraper and reamer, and below is a wire brush such as used in connection with lead burning on storage batteries.

posts by means of a hand reamer, such as shown in the upper view in Fig. 41, while the tops of posts and various other surfaces can be cleaned with a wire brush, such as shown in the lower view in Fig. 41, or with a coarse file.

40. PROCEDURE FOR BURNING A CONNECTION

Before starting to burn a connector strap in place on the terminal posts of a battery one should see that the tops of the posts properly fit the circular lugs of openings in the strap ends, so that there are no large openings between the post and strap, or otherwise the molten lead will run through on to the top of the battery.

The top of the post should project only about half way up through the opening in the strap. If the crack around the edge of the post is practically closed or only very small, the top of the post can be softened with a torch flame, and by pointing the tip of the flame into this corner between the post and strap and working the flame round and round

in the cup-like depression, the lead of the post and strap will be melted and run together in a smooth, rounded joint.

The torch should then be removed quickly by raising it straight up. Additional lead melted from the tip of a slender lead filler stick or bar can now be run into the cup to build up the post a little at a time, **thoroughly welding each added bit of lead to the top of the post and to the strap.**

Right here is a point on which many inexperienced battery men fail to produce a good lead burning job. A good permanent connection can be made only by having the built up top of the post and the upper half of the strap connection melted together as one, so it will not do at all to merely run or drip hot lead from the "filler stick," or bar, onto the hardened or cold metal of the cup as the hot lead will not unite with cold lead that has been allowed to harden.

There is always a slight, almost invisible, film or scum which forms on the surface of the lead almost immediately when it cools and this film will prevent additional molten lead from properly uniting with the lead beneath, making a very weak joint and one that offers very high resistance to the flow of current through the battery connections.

For this reason the surface of the lead in the bottom of the cup must first be melted by momentarily applying the torch, before additional molten lead is run in. This requires a sort of double operation with the torch flame that can be acquired only by practice.

In order to get the molten lead from the filler stick into the cup before the molten spot in the bottom cools, it is necessary to keep the torch playing on the molten spot and feed the end of the filler bar into the flame at the same time. This requires plenty of practice because there is quite a tendency for the end of the strap to become overheated and melt down, making it very difficult to complete the connection because the solid ring or lug on the strap end is needed as a form or mold to hold the molten lead and build up a good connection.

If the strap edge is accidentally melted down in this manner it is often better to remove the strap entirely and replace it with a new one. This trouble can be avoided by being very careful to keep the torch flame directed into the center of the lug and not allow it to play for any length of time over the edges of the strap lug.

It is also a good plan to build one post only part way up and then work on another post for a short time, giving the strap on the first one time to cool. By working from one connection to another, and building each one up a little at a time in this manner, none of the terminals is as likely to overheat.

Where only one or two connections are being worked upon the strap can be cooled occasionally by placing a wet cloth around it. When doing this, however, be extremely careful not to get any water
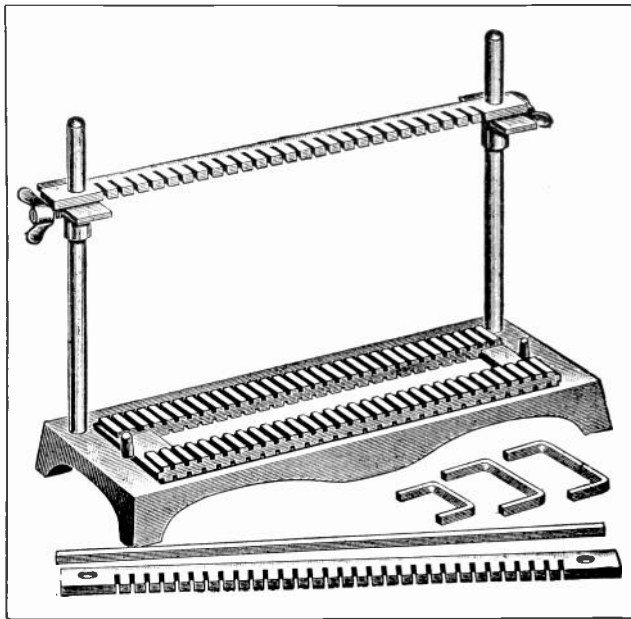
Fig. 42. Convenient racks of the above type are used for grouping and holding plates when burning on the terminal lugs on plate connectors.

into the cup, or it may cause molten lead to be blown into one's face when the lead burning is resumed.

When the post has been built up flush with the top of the lug or ring on the strap a very neat job can be done by adding a little more lead, and slightly rounding off the top of the connection.

This is a very critical operation and requires considerable skill and accuracy to avoid running the lead over the edge and melting down the side of the strap lug. Before placing this little additional cap on the connection it is well to let the work cool somewhat and brush off the top surface with a wire brush so that it is bright and clean.

The very center of this spot can then be slightly melted with the torch and a medium sized drop of lead run onto it. Then by raising the torch slightly and using a part of the flame which is not quite so hot, and running this flame quickly around in a circle the drop of molten lead can be pushed out just to the edge of the connection, making a very smooth and neat-appearing cap.

One should always be very careful not to jar or move a lead burned connection until the lead has had time to cool and harden, or otherwise the lead may be caused to crystallize as it sets, making a very weak and high-resistance joint.

41. CAUTION

Extreme care should be used when working with a torch on batteries that have just been removed from the charging line, as the cells may have quite a little hydrogen gas under their covers. This gas is highly explosive, and if a flame is brought near the small vent openings in the cell caps it is likely to blow the caps or covers completely off the cell.

It is, therefore, best to remove the vent caps and blow out each cell with compressed air if it is avail-

able. If no air pressure is available gas may be burned out by removing all vent caps, examining the electrolyte to see that it is below the lower edge of the vent hole tubes, and then using a soft flame with all oxygen turned off.

Standing at arm's length from the battery direct this flame into each vent hole for a second or two, and any gas will be safely burned out.

After the gas has been removed in this manner the battery may be safely worked upon. It is good policy, however, to have all vent plugs out when using a flame on the top of a battery, even after the gases have been removed, because it is still possible that some additional gas might form within the cells. This same precaution of removing vent caps should also be observed when batteries are placed on a charging line, or otherwise the hydrogen gas generated while they are charging may be ignited by a spark at one of the clips or charging connections.

Battery rooms in which large power plant batteries are located, or rooms in which a large number of small batteries are being charged or plates being formed, should always be kept well ventilated to avoid the accumulation of large quantities of hydrogen gas and the danger of serious explosions.

42. ASSEMBLING PLATE GROUPS. MOLDING STRAPS AND POSTS

The lead burning torch is also used when assembling plate groups, for welding on or attaching the terminal posts to the tops of the plate lugs.

Fig. 42 shows a burning rack used for spacing and holding the plates in a vertical position while the terminal posts are burned on to them. The small square bars shown beneath this rack are used for lengthening the lugs on plates, by laying the plate flat on a piece of hard asbestos or similar material, and using the little bars around the lug as a form in which to melt additional lead and run it together with the lead of the plate lug.
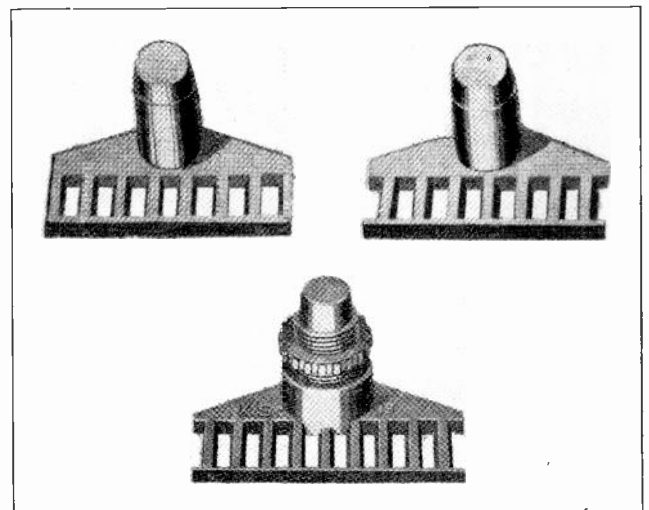

Fig. 43. Plain and threaded terminal posts and plate connectors for attaching positive and negative plates together in groups.
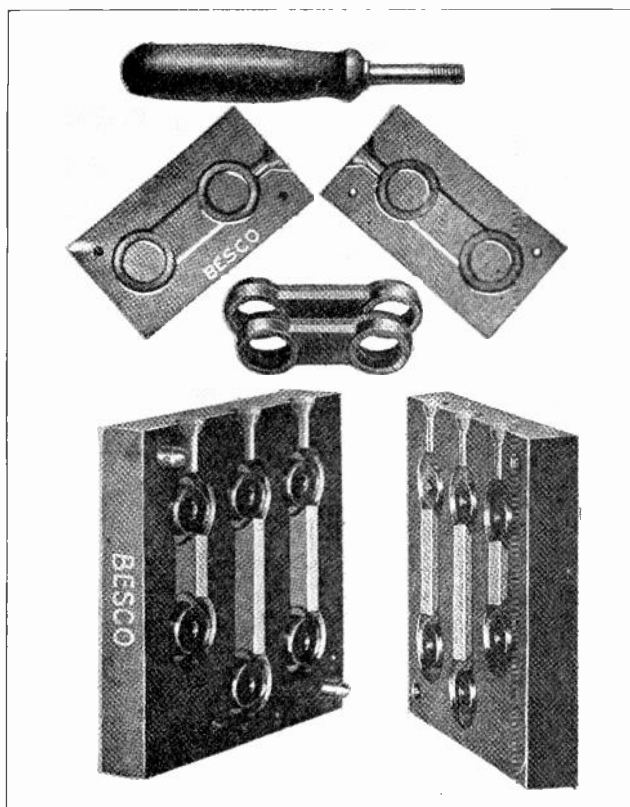
Fig. 44. Above are shown two types of straps or connector molds for molding lead straps of different lengths to be used in connecting together the separate cells of automotive batteries.

Fig. 43 shows several terminal posts which have been cast from lead and are ready for attaching to plate groups. The one on the upper left is a plain post for a positive group, and the one on the upper right a plain post for a negative group. The one shown below is called a "threaded type post" and has a cast lead nut which screws down on top of the cell cover after it has been slipped over the post.

Battery terminal posts and connector straps can be purchased from various battery supply houses, or they can be molded and cast from hot lead by means of special molds right in the battery shop.

Fig. 44 shows two types of strap molds, the one in the upper view being made for molding single straps of a certain length and the gang mold in the lower view is made for molding straps of three different lengths.

These molds are simply clamped in a vise in an upright position and the molten lead poured from a lead ladle into the funnel-shaped openings at the top of the mold.

When the mold is full and the lead has been given time to cool enough to set or harden, the mold is then removed from the vise or clamp and pried carefully apart. The straps can be removed by tapping on the back of the mold, or by prying up the filler tips and pulling them out with a pliers.

Carbonizing or blackening the surface of the mold with a plain gas flame torch will help to remove the straps more easily and prevent them sticking in the mold.

The upper view in Fig. 45 shows a combination mold for casting threaded posts and lead nuts to go with them, while the lower view in this figure shows a simple mold for pouring straight slender bars of lead which are used for filling strap lugs and making cell connections.

Fig. 46 shows several types of post cutters which are used for trimming off the tops of battery posts that are too long, in order to make them properly fit the strap lugs and to keep the straps down close to the top of the battery.

43. PREPARATION OF BATTERIES FOR STORAGE WHEN NOT IN SERVICE

There are two common ways of storing batteries when they are not in service, one known as the **dry storage** method and the other as the **wet storage**. If a battery is to be taken out of service for a long period of time and it is not possible to give it a monthly charge it should be stored dry.

For **dry storage** the following procedure should be taken:

1. Give the battery a thorough charge.
2. Remove the cell connectors and draw out the elements.
3. Remove the covers from the elements and separate the positive and negative groups.
4. Immerse the plates in distilled water for 10 to 12 hours keeping the positive and negative separate.
5. Remove the plates from the water and allow them to dry. If the negatives heat up when exposed to air they should be immersed in the water again
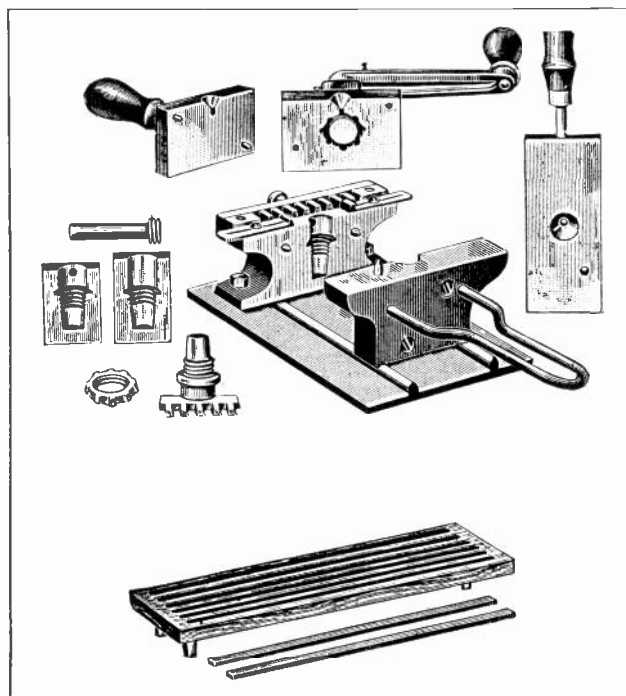

Fig. 45. Above is shown a combination mold used for casting threaded type posts and nuts, while below is a simple mold used for casting plain lead bars to be used in filling lugs when burning on connections.

to cool them, repeating this as long as they tend to heat, and then drying them thoroughly.

6. If the old separators are wood they should be discarded; if rubber they may be saved if they are in good condition. Clean the cell covers and all parts thoroughly and allow to dry.

7. When plates are perfectly dry put the positive and negative groups together, using cardboard instead of regular separators, and replace them in the jars or case in their proper positions.

8. Replace covers and vent plugs but do not seal the covers. Store in a dry place until ready to be put into service again.

9. To put the battery in service install new separators and reassemble the plate groups in the cells, replace the covers and seal them. Fill the cells with 1.320 specific gravity electrolyte, and allow the battery to stand for ten to twelve hours before putting it on charge. Then place the battery on charge at

Fig. 46. Several different styles of posts cutters or trimmers for clipping off the tops of battery posts.

the normal rate of 1 ampere per positive plate until the gravity stops rising and remains stationary for five hours. At the end of the charge the gravity should be between 1.280 and 1.300. If the gravity is not between these limits it should be adjusted by withdrawing some of the electrolyte and replacing it with 1.400 electrolyte if the gravity is too low, or with distilled water if the gravity is too high.

For placing a battery in **wet storage**, first give it a complete charge and then remove it from the charging line, and clean the outside of the battery thoroughly. Apply vaseline or light cup grease to the terminals and check the level of the electrolyte, adding distilled water if necessary.

Store the batteries on dry shelves, allowing a little air space between each battery and the next. Once each month replace with distilled water any electrolyte lost by evaporation and then give the battery a charge in the usual manner.

Before putting back in service batteries which have been in **wet storage** give them a thorough charge and make a high rate discharge test.

44. BUILDING NEW BATTERIES

After the parts for a new battery have been assembled and the battery is ready to be charged the procedure should be as follows:

First fill the battery with 1.250 specific gravity electrolyte. If stronger electrolyte is used the plates may overheat and become damaged.

After filling let the battery stand from six to twelve hours to allow the electrolyte to soak well into the plates and separators.

Next put the battery on charge at 1 ampere per positive plate. (5 amperes for 11-plate batteries, 6 amperes for 13-plate batteries, etc.) Keep the battery on the charging line until the voltage reaches from 2.4 to 2.5 volts per cell, with voltage test being made while charging. This voltage indicates that the active material on the positive plates is pure lead peroxide and that on the negative pure sponge lead. A gravity reading at this stage would be slightly below 1.250 if wet separators were used in assembling the battery.

The next step is to "set" the gravity by emptying out the electrolyte and replacing it with an equal amount of 1.350 specific gravity electrolyte. Then put the battery back on charge at 1 ampere per positive plate to equalize the electrolyte, and take the gravity reading after the battery has been on the charging line 30 minutes. The gravity should then be between 1.280 and 1.300. If it is below 1.280 withdraw some electrolyte and replace it with 1.400 specific gravity acid and put the battery back on the charging line again for 30 minutes, before taking another reading. If the gravity is above 1.300 remove some of the electrolyte and replace it with distilled water.

Correcting the gravity of a battery in this manner is sometimes known as "balancing", and it can be done while the battery is on the line and charging.

When the battery is ready to be removed from the line each cell should have a voltage of 2.4 to 2.5 volts, and the gravity should be between 1.280 and 1.300. **Caution: Be sure that the battery is charging at the correct rate when making a voltage test.** Otherwise the above mentioned voltages will not be obtained.

45. SHOP EQUIPMENT

Quite a number of our graduates sooner or later start a shop and enter into a battery repair business of their own, as it doesn't require a great deal of capital or material to start a shop of this kind.
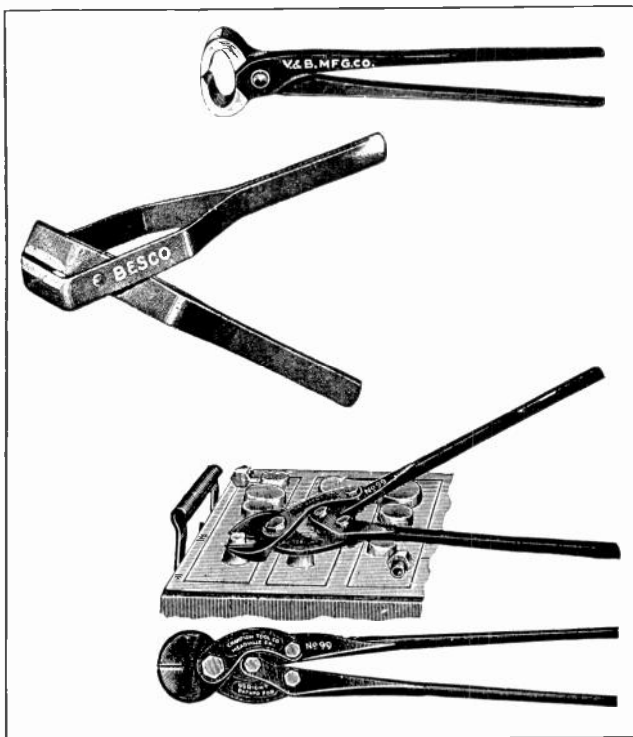
The following is a list of tools and equipment needed for a small shop:

1 10 or 20 battery Tungar charger
1 battery steamer and still
1 lead burning outfit
1 plate burning rack
1 hot-plate and compound pot
1 6-in. vise
1 low-reading voltmeter (Cadmium type)
1 temperature correction thermometer
2 hydrometers
1 pair of terminal tongs
2 pair nut pliers
1 10-in. screw driver
1 6-in. screw driver
1 battery carrier
1 putty knife
1 Cherokee tool for reaming down size of tapered posts
1 set of post builders
1 set of steel number stamps
1 set of positive and negative stamps
1 paint brush
2 wire scratch brushes
1 separator trimmer
1 triangular lead scraper
2 Vixen lead files
1 pair of end cutters
1 drill press and drills ½", ⅝" and ¾"
1 plate press
1 high-rate discharge set
1 cycling set
1 acid container
1 funnel.

Other tools such as saw, hammer, etc., will be found convenient. If a lead pot is used to melt lead for molding posts, straps, etc., in the shop, a set of assorted molds can be added.

Battery plates, separators, posts, straps, battery jars and cases, etc., can all be purchased from any regular battery supply company.

If you plan to open a shop of this kind at any time, remember at all times that courtesy, promptness, and first class workmanship are the essentials in building up trade and holding customers once obtained.

A sign on your place of business and some display of your work or supplies, along with some novel window attraction in the front of the shop, are great helps in getting attention and business.

Small ads placed in the local newspaper or little folders left at the homes of car owners in the locality will also help obtain business.

In many cases co-operative arrangement can be made with other local garages which may not have a battery shop, they sending their customers who need battery service to you, and you sending your customers who need general ignition or mechanical service to them.

46. GENERAL

Most of the material on lead plate batteries so far in this Section has been applied to the common small storage battery, such as used by the millions for automotive and radio work, as this is the field in which you will be most likely to have opportunity to make profitable use of storage battery knowledge.

However, it is well to keep in mind that there are numerous installations of large lead plate storage cells in power plant batteries, and that most of the general information covered in this Section can be applied to these batteries also.

Large cells such as shown in Fig. 2 and having plates with a surface area of several square feet are quite commonly used. These plates are generally set on porcelain bars or insulators laid in the bottom of lead-lined wood boxes.

Dozens or hundreds of these huge cells are then connected in series or series-parallel by means of heavy lead bus bars or lead coated copper cables, and kept in well-ventilated battery rooms at power plants or substations where they are used.

Such batteries are generally kept charged by means of motor-generator sets supplying D. C. at the proper voltage. In some cases the batteries are kept normally connected across the D. C. power busses, so that they are kept constantly charged up to the bus voltage, and ready to supply or feed current to the busses and load, as soon as any failure of the generators or any voltage drop on the system occurs.

In other cases special motor-generator sets known as **boosters** are kept connected to the batteries and are equipped with special relays or field connections so that they start charging the batteries at any time their voltage drops a certain amount.

Some large battery installations are equipped with additional cells known as **end-cells**, which can be manually or automatically cut in series with the main group as the voltages of the main battery drops slightly during discharge. By cutting in these end-cells one at a time the line voltage can be kept constant.

When charging batteries equipped with end-cells the steps of the switching process are just reversed, and the cells cut out one at a time after each has been charged the right amount. This gives the longest charge to those cells which were longest in service.

The voltage, electrolyte gravity, and the temperature are all kept carefully checked on such large battery installations.

It is well to give any storage battery about 10 to 15 per cent overcharge at regular periods to keep them in best condition.

Reversible **ampere-hour meters** are often used with batteries in power plants, farm lighting plants, emergency lighting installations, etc., to keep ac-

curate records of the amount of energy flow during charge and discharge, and to enable the operator to see that the right amount of charge is given both on normal charging and for the periodic overcharges.

47. EDISON NICKLE-IRON STORAGE CELLS

Edison storage cells differ from lead plate storage cells in that no lead is used in their construction; nickle being used for the positive plates and iron for the negative. The electrolyte is also different and instead of using sulphuric acid the Edison cell uses an alkaline solution of potassium hydroxide and distilled water.

The positive plates for these cells consist of a layer or group of perforated steel tubes $\frac{1}{4}$ inch in diameter and $4\frac{1}{4}$ inches long, which are filled with alternate layers of nickle hydrate and pure flake nickle. The nickle hydrate is a green colored powder-like compound and is the real active material in the positive plates, while the flake nickle is put in to improve the electrical conductivity and reduce the resistance of the nickle hydrate.

These two materials are packed into the thin perforated steel tubes under high pressure. The tubes are then banded with eight equally spaced steel rings which fit tightly around the thin walled tubes, reinforcing and strengthening them, and preventing them from bulging with the tendency of the active material to expand.

The proper number of these tubes, according to the size of the plates and cell, are then clamped in a steel frame to make up the plate. For plates
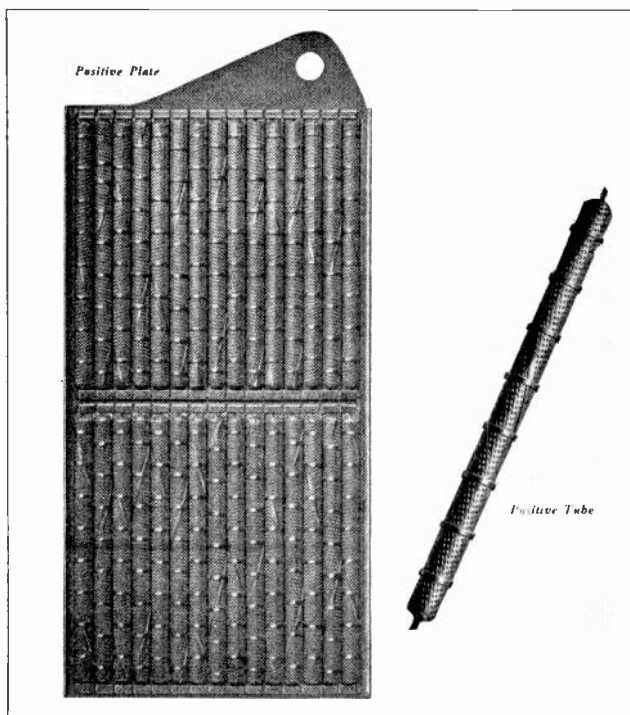

Fig. 47. This excellent photo view clearly shows the construction of the positive plate and individual positive tube for an Edison nickel-iron storage cell. Note the rugged construction of these parts. (Courtesy of Edison Storage Battery Co.)
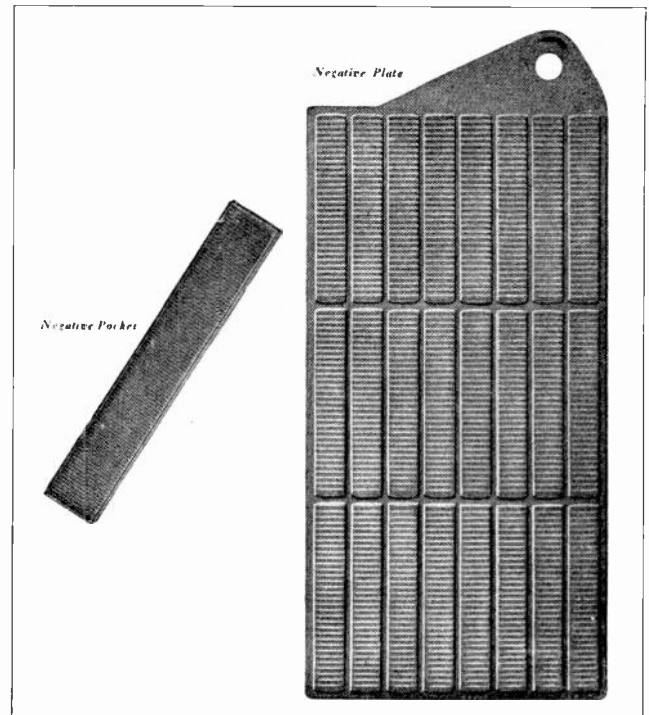

Fig. 48. Photo of complete negative plate and one separate negative pocket used in nickel-iron storage cells. The active material is contained within these pockets which are all grouped together in a steel frame. (Courtessy of Edison Storage Battery Co.)

longer than $4\frac{1}{2}$ inches two or more sets of tubes are arranged end to end and held in a nickle plated steel frame, as previously explained.

Fig. 47 shows a complete positive plate for an Edison storage cell and also one of the separate positive tubes from which the plate is made up. Note the manner in which the tube is constructed of a spirally-wound, thin steel ribbon, and also note the numerous small perforations to allow the electrolyte to penetrate through the active material in the tube.

The negative plates in Edison storage cells consist of a group of perforated flat steel pockets which are filled with iron oxide as the active material of these negatives. Iron oxide is also commonly called "black iron rust".

A group of these small pockets are then arranged edge to edge and clamped in a steel frame to make up the complete negative plate, as shown in Fig. 48. These positive and negative plates are then assembled in groups by clamping them securely on a threaded steel rod with nuts which draw them tight, the plates being equally spaced by means of steel washers between their lugs where they attach to the rod. A vertical terminal post is also securely attached to this rod.

The positive and negative plate groups are then meshed together similar to those of lead plate storage cells, except that in the Edison cells slender, hard rubber rods called "pin insulators" are placed vertically between the positive and negative plates to act as separators and insulators.

The assembled positive and negative groups or cell elements are then placed in containers of nickle plated steel with welded seams. Thin sheets of hard rubber are placed between the elements and the metal container to act as insulators, and after slipping a hard rubber washer down over each terminal the metal covers are welded permanently in place on the containers. This permanent closing of the cell is possible because of the very long life of the cells, and due to the fact that they require practically no mechanical servicing or attention throughout their life.

The sides of these containers are corrugated to give maximum strength with light weight material. The terminal posts are insulated and sealed into the cover by means of rubber gaskets.

The cell tops are fitted with combination check valves for allowing the escape of gases formed in the cell, and a filler cap which can be opened to add distilled water to the electrolyte or to change the electrolyte when necessary.

Fig. 49 shows an excellent sectional view of a complete Edison alkaline or nickle-iron cell. Note carefully the arrangement of all the parts, and the general construction of this cell.

The completed cells are filled with a solution of potassium hydroxide and water, the specific gravity of which should be 1.200. This electrolyte doesn't attack iron or steel the way sulphuric acid does, and it is thus possible to use the steel containers and obtain a much more ruggedly built battery. A group of cells of the desired number are commonly assembled in trays or frames for convenient handling.

The voltage of Edison nickle-iron storage batteries when fully charged is 1.2 volts per cell which you will note is a little lower than that of lead plate storage cells.

48. ADVANTAGES OF NICKLE-IRON CELLS

The Edison cell has a number of decided advantages, however, which make it much more suitable for many classes of work than lead plate storage cells are.

Some of these advantages are as follows:

The all-metal construction provides a cell of maximum mechanical strength and durability, and the construction of the plates makes them much more rugged and able to stand severe vibration, such as batteries are subjected to when used on electrical vehicles or in train lighting service.

The electrolyte, being of a non-acid nature, will not corrode any of the metal parts of the battery or other metal parts on which it might be spilled. Neither does this alkaline electrolyte solution attack or use up the active material of the plates when the battery is not in use, as does occur with lead plate storage batteries if they are not frequently recharged. For this reason Edison cells can be left
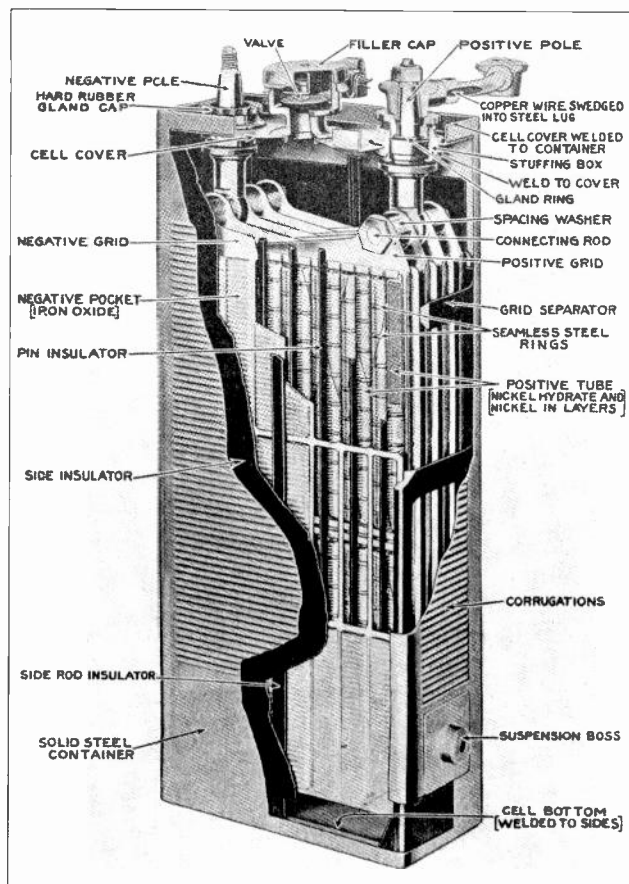

Fig. 49. This excellent cut-away view clearly shows the construction and parts of an Edison nickel-iron storage cell. Note the very rugged construction throughout, and also the strong sheet metal container used with these cells. (Courtesy Edison Storage Battery Co.)

standing idle for long periods in a discharged condition without injury.

These cells can be reversed and charged backward, or can be charged and discharged at very heavy rates, or even short-circuited without injury. The active material of the plates, being encased in steel tubes and pockets, doesn't shed so these cells do not have to be dismantled for plate repairs or cleaning out of sediment.

Another great advantage is that the plates of Edison cells are not subjected to warping and buckling under excessive current rates, and, being equipped with hard rubber separating strips, it is almost impossible for them to become short circuited as so often occurs with plates of lead and acid storage batteries.

49. CHARGE AND DISCHARGE ACTION

The basic principle of the Edison cell is the reduction and oxidation of metals in an electrolyte which doesn't combine with or dissolve the metals or their oxides. Due to this fact the specific gravity of the electrolyte is always constant whether the cell is in a charged or discharged condition.

Hydrometer readings are, therefore, of no use in determining the state of charge of Edison storage cells.

After about 300 cycles of charge and discharge the electrolyte gravity tends to become lower, and the old solution should be emptied out and replaced with new solution of the correct gravity.

During charge the chemical reactions in Edison storage cells are as follows: The nickle hydrate or active material of the positive plate becomes oxidized and is changed to nickle oxide; while the iron oxide or active material of the negative plate is reduced to metallic iron.

Thus, for practical purposes, the charged positive plate can be considered to consist of nickle oxide (NiO_2) and the charged negative plate consists of pure iron (Fe).

During discharge some of the potassium from the electrolyte in the cells unites with the nickle oxide of the positive plate and reduces it to a lower oxide of nickle (Ni_3O_4), and some of the oxygen unites with the pure iron, changing it to iron oxide (Fe_3O_4).

When the cell has been discharged these actions can be reversed and the plates and electrolyte both changed back to their original charged condition, by passing current through the battery in the direction opposite to the flow during charge.

50. CHARGING NICKLE-IRON CELLS

The charging voltage required for Edison batteries is from 1.7 to 1.85 volts per cell. These batteries can be conveniently charged by means of the constant current system, or with batteries connected in series to the source of direct current of the proper voltage.

They are also sometimes charged by the constant potential or parallel method, but the handling of this system is very critical, because if the generator voltage rises at all above 1.7 volts per cell there will be a very heavy current surge through the battery, which may cause it to overheat.

External series resistances are sometimes connected in series with each battery when they are to be charged by the constant potential or parallel method. These resistances serve to limit the current flow and prevent heavy surges and charging current through the batteries.

The open circuited voltage of a fully charged Edison storage cell is about 1.5 volts per cell, but this falls off very rapidly as the rate of discharge is increased so the average discharge voltage of a well-charged cell is about 1.2 volts.

When the voltage drops to .9 volts per cell these batteries are considered to be discharged and should be put back on the charging line again. In many installations of batteries of this type they are recharged as soon as the voltage falls to 1 volt per cell. Nickle-iron storage batteries can be completely discharged, however, without damaging the plates as occurs with lead plate batteries.

While a hydrometer is of no use to indicate the state of charge of the nickle-iron storage cell, it should be used occasionally to check the specific gravity of the electrolyte to determine whether the solution should be changed or not.

As previously mentioned, the gravity of the electrolyte gradually becomes lower with repeated cycles of charging and discharging, and when this gravity drops as low as 1.160 it should be changed and renewed with 1.200 gravity electrolyte.

Edison cells should not be operated with electrolyte of lower gravity than 1.160, or they become sluggish and lose capacity and are also subject to breakdown on severe service.

Caution: When using a hydrometer to test the specific gravity of the electrolyte in nickle-iron cells, if this device has been used with lead plate cells be sure that it is free from all traces of acid. Be careful never to use with Edison cells any utensils that have been used with sulphuric acid, as even a slight amount of acid may cause serious trouble or ruin the cells if it gets into the alkaline electrolyte solution.

51. INTERNAL RESISTANCE AND EFFICIENCY

The internal resistance of nickle-iron cells is approximately three times as high as that of lead storage cells of the same capacity and voltage, and will cause a voltage drop of about 7% of the open circuit cell voltage when the cell is discharging at the five-hour rate.

Edison cells have a rather peculiar temperature characteristic in that their capacity falls off very rapidly when they are operated at cell temperatures below about 50° F. Under normal conditions, however, the charge and discharge action generally keeps the internal temperature of the cells considerably above this point, particularly if the batteries are enclosed in a box with temperature insulation when they are to be used in cold places.

The efficiency of nickle-iron cells is considerably lower than that of lead storage cells, so they require considerably more current in ampere hours to charge them than can be obtained from them during discharge.

Their efficiency is about 60% in ordinary operation. This lower efficiency is more than made up for, however, by the many other advantages previously mentioned which these cells have over lead plate batteries.

52. CARE OF NICKLE-IRON STORAGE CELLS

In order to give the most satisfactory service nickle-iron storage cells should be recharged often enough to keep their voltage above .9 volt or 1 volt per cell, and will give still better service if used in such a manner that they can be given frequent boosting charges at intervals between the discharge periods, in order to keep the voltage up nearly to the full charged value.

It has already been mentioned that the electrolyte in these cells should be renewed approximately once every six or eight months, or after the cells have been charged and discharged about 300 times.

The cells should be refilled with standard refill solution obtainable from the Edison Storage Battery Company. Don't pour out the old solution until you have received the new and are ready to refill the cells with it, as they should not be allowed to stand empty.

When renewing the electrolyte, first completely discharge the battery at normal rate to zero and then short-circuit it for one or more hours. This is done to protect the battery elements. Next pour out half the solution and shake the cell vigorously, and then empty the balance.

Never rinse the cells with water but instead use only the old solution. Never use a galvanized funnel or one that has soldered seams, or anything else of this nature in handling solution for these batteries. Glass, enamel ware, or plain iron funnels and utensils should be used.

Under good operating conditions and with proper care the total life of these cells should be somewhat over 1000 complete cycles of charging and discharging. When the electrolyte level becomes too low due to evaporation these cells should be refilled with pure distilled water, the same as used for lead plate storage cells, except that it is well to use water that has not been exposed to air for any length of time, but which has instead been kept in a corked bottle or sealed container after distilling.

The level of the electrolyte in nickle-iron cells can be conveniently tested by lowering a ¼ inch diameter glass tube vertically into the filler opening, until its lower end touches the tops of the plates. Then, by placing the finger tightly over the top end of this tube, it can be raised out of the cell and will hold a small amount of the electrolyte at its original level inside of the tube.

This level can be measured from the bottom of the tube, thus determining the height of the electrolyte above the plates.

A small piece of rubber tubing fitted tightly around the top end of the glass tube helps to provide a better air seal when the finger is placed against it.

The metal containers of nickle-iron cells must be kept carefully insulated from each other at all times or there will be a small leakage of current between them, and the cell containers may become punctured due to electrolytic action.

The cells and their trays should be kept well cleaned and free from collections of dirt and moisture. They can be cleaned by blowing with compressed air, or with a steam hose, but the steam hose should not be used on the cells while they are located in their compartments.

It is a good plan to coat the tops of these cells with a light coat of rosin-vaseline which has been warmed to about 180°, and thinned to paint consistency with benzine. This material can be applied with a small paint brush. The outsides of the cell containers should be kept painted with some good alkili-resisting insulating paint. Nickle-iron batteries should not be operated at temperatures above 120° F.

53. LOCATION AND CONNECTIONS

When locating nickle-iron cells in storage or carrier compartments, the compartments should be lined with wood and constructed to afford ample ventilation, good drainage, and ease in cleaning. A compartment should be provided with slots about an inch wide, running the full length under each battery tray where bottomless trays are used, and between the trays when trays with bottoms are used.

Openings should be provided in the sides of compartments above the highest point of the battery. These openings should have a total area slightly greater than the total of the bottom openings and they should be located to keep out as much dirt and water as possible.

If the battery is used out-of-doors in cold climates these openings should be closed during cold winter weather.

Nickle-iron cells can be connected in series or series-parallel, the connections being made and tightened under the nuts provided on the top of the terminal poles. Regular steel jumper connectors with terminal lugs are provided with batteries of this type. These lugs seat firmly on the terminal posts if the steel jumper wires are properly bent and shaped to allow them to.

The lugs should never be driven or hammered into place, but should have their jumpers so shaped and adjusted that the lugs slip easily in place where they can be securely locked by means of the nuts.

It is good practice to slightly grease the threads on the terminal posts, after the lugs are in place and before the nut is put on. Make sure that all contact surfaces between terminal posts and lugs are clean before making connections, and always see that all connections are kept tight and clean.

For removing these connector lugs after they have been forced tight with the terminal nuts, a small disconnecting jack or terminal puller is shipped with each battery. This jack can be placed straddle of the terminal post so that it engages the lug and will then pull the lug loose if the screw of the jack is turned.

One should be very careful never to handle flames of any kind around these cells when they are charging or discharging, as explosive gases are liberated from the cells during these periods.

The material covered in this Section on Storage Batteries of common types has been applied particu-

larly to automotive batteries of the lead and acid type, and to nickle-iron storage batteries which are so extensively used for operation of electrical vehicles, and in train lighting, and various classes of signal work.

However, a great many of the principles and rules given can also be applied to larger storage batteries of the lead plate type, which are used in power plant work and which have been generally explained.

A good understanding of the material covered in this Section can be of great value to you in various classes of electrical work, such as telephone, telegraph, railway signal, farm lighting, radio, automotive, and power fields.