The Electric Storage Battery
and its Commercial Applications,
with a test of a small battery
in use at Haverford College.

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Although the storage battery has only been known commercially for the last thirty years and used to any extent for the last fifteen, it was among the first of the great discoveries in the electrical world which have revolutionized our modern life. In 1801, but one year after Volta prepared the first primary cell, it was observed that if a current of electricity had first been passed through a circuit containing two inactive metal plates in an electrolyte, and these were then connected through an external circuit, a current would flow for a short time in the opposite direction. Like most such discoveries, but slight progress was made for many years, although in 1837, it was
found that peroxide of lead was even more satisfactory than lead itself as one of the elements of the secondary cell. The first practical secondary battery was made in 1860 by Gaston Planté, and his work extended over a period of near twenty years. About 1880 the patent for mechanically formed plates was granted to Faure; and it has been, since then, that the storage battery has been an important factor in the electrical world. At the present time the battery is a necessary adjunct of almost all of the large, light and power plants in operation, and in many other fields as well. Such is a very brief history of the rise of the storage battery.

I shall now take up briefly,
a description of the construction and theory of a few of the more important types of battery and then follow with a more detailed account of the rise of the secondary battery in some of its various phases. The simplest form of the secondary cell consists of two lead plates immersed in dilute sulphuric acid. This cell does not have a very large capacity nor does it give a large electro-motive force. Before taking up the various types of cells, it will be necessary to examine somewhat into the elementary chemistry of the battery. The dilute sulphuric acid or H₂SO₄ is conjuogated and the solution contains the positively and negatively charged radicals H₂ and SO₄. On the passage of a current the hydrogen ion appears at the negative pole
and the oxygen at the positive where it oxidizes the lead to the peroxide PbO₂. At the same time if there is any oxide on the negative plate it is reduced by the hydrogen to metallic lead in a very fine form. On discharge some of the energy stored in the plates is given back. The common name for the storage battery or accumulator did not however arise from this accumulation of energy but from the imperfect knowledge of early experimenters who thought that an action similar to that in a condenser took place. If the plates to begin with were one of the peroxide of lead PbO₂ and one of spongy lead Pb and our electrolyte was dilute sulphuric acid H₂SO₄ the action would be as follows:
on discharge \( PbO_2 + Pb + 2H_2SO_4 = 2PbSO_4 + 2H_2O \)

This \( PbSO_4 \), or lead sulphate, is formed in all batteries on discharge and will destroy the battery if discharged too great an extent. It is a white insoluble salt and is a very good insulator. Hence its formation on both plates tends to increase the internal resistance of the cell and its voltage consequently falls. In charging, the reverse action takes place; the \( PbSO_4 \) on the plates being converted into \( PbO_2 \) at the positive and \( Pb \) at the negative by the action of the charging current.

At positive plate: \( PbSO_4 + H_2O + O = PbO_2 + H_2SO_4 \)

At negative plate: \( PbSO_4 + H_2 = Pb + H_2SO_4 \)

On combining equations:

\[ 2PbSO_4 + H_2O + (H_2 + O) = PbO_2 + Pb + 2H_2SO_4 \]

The storage batteries in present use are of three types: the Planté, the
Fame, and the combination of these. Plants据此 lead plates in \( H_2 SO_4 \),
and charged them by the passage of
current. He then discharged them
fully and recharged in the opposite
direction. After several such
reversals, he observed that the capacity was
greatly increased. But however, this
method would not pay commer-
cially, owing to the great time and
amount of current expended in the
"forming" the plates. Three quicker
and more economical methods of
forming have since been devised.
In the first of these the lead is lamina-
cated to great surface by using ribbons
or wires or else by growing by means
of some forming tool. In the second, the
plates were placed in nitric acid bath
and pickled for some time. This
produces the same result, oxidation, and
so much quicker. Thirdly, in the Plante type plates the active material is often formed by an electrochemical action. One of the most satisfactory and the most used method of forming is to use some compound of lead and by the action of the current reduce this to a porous metallic lead plate. There are very many different ways of thus forming the plate, all of which are used to some extent and are patented; the object being in each case to obtain a positive plate covered with a layer of brain provided of lead and a negative plate of sponge lead; an allotropic form of the pure metal which gives a higher E.M.F. than ordinary cast lead, when used with PbO positive in H2SO4 electrolyte.

About 1880 Camille Faure patented a process of forming the
Plates which were a great improvement over the methods of Plante. This was radically different, consisting of some method of covering the lead plates with a paste of an oxide of lead and sulphuric acid. This paste was held on in different ways, usually by roughening the surface of the plate, by a lime, and then forcing the paste on the surface by means of a heavy pressure. The common methods were to use a paste of minimum 67 per cent lead, PbO, on the positive plate and PbO on the negative. A current of electricity on being passed through the sulphuric acid electrolyte and the plates changed the PbO to PbO₂ and the PbO was reduced to sponge lead. The chief difficulty experienced was that of making the paste stick to the lead grid and to
obtain good electrical contact between the two. The result was that many different methods were tried to obtain these results. The common method of applying the paste was to punch holes in the plate and then the paste was forced through these and after hardening 117 was practically rivited fast to the lead. Another satisfactory method was to roughen the lead surface into grooves and fill these with the oxides. At the present time the battery built in this manner which is used to the greatest extant in this country is known as the Crude Battery manufactured by the Electric Storage Battery Company of Philadelphia, and is used chiefly for electric vehicle work.
The third main type of battery is that wherein a combination of the Plants' and Danae types are used. This has its largest use in the plates of the "Chloride Accumulator," also manufactured by the Electric Storage Battery Company, and is used almost to the exclusion of all other types in recent storage battery installations throughout America. The old form of Chloride Accumulator used a negative plate of the Danae type and a Plants' positive. The negative originally used was a solid lead grid filled with small squares of active material consisting of an intimate mixture of lead and zinc chlorides. When placed in a solution of zinc chloride together with plates of metallic zinc and then short circuited, the mixture on
The plate was reduced to metallic lead. At the present time, however, the negatives are made in the customary manner of filling plates with litharge and then reducing. The chloride accumulator positive plate is a solid lead-anode arrangement grid with circular holes punched in it. Then corrugated sections of chemically pure lead are tightly rolled and forced into these holes in the plate. An electro-chemical process taking about thirty hours is then applied, and the spirals are changed to the active material. Pole. During the chemical change an expansion takes place which forces the active material more closely against the lead thus giving a firm, true, better contact and support.
Total Generator & Batt. Load Curve of the Hartford Elec. Light Co. Hartford, Conn. Half Hour Readings Nov. 25, 1905
The plate was reduced to sheet lead. At the present time, however, the negatives are made in the customary manner of filling porous litharge, and then reducing the Chloride Accumulator positive plate to a solid lead-antimonial grid with circular holes punched in it. Then corrugated strips of chemically pure lead are rolled and forced into the holes of the plate. An electro-chemical process, taking about thirty minutes, is then applied and the special material is changed to the active material, PbO

During the chemical change an expansion takes place which forces the active material more closely against the lead, thus giving at the same time better contact and finer support.
There are various other types of secondary batteries made, using other metals than lead and other electrolytes than sulphuric acid, but they are not used to any extent outside of the experimental laboratory, and since they are so seldom seen in the commercial application of the secondary batteries, they will not be taken up at all.

Before taking up the discussion of the applications of the primary battery it will be well to examine and state some of the physical facts which the various types of batteries have in common. All well constructed batteries give an average E.M.F. on discharge of approximately 2.0 - 1.8 volts per cell. The charge should be continued until a voltage of 2.5
is reached or the electrolyte gasses freely showing that the negative plate has been fully reduced to the pure lead state. The voltage may rise slightly or fall below due to variations in construction of the batteries. In discharging the voltage should never be allowed to fall lower than 1.8 volts, else the plates are in danger of being destroyed through sulphating or blooming. The first of these two diseases of the plates is caused by the formation of an excess of an impermeable layer of lead sulphate on the surface, and the second is warping of the plates due to unequal expansion of the metal and the active material. The latter action is attended by internal short circuits and detachment of portions
of the materials. The current varies directly as the area of positive plate surface, the normal charging current usually being 0.40 ampere per square inch of such surface. The density of the electrolyte as well as its temperature is an important factor. Only chemically pure sulphuric acid should be used, and the density at full charge should be approximately 1.24 at 60°F. During discharges the formation of PbSO₄ causes a fall in density to about 1.185 at a voltage of 1.8 volts. Any water which evaporates should be renewed frequently, otherwise the density of the electrolyte will become too great and sulphating will occur. The most important data to be determined in respect to any battery is its capacity. This is obtained by
discharging at a normal constant current rate, and noting the time required to discharge to 1.8 volts. The product of the current and the hours gives the ampere hour capacity. During this discharge the voltage is observed at frequent time intervals, and the average voltage during the period of discharge is calculated. This result, multiplied by the ampere hour capacity, gives the watt hour capacity, which is the true capacity desired. The discharge capacities at greater rates than the normal should also be known in order to be sure that the battery installation would be able to meet the most exacting demands.

The efficiency of a battery is the ratio of the useful current energy given out on discharge to that put in. There are two kinds of efficiencies
usually determined. The ampere-hour efficiency is the ratio of the discharge in ampere-hours to the charge in the same unit when discharged at the same rate as the charge. The watt-hour efficiency is the ratio of the watt-hour discharge to the watt-hour charge. The ampere-hour efficiency is not so satisfactory because it gives no definite idea of the amount of energy of the battery. Ampere-hour efficiency is often inaccurate because if discharge is continued below 1.8 volts the rate of output may apparently be greater or equal to the input and we would have 100% efficiency. The watt-hour or energy efficiency is the only result valuable to the engineer. The battery efficiency depends on the rates of charge and discharge; the internal resistance, the structure and quantity
of the active material, the density of the electrolyte, the length of time between the end of discharge and beginning of next charge, freedom from local action in the cells, and temperature variation. Efficiency is higher at low rates of charge and discharge than at high because less energy is lost in gas formation and heat and counter E.M.F. of polarization. Efficiency is less at high than at low temperatures. Hence it is well to keep the battery in a room where the temperature is fairly low and constant. The efficiency of a battery depends somewhat on its age, a new battery never being charged and discharged through such a wide voltage range as a small one and hence having a higher efficiency. With small batteries, used for storage of energy, the watt-hour efficiency range
from 70% to 80%. Very large batteries have higher efficiencies from 80 to 85%. Batteries used solely for regulation purposes may have an efficiency as high as 92%.

Use of Batteries.
Secondary batteries are principally used in connection with power stations and distribution work for the following purposes:— First, storage of electrical energy; second, regulation of station output; third, regulation of station voltage; fourth, compensation for feeder drop; fifth, insurance against shut down; sixth, as an equalizer in three wire systems; seventh, a combination of any or all of these and also many minor uses which will be discussed later. Each of the above will now be taken up in turn.
In discussing the first three of the above cases great difficulty is experienced in making sharp dividing between them as in most cases an installation for one purpose involves the other two. The storage of electrical energy is, of course, the original field of the secondary battery and should naturally be taken up first. In any electric power station no matter what its character, the load varies from a maximum to a minimum during the twenty-four hours each day. A plant furnishing power to a mill only the load is usually constant a definite number of hours and then becomes zero the rest of the day. Thus in such a case the cost of maintenance is less than with a fluctuating load. The whole twenty-four hours in planning a power plant installation it is a
common question of whether generating units shall be installed sufficient to supply the maximum load and then run the rest of the time under light load, or to install sufficient machinery to carry the average load easily and use a battery system for the peak. During part of the day the load is light and the battery will be charged while during the peak of the load, usually in the early evening, it may discharge in parallel with the generator and thus give an energy which the generator alone could not be able to furnish.

It is a question of being calculated to determine the efficiency of the battery system will be greater than the loss in shutting down generator units or not. Local conditions are the determining factor in the
question. Will the increase of the demand in the near future warrant the installation of large enough generators to carry the peak load at the present time? If not, then what is the local cost of fuel and labor? How often it is cheaper to run the station at lower efficiency than with the battery installed. The cost of the battery itself and its necessary auxiliary apparatus enters largely into the calculation. Different cases where it has been tried the battery has proven more economical. The use of a storage battery in thus carrying the peak load is best shown by the following curves taken from typical plants having battery installations. It can be shown where the battery takes care of the entire load during
The lighter hours of the day.

Battery handling Lighting Peak and discharging in emergency service.

**Fig. I**

Battery handling Lighting Peak.

**Fig. II**
In the regulation of load the storage battery plays an important part. In nearly all electric railway service the load varies as much as 50 to 100% from the average in very sudden fluctuations. This is due largely to starting several cars at the same time and thus
suddenly putting a very great load on the generator for a short time. If we have a generator working at normal full capacity and have in addition the battery in parallel across the line, it will absorb energy at points of light load and give it back at moments of overload, which could not readily be carried by the generator. When the load is light, the battery is being charged and at such a rate that the current absorbed by the battery is the difference between that given out by the generator and that used by the load itself. This use of a battery in order to give a steady load on the generator is most economical. All steam engines show a much lower efficiency or light or rapidly fluctuating loads than when
This is full and constant. The battery saves money in the coal pile, and in addition saves largely in the general depreciation of the machinery, which are saved. The destructive shock and wear due to varying loads.

In a case such as this, the efficiency of the battery itself is very high and the battery units do not necessarily have to be of very great size, but the efficiency of the plant is very largely increased. When the peak of the load comes, the battery may give out energy continuously in addition to carrying the fluctuations.

One important advantage of such a battery is the medium sized or small plant is when but one generator is being run in order to supply a light load. Suppose an accident happens to the generator or its
engine necessitating a shut down and the starting of another unit. At such times a battery is well able to carry the entire load the necessary few minutes while the generator is starting. Thus the consumption of power is not caused to suffer any inconvenience due to the failure of the current. This is well shown in the curves in Fig I and Fig V.

Battery discharging in emergency service during interruption of power supply. Fig V.

No better illustration of the fluctuating load is found than in the operation of a steel mill. Here, where most of the machines are motor driven, a large load is placed upon the generator.
for short intervals which severely tax the generator. In a particular test made the average load of 17,260 amperes suffered fluctuations as high as 45,000 amperes or nearly double. After the battery installation the generator load scarcely fluctuated at all while that of the total load was as great as ever. Thus the batteries relieved the generators of all the excess load and enabled the great saving to be made in the cost of running. This saving in steam economy is best shown by the occasion.

Ranging Photographs of Sample indicator cards taken when the engine was running. The smooth sine card shows the almost uniform point of cut off at which the engine was run as compared to the widely varied cut off as
regulated by the governor in attempting to take care of the fluctuating load.

Fig IV  Before battery installation

Fig V  After battery installation.
The saving in the above case is ten
conservatively estimated at about 3500
tons of coal per annum or over $1,500.
This does not include oil and engine
saving and although the increased
life of the generating apparatus, due
to relief from shocks, is not calculable
in exact dollars it is without doubt
very great.

The third use of batteries, namely
that of voltage regulation is very
closely connected with the load
regulation. In fact a battery used
for current regulating purposes will
necessarily give a voltage regulation.
Oftentimes this is required where the generator
could easily carry the maximum load
and there is no need for a regulation of
current. Like for example a lighting
and power plant for any large building
were the current in very often used for
both lights and elevators. Whenever an elevator starts a large current is used and although the generator can easily handle the increased load yet the voltage will fluctuate with the sudden increase and a very bad mingling of the lights will take place. This is not tolerated in most cases and the battery is the natural solution of the problem by absorbing all the load fluctuations and thus avoiding the sudden voltage drop which causes the mingling of the lights. All large railway plants need a battery for this same reason. The fluctuations of the car lights, although annoying, does not cause the trouble. However, if the transmission lines are long and the voltage falls off to any considerable extent, then it is found very difficult to keep the
Trains moving satisfactorily as their demands on the central station are more than this can supply. This ties up the whole system and causes numerous aggravating delays. This use for railway service is ultimately connected with the compensation for the drop in the feeders. When a long line is in use it is extremely difficult to keep up the current and voltage necessary at the end of the line without excessively heavy and hence expensive feeder cables. As a concrete example, in one of the divisions of the Brooklyn Rapid Transit Company it was necessary to use for a few hours each day during the summer months a large current at a distance of over eight miles from the central power station. Long and heavily loaded electric trains were started in close
succession for a few hours. The problem confronting the engineers of the company was how to avoid the large cost of the necessary additional feeder cables to carry this large current. As a solution of the problem several old passenger cars were rebuilt containing a moveable storage battery. During the summer months this train was hauled to the end of the line and connected with the feeders. At hours of high load the batteries were charging but during the few hours peak they were able to furnish all the energy needed over and above the normal capacity of the feeder cables. The cars were moved with no difficulty whatsoever as a result of this arrangement. The cost of the battery installation was a small portion of the
4 To the feeder cables that
would have been required and in
addition, during the winter months.
The movable battery was taken
to a position near the Brooklyn
Bridge where heavy loads were
frequent occurrence, and used there
as an aid to the generator plant
for load regulation and to carry
the feeder during the morning and
evening rush hours. Thus it can
be seen that in this and many
other smaller installations the
battery enables feeders to be used
capable of carrying the average
rather than the maximum
current, and hence allowing a
great saving of copper and therefore
of expense. These batteries kept up
the voltage when an excessive
current was demanded and thus the
Our motors would run satisfactorily.

As a sample of voltage regulation by batteries, the accompanying figures show two charts taken from a recording multimeter, one before and after the installation of the battery, and are conclusive evidence of the value of regulation and will need no further explanation.

Fig. VIII

Before battery installation  After battery installation
The foregoing charts were taken from the plant of the Ottawa Electric Railway Company.

As a safeguard against the shutdown of a plant, the battery is a most valuable adjunct of any station. This is especially true in stations producing alternating current where one or several small direct current units are used for excitation purposes. The battery would be connected across the brushes of the exciter switchboard and would do no regulation work as there is no fluctuating load; but however, if for any reason whatever the exciter generator was compelled to shutdown for a short time, the battery would be able to give out its prime to the alternator fields and allow no interruption of the service. On
Occasional light charge keeps the battery in a state of full charge ready for all emergencies. The battery does not need to be of large size because it is only to be operated for a short time, usually while one exciter is cut out and another started and a high rate of battery discharge is permissible. This small size covers the fixed charge of interest on the first cost and the cost of maintenance, and the insurance against shutdown is considered by successful managers to be well worth the expense. As an aid in emergencies the battery is sometimes used in a different manner. The reserve starting battery may be backed up by various lights scattered about the power plant which may be lighted should any accident be serious enough.
To involve the shut down of the entire plant. Such a system would be invaluable in such a case as the difficulty of repairs is greatly increased by absence of proper illumination and the light would mean in all probability a complete stop of operation in a much shorter time than would otherwise be the case. As a practical example of the emergency use of batteries a case occurred in an installation at Columbus Ohio. The boilers feed pumps at the power house became clogged, and when the steam failed the battery took the whole load, much more than its rated capacity until the boilers were sufficiently cooled to be filled with water from the city mains. The boilers were then fired and carried the entire load and charged the batteries in addition.
until their water was exhausted. This process of refilling boilers and using battery and then charging battery, was repeated every twelve hours until the pumps were repaired and the customers were aware of the slightest trouble at the powerhouse at any time.

The use of a storage battery on an Edison three-wire system is in the nature of an equalizer in connection with the generator. It is sometimes advisable to use but one generator as conveniently be shown. This saves the cost of equipment and allows the three wire system to be used. A simple 220 volt generator may be thus used by connecting a suitable sized battery across the terminals and having the neutral wire connected at the central cell of the battery. Should the system become
imbanced, one half of the battery is being charged and the other half is discharging. This enables 110 volt circuits to be used without the usual effect of but one generator and an imbalanced system.

The combinations of these functions of the accumulator are very important, but are all in the nature of special cases, each installation necessitating individual treatment. To cover its own special requirements.

Besides these general uses there are a number of special cases where batteries are used. These installations might be placed under the foregoing subdivisions, especially that of the storage of electrical energy, which in what it nearly every case they perform. But however it seems best to take them up.
separately now. The first few cases are wholly for storage purposes. That which is most familiar to the average student in science is the portable storage battery largely used in the laboratory. These are made in a convenient size for handling and are a very useful adjunct when no low voltage direct current is available, and are a great improvement over primary cells. For laboratory use where absolutely constant voltage and current is required, as in the calibration of instruments, the storage battery is most satisfactory. By the slight adjustment of a rheostat in series with the battery, the voltage and current can be kept at any desired point. For large currents necessary in some tests the battery may be connected
in parallel, thus solving this difficulty without the great loss of energy usually involved in such a test. The battery has been used in special cases in a similar manner to a Transformer to obtain high voltage for Direct Current tests. The battery is charged having the cells in parallel groups and discharged with them arranged in series. This high voltage with small current is used for insulation tests.

Another peculiar use of the Storage Battery is for train lighting. The average American who travels desires the conveniences to which he is accustomed at home and among the foremost of these is the incandescent electric light. The steam railroads of America are now fast adopting the storage
batterystem to light their cars
used in through train service. Here
has been tried and is used to a certain
extent a system eliminating the
batter system, by installing a turbine
dynamo on the locomotive and
connecting the cars by a continuous
system of wiring. This is unsat-
sfactory due to the inability to
light the cars when detached from
the locomotive. The majority of
electrically lighted cars use what
is known as the axle-light system.
A small dynamo is belted to the
axle, which, when running at an
average speed, charges a storage
battery suspended beneath the car
and also furnishes lights in the
car. When travelling at a slow speed
or while standing, the battery is
discharge automatically, thus
Lighting the car. Usually provision is made for charging the battery from outside sources when at rest in a depot. The automatic regulation provides that at all speeds the current and voltage do not rise too high for the battery and as a whole the system is extremely successful. This is by far the safest system of train lighting that has been devised as it permits individual lights in sleeping cars. Also in case of accident there are no gas tanks to take fire and cause the general conflagration.

One of the most familiar sights of a large city at the present time is the number of electrically propelled vehicles. The development of the electric automobile has, however, not been nearly as rapid as
That of the gasoline driven machine, due in a large measure to the excess weight necessary in connection with the storage battery and also the difficulty of forming long lines owing to the lack of frequent charging stations in our large cities. The electric omnibus is coming to the fore as are also light weight runabouts. There can be no doubt of the superiority of electricity over gasoline on account of the absence of explosive vapor, with the accompanying noise, vibration, and odor. In connection with the gasoline driven machines the small portable storage battery is rapidly taking the place of the primary battery for ignition purposes, it being much more reliable and convenient. Please of storage batteries in street cars.
has been tried but is not very successful and is not used at all in this country although used in a few cases in Europe. As an motive power for boats, small pleasure launches using the storage battery have been and still are used but always within short range of a charging station.

The telephone has come to be a necessity rather than a convenience of modern times and with the thousands of instruments in use it would be no longer practicable to use the older magneto or dry battery system. The current for operating telephone systems is best produced at the central station. It is unsatisfactory to use the generator in direct connection with the line. The storage battery is now the source of current for all telephone circuits in our cities.
and within the last ten years there have been installed for this service alone over one hundred thousand storage battery cells. The Electric Storage Battery Company has had the construction and installation of practically all of these. Usually all battery installations for telephone works are in duplicate so as to ensure the system against shut down and also to allow one battery to be charged while the other is in use, thus avoiding all interruption and fluctuations of current.

In the last few years the storage battery has come into a new field of operation in railway work, namely the operation of electric signals and interlocking devices. Various methods are used, either a portable battery replaced frequently or recharged.
Battery or else a charging line wire. In the operation of a short section of track in Philadelphia, the Philadelphia and Reading Railway Company, as an experiment, replaced 1203 primary cells by 268 two plate chloride accumulators. The total cost of cells, charging equipment, etc. was approximately $2,300. After a year's service a return of 135% on the investment was made. Since then other sections of the system have been so equipped. The Southern Pacific Railway found that the cost of primary cells would have been 75% greater, and the maintenance 307% greater than on equivalent storage battery equipment. For long distances, the cells may be charged by a line wire fed from gas engine charging stations and
yet a large saving is effected in this case, even including the cost of the charging stations, and line wires.

There is nothing more satisfactory than the storage battery in connection with residential lighting and power plants. Many large residences are at a distance from any central source of power and have in their grounds a small available water power. Such being the case it is a very simple matter to utilize this to run a small generator for charging a battery which may be discharged a few hours each evening supplying the residence with all the electrical power required. If sufficient water power is obtainable the plant may be run under the supervision of an attendant a few hours each day while if small
Continuous automatic operation is usually possible. The great advantage of the battery is the avoidance of flickering of the lights which would occur if a small generator were to be used at the time these lights were operated. Such a system is sometimes used in connection with outside service as a trolley line. The fluctuating voltage of the usual interurban trolley system is thus made steady and all inconvenient due to flicker and consequent stoppage of current are eliminated. A few isolated plants use accumulators in connection with wind power, this driving a small generator by wind mills and thereby charging the accumulators which may be drawn upon for energy at night.
or when wind is blowing.

A peculiar use of chloride accumulators is in the regulation of an alternating current system.

In this particular installation, the railway company bought 60 cycle 3 phase alternating current from a power company and used on their lines 25 cycle, single phase. At their power house these machines were united in one piece of apparatus. A three phase induction motordriving a single phase alternator and a direct current generator. The latter is connected to a storage battery. When the load is light, the induction motor drives the system and thus charges the battery. At heavy load the battery discharges by means of a

[Page 53]
The direct current generator which acts as a motor and acts as the induction motor in driving the alternator. The result of this adaptation was a reduction in power bills of about one half what they had been without the battery installation. The effect of this regulation of power is best shown by the following curves, from which the constant load on the transmission line from which the company purchased its power is seen together with the wide variations in total load on the single phase system.

A.C. REGULATION OF SINGLE PHASE RAILWAY LOAD BY A BATTERY OF "Chloride Accumulators"
The foregoing are the most important rules of the secondary battery. It will now be well to mention some of the auxiliary apparatus needed in connection with their operation. Nothing has yet been said of the regulation of the battery itself. This is an essential part of all installations, and although the various methods used in practice will not be taken up in detail it is well to mention a few facts in connection with them here. It is known that a single cell will give on discharge a voltage from 2.0 to 1.8. For charging a voltage of approximately 2.5 is needed. Hence it is obvious that some method must be provided for obtaining this. The method used in practice is by the booster which
is a motor-generator of high efficiency used to generate a sufficient voltage for charging purposes. The method of working and using such boosters is of a complicated nature and varies according to the use to which the battery is put and to the conditions of the individual installation. The booster may be hand regulated or automatic although the latter is more common and the arrangement usually is such that on light load the motor drives the generator while on heavy loads, the battery discharge directly into the mains. The Carbon Regulator provided for this purpose by the Electric Storage Battery Company is the most modern and satisfactory of all.
booster regulator. The principle employed is the variation of the resistance of a pile of carbon plates and by reversing causing variation in the field excitation current of the battery booster. This variation of resistance is obtained by a lever worked by a solenoid through which passes the entire arm's current. This is shown in the accompanying illustration of the apparatus.
When a long line is used with batteries at the substations to compensate for feeder losses in heavy current, then a booster is not necessary. The battery, while floating, as it is called, across the line, charging at moments of high load when the line drop is small and effective voltage high, and discharging at heavy load when the voltage falls due to heavy line losses, thus aiding in keeping up the voltage at the end of the feeder line. Most installations however use a booster of some sort.

As another important auxiliary to the storage battery we have the end cells and their variable switches. If it is required to keep up a constant voltage with
little variation, when it will be necessary to provide against the falling off of battery voltage on discharge. This is accomplished by the end cell switch. When the voltage falls, by means of a multi-point switch, additional cells are cut into series with the battery circuit one at a time. This keeps the voltage practically constant. Suppose a 110 volt circuit is required. On beginning discharge each cell will give 2.08 volts. Thus the number of cells required would be

\[
\frac{110}{2.08} = 53
\]

When however the battery is nearly discharged there would be required \( \frac{110}{1.88} = 61 \) cells. Thus the installation requires 61 cells in series with taps from the last eight to an end cell switch.
for voltage regulation purposes. In charging the reverse tubes place, and the last cell, but partially discharged is the first to be cut out of the series. The end cells always amount to about 13 1/4% of the total number used in a battery. These end cells may be regulated either by hand or automatically but the latter is preferable. The Electric Storage Battery Company manufactures a high-speed magnetic control and cell switch for use in connection with their battery installations. This is operated by a motor and is controlled absolutely by the magnets in which can be set for the constant voltage desired.
In conclusion let us look at the future prospects of the accumulator. There is no doubt that more and more of the power plants throughout the world will sooner or later adopt the storage battery in connection with their operation. The great wave of electrification of steam railroads throughout the country will in a large measure demand the adoption of storage batteries as the great aid to successful operation. All such roads now exempt from direct current use the battery in connection with their generator systems and those running alternating current use batteries as an auxiliary for the excitation of their generators. No better illustration of the growth
of the battery and the fact that the engineer places in its successful operation, than in the large power plant installations in nearly all of which provision is made for largely increasing the capacity of the system by the addition of more plates to the cells. In many cases the opportunity for increase has been utilized.

The present age is essentially one of progress and rapid transit, and the electric automobile is bound to be developed in the near future. Many of the most famous engineers of the world are working to produce a lighter cell than the lead plate type for use in the automobile. Yield and power or, later on, the solution of the problem will be
enlisted: Herein may be found a cheap and efficient method of automoblie transportation without the inconvenience of the explosion motor.

In this paper I have endeavored to give a basty account of the use of the secondary battery with special reference to its practical side and its applications. Following this I shall give a description of a small battery in use at Haverford College, together with some tests made upon it.
The storage battery in use at Haverford College consists of ten chloride accumulate cells manufactured by the Electric Storage Battery Company of Philadelphia. Each cell is of glass and stands in a wooden tray filled about one inch deep with sand. Each tray stands upon four porcelain insulators. The cells are in two sets of five each, one set above the other. Each cell measures 12 1/2 by 12 by 15 inches and is filled within two inches of the top with the electrolyte. Each cell contains seven positive and eight negative plates, each approximately nine by nine inches in size and 3/16 inch thick. Their edges average a depth of one quarter inch below the surface of the sulphuric acid and are supported from below on
Rectangular blocks of lead raising their lower edge three inches from the bottom of the cell. These plates are separated from one another and insulated by rubber separators. The positive plates of one cell are joined to the negatives of the next by a mechanical connection consisting of a lead nut screwed upon the two halves of a split bolt, each half being the lead lead from one of the sets of plates. The connection to feeder wires are all made by mechanical connection to copper washers which are all made of copper and are all more or less corroded and in a poor condition. The density of the electrolyte varies slightly in the different cells. The mean value being when the open circuit voltage is 20 volts.

The battery is used chiefly in
The Laboratories and for a constant source of current for supplying the electric bell system. The various laboratories, chemical, physical, and electrical, each have a connection with this source of 20 volt direct current. In the physical and chemical laboratories these are leads from two cells thus giving a four volt circuit. The current is used in the chemical laboratory for the purpose of electrolysis, and in the physical laboratory chiefly for running an induction coil and for other similar purposes. In connection with the bell ringing system these leads from four cells make a four volt circuit, in connection with the electric clock and bells in the main rooms, and the entire twenty volt circuit is used in driving
as small as one eighth horse power motor
used in operating the large bell in Founder's
Hall. This is operated by a relay in the
Clock Circuit. This bell operates about
eighty times a week and rings approx.
imately fifteen seconds at each operation.
At a rate of 2.5 to 3.5 amperes.
The rated capacity of the battery
is 30 amperes for 8 hours but it
is very seldom discharged at over a
ten ampere rate and this never for
a long time. The battery is charged
from a small direct current
generator at the Power House furnishing
about 110 volts. This current is
passed through a rheostat which
absorbs about 75 volts and the rest
is accounted for by the drop in
the battery itself. The full charging
current of approximately 20 amperes
kept up during the charge. The
Battery is charged every Sunday evening for from three to five hours depending on the quantity of energy used during the previous week which it is necessary to replace. In regard to any test it was thought advisable to attempt to measure the entire energy output for a week rather than for a short time as this was the period for which the battery was used between charges. This was best accomplished by means of a copper voltmeter in series with the 20 volt discharge circuit. This would record by the deposit of metallic copper on the anode the amount of energy used. The voltmeter consisted of three copper plates immersed in a solution of copper sulphate of density 1.16
The plates were 3/8 of an inch apart and were kept parallel by means of wooden separators. Before the passage of the current the plates were dried and carefully weighed. The same was done after the test was finished and the loss in weight of the cathode should have been equal to the gain in weight by the anode. This increase, in grams divided by 1,777 would give the ampere-hours of energy given out by the battery. Most unfortunately after a week's unsuccessful discharge through the voltmeter the switch was not thrown properly before beginning the charge the following Sunday evening. This resulted in a passage of a small current in the opposite direction for some time and thus probably completely spoiled the result.
of the test. Nevertheless the plates were weighed and the energy output as found was calculated and found to be approximately 1.95 amper-hour. For the bell system it has been estimated uses about one amper-hour per week so this figure may not be so very far from correct as it is known that very little current was used in the laboratories during this week. However, a record of the input was obtained during the charge on the evening of May 9th. This is shown and the amper-hour input is calculated. Together with a curve showing the relation of the charging terminal voltage and current with the time of charge the great variation in the voltage and current are due in a large
measure to inability to read the
voltmeter accurately there and
also to slight fluctuation
there.

The data taken during change
is given below.

<table>
<thead>
<tr>
<th>Time</th>
<th>Current</th>
<th>Voltage</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.08</td>
<td>0.0</td>
<td>19.7</td>
<td>Before beginning change</td>
</tr>
<tr>
<td>7.09</td>
<td>19.2</td>
<td>21.2</td>
<td>At moment of beginning</td>
</tr>
<tr>
<td>7.091</td>
<td>18.7</td>
<td>22.2</td>
<td></td>
</tr>
<tr>
<td>7.101</td>
<td>17.5</td>
<td>22.2</td>
<td></td>
</tr>
<tr>
<td>7.12</td>
<td>17.4</td>
<td>22.3</td>
<td></td>
</tr>
<tr>
<td>7.15</td>
<td>17.3</td>
<td>22.3</td>
<td></td>
</tr>
<tr>
<td>7.18</td>
<td>17.2</td>
<td>22.7</td>
<td></td>
</tr>
<tr>
<td>7.20</td>
<td>17.0</td>
<td>23.0</td>
<td></td>
</tr>
<tr>
<td>7.25</td>
<td>16.7</td>
<td>23.1</td>
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</tr>
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<td>16.3</td>
<td>23.2</td>
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</tr>
<tr>
<td>7.35</td>
<td>16.2</td>
<td>23.2</td>
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</tr>
<tr>
<td>7.40</td>
<td>16.0</td>
<td>23.2</td>
<td></td>
</tr>
<tr>
<td>7.45</td>
<td>17.0</td>
<td>24.2</td>
<td>Cells begin gassing</td>
</tr>
<tr>
<td>Time</td>
<td>Current</td>
<td>Voltage</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>---------</td>
<td>---------</td>
<td></td>
</tr>
<tr>
<td>7.50</td>
<td>16.9</td>
<td>24.2</td>
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<td>25.1</td>
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</tr>
<tr>
<td>9.25</td>
<td>16.3</td>
<td>27.0</td>
<td></td>
</tr>
</tbody>
</table>

**Remarks:**

Much brown gas and astrigent odor.

Cells 182 and 9812 not gassing as freely as rest.

All cells gassing freely except No. 2.

Individual cell voltages tested all around 2.6 volts except No. 2 which was 2.2 volts.
<table>
<thead>
<tr>
<th>Time</th>
<th>Current</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
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<td>16.2</td>
<td>26.8</td>
</tr>
<tr>
<td>9.32</td>
<td>19.2</td>
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<td>9.41</td>
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<td>22.3</td>
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<tr>
<td>10.03</td>
<td>0.0</td>
<td>22.0</td>
</tr>
<tr>
<td>10.04</td>
<td>0.0</td>
<td>21.7</td>
</tr>
<tr>
<td>12.45</td>
<td>2.7</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Current increased by cutting out resistance in large shunt. Cell No. 2 begins depo. Voltage K# 1 = 2.3.

Charging current reduced.

Open circuit voltage

Discharge test.

Weight of anode before test = 275.85 g.
Weight of anode after = 277.87 g.
Increase in anode = 2.02 g.

Weight of cathode before test = 531.25 g.
Weight of cathode after = 528.66 g.
Decrease in weight of cathode = 2.59 g.
Mean of increase & decrease = 2.295 g.
Any four hours output = \[ \frac{2.295}{1.177} = 1.95 \]

On the whole the tests made were not sufficient to be of any great value but however the study of the battery was to a great advantage due to the knowledge gained in battery usage and to see the general value of this particular installation. The battery at college is simply large for the use to which it is put being almost never drawn upon for but a small fraction of its total capacity. Now it would act when discharged at full load is not known but there is no reason to suspect that the efficiency would not be satisfactory. The battery is a valuable adjunct of the college being a condenser of current of low voltage for many
Average Current = 17.29 Amperes
Time for Charge = 2.85 hours
Charging energy = 49.3 Amperes-hour
Purposes and as a useful agent in the demonstration of the accumulators and their properties to students in electricity.