

T H E S I S

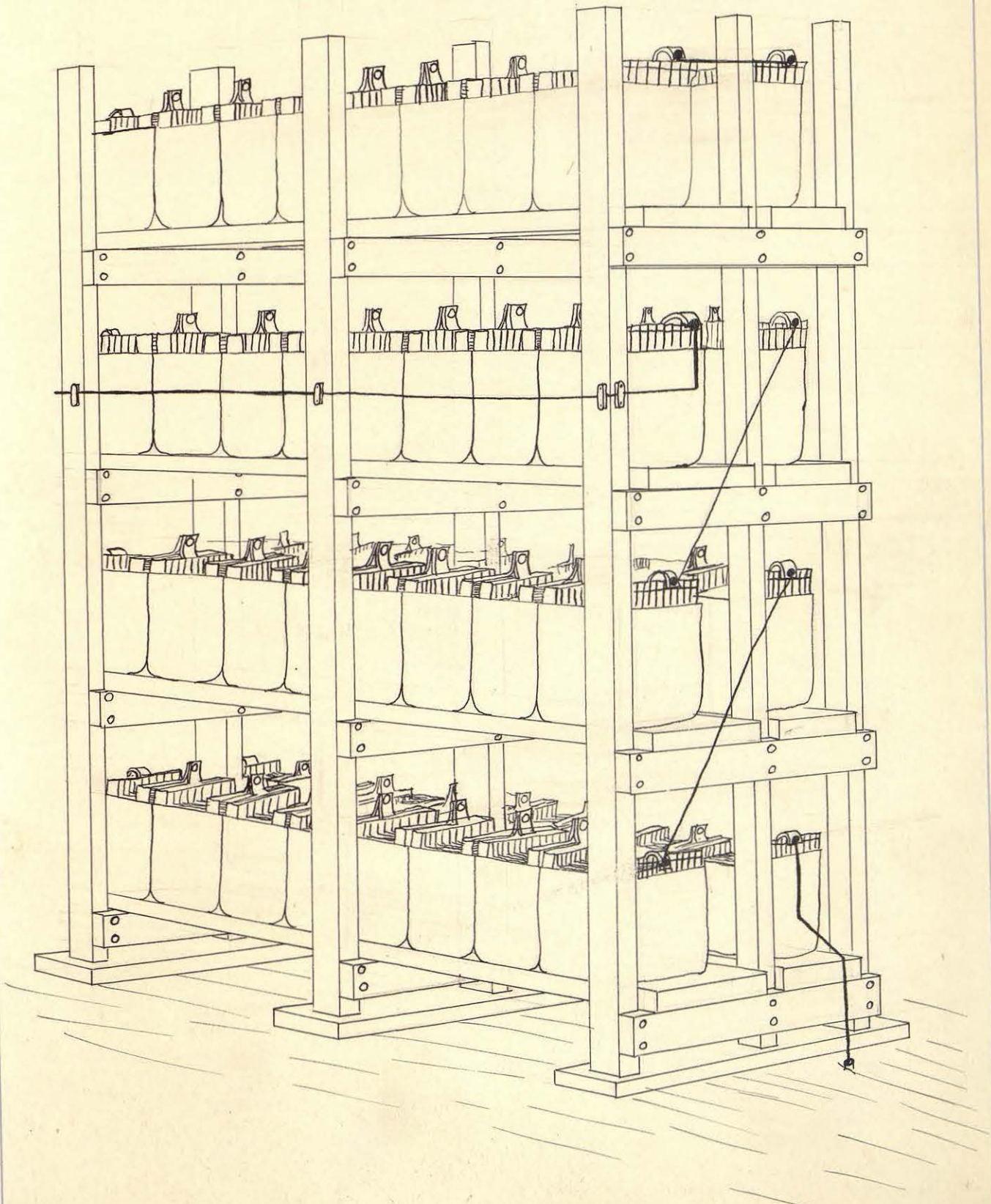
EFFICIENCY OF STORAGE BATTERY
CHLORIDE ACCUMULATOR TYPE

by

G. P. Berger.

H. H. Momyer

June 18, 1908.



Data for 20 Amperes. Discharge and Charge.

Time	Circuit voltage		Specific gravity	Watt-hours.
	Open	Closed		
4:40	137			
4 41	133.7			
4 43	132			
4 45	130			
4 50	129			
4 55	128			
5	128			
5 15	127			
5 30	126			
5 45	125.2			
6	125			
6 15	124.6			
6 30	124.4			
6 45	124			
7	124			
7 15	124			
7 30	123.8			
7 45	123.7			
8	123.6			
8 15	123.7			
8 30	123.5			
8 45	123.4			
9	123.4			

Time	Circuit voltage		Specific gravity	Watt-hours.
	Open	Closed		
9 15	123.4			
9 30	123.2			
9 45	123.8			
10	123.9			
10 15	123.0			
10 30	123			
10 45	123			
11	123			
11 15	123			
			Discharge	
11 30	123	116.5	1180	0000
11 45	120	115 7	1180	579
12	120	115 5	1178	1150
12 15	119.5	115 5	1177	1731
12 30	119 4	115 5	1176	2210
12 45	119 1	115 3	1176	2860
1	119 1	115	1174	3245
1 15		115	1172	4025
1 30	119	114 7	1171	4590
1 45	119	114 4	1170	5150
2	118.6	114	1169	5700
2 15	118 5	113 9	1168	6250
2 30	118 5	113 7	1167	6570
2 45	118			
	117 9	113 3	1165	7355
3	117.7	113 0	1164	7910

Time	Circuit voltage		Specific gravity	Watt hours
	Open	Closed		
3:15	117.5	113.0	1164	8475
3 30	117	112 5	1162	9000
3 45	117	112	1161	9520
4	117	112	1160	10090
4 15	116 5	111 4	1158	10600
4 30	116 4	111	1157	11000
4 45	116	110 7	1155	11600
5	116	110	1154	12100
5 15	115 6	109 5	1153	12600
5 30	115	109	1151	13090
5 45	115 5	108 5	1150	13590
6	114	107 8	1148	14000
6 15	113	106 8	1150	14400
6 30	112	106	1145	14850
6 45	111 5	103 5	1145	15000
6:50	111.0	103	1145	15450
Discharge at 30 Amperes.				
7 00	104.0	000 0	1145	15713
7 05	105.0	107 0	1145	
Charging				
7 15	115.0	122	1140	0000
7 30	124	128.5	1140	642
7 45	125	129	1140	1290

Time	Circuit Voltage		Specific Gravity	Watt Hours
	Open	Closed		
8:00	125.0	127.0	1140	1935
8:07	Power went off			2260
8 15	124 5	128 5	1140	2860
8 30	125	129	1145	3522
8 45	125	129	1150	4160
9	125	129	1152	4800
9 15	125 5	129 5	1150	5500
9 30	126	130	1152	6150
9 45	126	130	1154	6800
10	126 5	130	1156	7450
10 15	126 5	130 7	1157	8150
10 30	126 5	131	1158	8820
10 45	126 5	131 2	1160	9450
11	127	131 5	1161	10100
11 15	127 5	132	1162	10870
11 30	127 5	132 3	1163	11520
11 45	127 5	132 3	1165	12210
12	128	133	1166	12930
12 30	123	000 0	1166	12930
12 45	123	000 0	1166	12930
1	123	128	1166	13650
1 15	128	133	1167	14250
1 30	128	133	1167	14500
1 40	125	000	1167	15390

Time	Circuit Voltage		Specific Gravity	Watt Hours
	Open	Closed		
1 45	125 0	000.0	1168	15390
2	128	133	1170	15000
2 15	127	134	1170	151200
2 30	130	136	1172	157800
2 45	125	000	1172	157800
3	124	130	1175	16700
3 15	131	136	1175	17150
3 30	132	138	1178	18100
3 45	133	140	1179	19070
	134	141	1177	19070
4 00	136	143	1177	19750

Charging at 15 amperes.

4	136	141	1177	19750
4 15	135	141.5	1178	20500
4 30	135	143.5	1150	21350

Average voltage for charging --- 133
 Total watt-hours for charging -- 19790.4
 Average volts for discharge --- 114.3
 Total watt-hours for discharge --16436.34

Efficiency equals $16436.34/19790.4$ equals 83%

Time	Circuit Voltage		Specific Gravity	Watt Hours
	Open	Closed		
5:00	137			
5 05	129	5		
5 10	128			
5 15	128			
5 20	126	3		
5 25	125	8		
5 30	125	5		
5 35	125			
5 40	125			
5 45	124	7		
6 38	123			
6 45	122	8		
7	122	8		
7 15	122	5		
7 30	122	3		
7 45	122			
8	122			
8 15	122			
8 30	122			
8 45	122			
9	122			
9 30	121	5		
10:05	121	3		

Time	Circuit Voltage		Specific gravity	Watt Hours
	Open	Closed		
1:30	121.3		1182	
2:00	121.2		1182	
Discharge at 28 amperes.				
2 30	121 2	114 2	1182	000
2 45	118 2	114	1182	829
3	118 0	113 5	1180	1591
3 15	118 5	113	1178	2375
3 30	117	112 5	1178	3125
3 45	117	112 5		3940
4	116 5	112	1177 1175	4700
4 15	116 5	111 3	1175	5455
4 30	116 0	111	1174	6210
4 45	116	110 5	1174	6955
5	115 5	110	1174	7700
5 15	115	109 3	1170	8420
5 30	114 5	108 5	1168	9110
5 45	114 5	108	1162	9825
6	113 5	107 3	1162	10550
6 15	113	106	1117	11120
6 30	112 5	105	1156	11750
6 45	111 5	103	1156	12270
6 50	113	105	1156	12270
7:00	111 5	103	1156	12750

Time	Circuit Voltage		Specific gravity	Watt Hours
	Open	Closed		
7:00	112.0	122.0	1156	
7 15	123	127	1152	635
7 30	123 5	128	1152	1280
7 45	123 5	127 3	1153	1910
8	124	127 6	1154	2525
8 15	124	127 9	1155	3200
8 30	124	127 5	1155	3811
8 45	124 3	128	1160	4475
9	124 5	128 7	1162	5150
9 15	124 5	128 9	1163	5800
9 30	124 5	128 5	1165	6420
9 45	125 5	129	1165	7100
10:00	125	129 3	1166	7750
10 15	125 5	129 5	1168	8420
10 30	126	130	1170	9100
10 45	126 3	130 5	1172	9800
11	127	131	1172	10490
11 15	127	131 5	1176	11190
11 30	128	131 8	1177	11860
11 45	128	133	1178	12600
12	129	134	1180	13400
12 15	130	135	1180	14190
12 30	132	137 5	1181	15150

Time	Circuit Voltage		Specific gravity	Watt Hours
	Open	Closed		
12:45	133.0	140	1183	16110
1	134	143	1182	17150
1 15	135 5	145 5	1182	18200
1 30	136	146 5	1182	19050
1 40	136	147	1182	19850

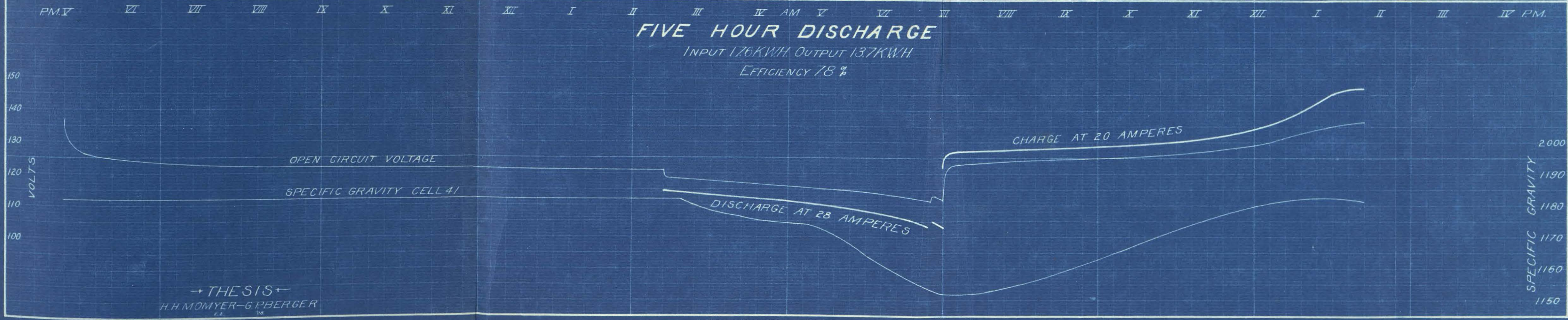
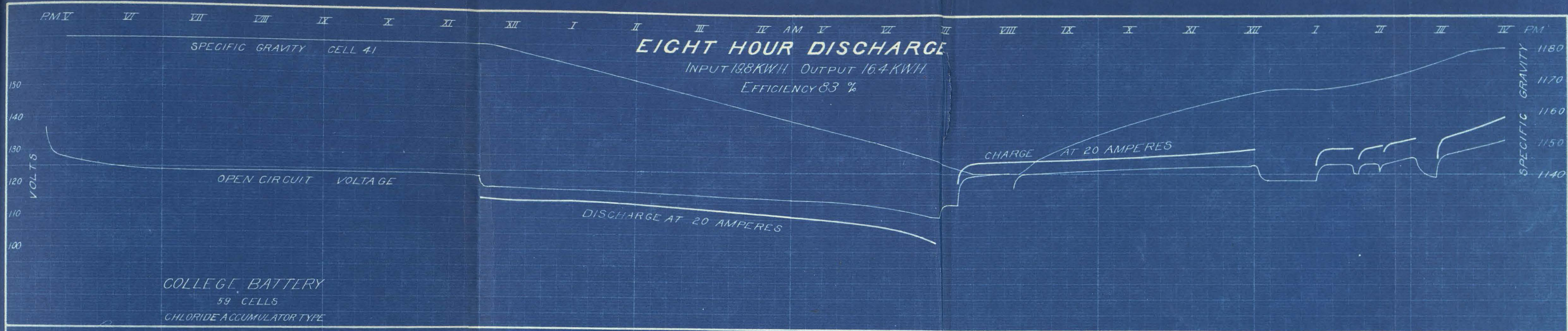
Average volts charging equals 132.3

Total Watt-hours for charging " 17635.59

Average volts for discharging 109.4

Total watt-hours for discharging 13707.82

Efficiency for 28 amperes equals 77.7 per cent.



History.

The College Storage Battery was purchased from the Electric Storage Battery Co., of Philadelphia, Pa. and was installed in August, 1905. Its rated load is 110 volts, 20 amperes for eight hours or 160 ampere-hours, which would be 17600 watt-hours.

The battery has been used by the students for testing work in the laboratory and for some lighting. It has been used at various times throughout the college year, the load varying from $1/2$ ampere to 20 amperes and sometimes for a very short time the load has been 30 amperes. The discharges lasted from several minutes to several hours, the rate of discharge depending upon the nature of the load.

The battery was always charged at 20 amperes from the 220 volt mains of the college power house: The current kept down by inserting resistance in series with the battery.

The chief work of the battery has been to excite the fields of the alternators and to run motors when a constant speed is required. It has also been used for calibrating instruments.

The battery has never been completely discharged nor has it been discharged below the minimum limit of 1.75 volts per cell. In general, its discharge does not exceed 60 ampere-hours, which is a little better than $1/3$ its rated discharge of 160 ampere-hours.

Throughout the summer the battery has been cared for by the assistant janitor. Under his care it received one discharge and one over charge every two weeks of 20 amperes for four hours or 80 ampere-hours which is $1/2$ its rated load.

The specific gravity of the electrolyte has not been given the attention that it should have received. The density has not been recorded but the last test showed an average of 1.180. Not one of the cells exceeded 1.190. The density should be near 1.200 and should not exceed 1.210.

Discussion.

The storage battery is made for storing electrical energy in the form of chemical reaction between lead and sulphuric acid.

If two plates of pure lead be immersed in sulphuric acid and their free ends connected by a wire no current will flow as the action of the acid is the same on each plate. Should a current be passed through the solution from one to the other, a change will appear in the color and composition of both plates. The plate at which the current enters called positive, has its surface layer changed to lead oxide by the electrolytic action of the current flowing through the cell, while the opposite electrode becomes coated with hydrogen and expands slightly.

By removing the source of the charging current and connecting the plates together, a current will be found to flow from the positive plate through the wire or other connection outside the cell to the negative plate.

An examination of the plates with this connection broken will show a difference of potential between the negative plate and the acid, and also between the acid and the positive plate, both acting in the same direction and tending to force a current through the outside circuit when it is completed.

As the discharging current flows oxygen is taken from the positive plate and the sulphuric acid unites with the free lead forming lead sulphate and allowing the hydrogen of the acid to unite with the oxygen to form water.

At the negative plate the electrolytic action sets free oxygen from the solution which unites with the hydrogen on the

plate and sets free the sulphur oxide which unites with the lead of the negative plate.

In practice this layer of active material is either formed artificially and pasted on the plate or a large number of charges and discharges are used to form the coating.

On recharging the second time the loose, disintegrated lead sulphate is first acted upon by the current and the cell takes a deeper and heavier charge.

As the current flowing depends upon the potential between the plates and it in turn upon the condition of the plates and the strength of solution, the efficiency of the storage battery depends upon the following things:

1. For voltage on the number of cells in series and the strength or density of the acid.

2. For current upon the exposed surface and thickness of active material which may be changed without excessive weakening of the acid solution or of the plates themselves.

3. For durability, upon the construction of the plates, composition of the form or grid which supports the active material and upon the method of supporting from the sides of the cell

The first or voltage efficiency at first sight might seem out of place but when it is considered that the battery must give a practically constant value when used for lighting purposes, its real significance becomes apparent. Take a lighting load using 110 volts, with a small load 55 cells would be sufficient or if fully charged, 54 would give full voltage until nearly one quarter discharged.

If the load were kept on longer or a larger load put on at the start the drop would be greater, and the regulation would be very poor, unless some means, such as adding extra cells, or running a booster, be used to maintain the required voltage.

This means that either some one must look after changing the number of cells or a direct loss in the booster must be accounted for, although it is possible by a greater expenditure in the first instance to put in a battery which will carry the maximum load, without discharging enough to seriously lessen its voltage.

On account of the fact that at low rates of discharge (not to exceed normal) the gas which fails to unite with the active material has time to leave the pores of the material, and the decrease of voltage is constant; it is best to install a battery which will carry the full load at normal rate.

The second or current efficiency depends upon the size of plates and thickness of active material, the voltage and resistance being constant. If the current becomes too great for the exposed active surface the resistance of the cell is increased by the formation of gas on and throughout the pores of the material. In case of short-circuit the sudden expansion of gas occurring before it has formed sufficiently to partially insulate the surface, will buckle or bend the plates, especially if they are not properly spaced and the resistance of the electrolyte is greater between two faces than the others. As the material of which the surface is composed is very loosely knit together the sudden expansion and change of shape causes loss of active material even though the plates do not buckle enough

to permanently short circuit the cell.

Also discharging a cell below a certain voltage is injurious in that the active material expands greatly and if more than thirty per cent is converted into lead sulphate it becomes very rotten.

If allowed to stand the sulphate forms a crust which is hard to reduce and when reduced tends to scale off in flakes, removing active material from the plates as once the lead becomes separated from the plates it drops to the bottom of the cell and no further action can be taken on it by the current and the acid is too weak to dissolve it.

The plates can be made as large as wanted although the tendency is to put a number of them in parallel to reduce space and the size of the jars. On the other hand the active material cannot be greatly increased in thickness.

Consisting as it does of materials, naturally weak and held together with a very weak bond it must not be so thick as to allow gas forming during the charging process to lift it away from the plate and strip the frame of its working material.

For the sake of durability the solution of sulphuric acid should have a low density, as high density or strong acid will attack the lead frames even when no current is flowing.

For ordinary cells a density of 1.2 taking water as 1, gives the best results although as high as 1.3 or 1.4 are used in batteries where a large current is wanted for a short time. Such batteries are smaller and somewhat lighter but they have a much shorter life than cells worked at normal density. If

lower than 1.15 the acid is too weak to keep up the full voltage and the cell tends to absorb the sulphate and give off only a small part of its maximum output.

The forms are cast from pure lead to which a small percent of antimony has been added to make them harder and less liable to attack from the acid. In the spaces formed in these plates the active material is pressed and fastened by cold riveting the edges of the spaces.

Joints between plates are made by heating the lead nearly to the melting point and clamping firmly together. The surfaces unite and form an almost perfect joint.

The durability of the plate depends almost entirely upon how well the active material is united to its base and its thickness. If imperfectly united to the plate the solution will penetrate below the active material and acting on the smooth even surface of the solid lead, form a coating of lead sulphate which will prevent the current flowing from the lead to the working material or if broken down by excessive current leave a gap and consequent weak place in the cell.

As the potential difference between plates and therefore the E. M. F. of the cell depends upon a physical property of the metal and acid, for a given number of cells the potential is practically a constant quantity affected only slightly by the temperature and the charge. Its current therefore, is very constant and up to its normal rate, the voltage remains practically constant for some time.

For purposes of measurement, field excitation or for running small motors, at constant speed, it is unequalled, espe-

cially as used by the College, the power plant having very poor regulation and motors driven from the power mains have a poor speed regulation.

The load on the College battery on which the test was taken varies from one to six amperes for field excitation to as high as thirty or for very short periods, thirty-five amperes. The care required is small; filling the cells with distilled water to replace evaporation as needed and keeping it charged.

The last is done by 220 volt current through a resistance bank of 110 volt lamps.

Two complete discharges and charges were taken together with the drop on open circuit from time of full charge to full charge with the specific gravity, all readings being taken at 15 minute intervals.

As power for charging was only available from seven A. M. to six P. M. it was necessary to charge one day, discharge at night and charge the following day. Records were kept as shown by the data from the time of breaking circuit on preparatory charge until the battery was fully recharged.

The open circuit voltage dropped very rapidly for the first fifteen minutes as the gas left the plates, then became nearly constant, falling off only slightly until the discharge was started.

The reason for this fall of potential may be found in the fact that gases formed at and through the pores of the plates have a definite value of potential over and above that due to the lead oxide to acid and acid to lead potential of the cell itself.

When the charging circuit is broken the gas ceases to form, and slowly dissipates through the solution, that in the interior of the plate requiring some time to be taken back.

The lead oxide and sponge lead are also undergoing slight changes. During the charge the current acting first on the outer layers charged them higher or to a greater degree than the internal ones and when the charge ceased the two tend to equalize, reducing the effective charge on the exposed outside layer, thus accounting for the continued gradual falling off in E. M. F.

The discharge current causes a slight surface polarization in the opposite direction giving what may be called a double drop, one part due to this counter E. M. F., and the other due to the internal resistance of the cell.

The outside surface of the plates being more exposed, discharge faster than the plates themselves and their drop must be added to the two given above, as the acid cannot penetrate fast enough to maintain a constant field value of E. M. F., and the voltage drops slowly until the cell is about three fourths discharged as based on normal charge.. From this point the drop is much more rapid as there is no reserve to fall back upon to maintain the current.

The short second discharge on the five hour discharge shows how the voltage rises as soon as the acid has time to penetrate as by being left on open circuit. Good practice requires that a battery should not be allowed to discharge below 1.8 volts on account of this expansion and consequently loosening

of the active material.

For batteries that have been put away dry without completely charging beforehand this very tendency may be made use of in restoring them to normal condition. Charge them at full normal current, recharge at about one half normal and then discharge at normal rates to 1.7 volts. Add enough resistance to make the current from one half to one third normal and continue discharge keeping a close watch on the plates that discharge may be stopped before they expand sufficiently to loosen the active material from the plates. An expansion of one third original size of active material is sufficient, and will leave the plates in a spongy, porous condition.

Charging them now at a low rate of current will bring them back to their original size while the increased surface of action on the sulphate will greatly aid in its reduction.

In charging the open circuit voltage rises immediately above the value of the lead oxide--sulphuric acid--lead, voltage and as the cell charges the surface becomes still higher charged and both open and closed circuit voltage continues to rise until the cell reaches full charge. Just before full charge is reached the rise becomes more rapid as at this point the surface and most of the active material is charged and the resistance offered by the gas itself tends to cause the potential to rise besides the actual E. M. F. between the gas and the liquid.

From this point the plates begin to act as two electric terminals, immersed in water. The negative gives off eight parts of oxygen to one part of hydrogen liberated at the positive

tive plate and the current is used in decomposing water causing a violent boiling of the acid and water solution.

Further charging is injurious as the gas tends to break up the active material as it comes out from the plate. The change in density of the electrolyte is interesting. In the eight-hour or normal rate the density curve was practically a straight line during discharge showing that the plates had sufficient area to allow the acid to penetrate the material as fast as required to supply the current without excessive drop.

In the five hour discharge the density varied somewhat falling off quite rapidly at the start, then apparently holding its own for a short time at about the middle of the discharge and then falling off very rapidly to nearly the same density as in the eight hour discharge.

The specific gravity is the best test of the condition of the cell for if the density of the solution at complete charge and discharge be known the amount of lead sulphate may be closely approximated.

Continued decrease of density would therefore indicate that the cell was becoming sulphated and should be given an overcharge at less than normal rates.

Owing to the formation of gas in and on the plates and the weakening of the acid as the discharge proceeds, the resistance of the cell increases, varying in amount by the rate of the discharge. It was found to vary from .200 to .375 with normal discharge for the entire battery of 59 cells.

With five-hour rate of discharge, the resistance varied from .21 to .42 This would give for minimum resistance of

cells .2 divided by 59, equals .0034 ohms the density at the time being 1.18 which is .02 lower than standard. If the density were up to standard, the resistance would be somewhat less, about .0028.

In case of cells which have been over discharged or discharged at too low a rate and sulphate has formed in flakes or spots on the plates, it may be advisable to continue charging but at a lower rate of current, to reduce the sulphate, a battery that is not in steady use or that is used for short cycles of charge and discharge, is likely to become choked up or as it is commonly called, sulphated, owing to the formation of sulphate below the layer of material that is in constant use.

As this sulphate is generally thoroughly mixed with the active material it will give no trouble if the battery be occasionally discharged completely to 1.8 volts and then given an overcharge.

If allowed to stand for some time in this condition the plates will harden and become almost impenetrable, although with properly made plates in which the active material is firmly pressed up against and united to the plates, the sulphatation need cause no apprehension as it may be reduced by over-charging and moderately heavy discharging, the discharging aiding by opening up the pores of the cell and allowing the solution to penetrate where it will give the best results. The best policy however, is to keep the battery well charged as it is much easier to keep the battery in shape than to bring it back into condition.

Should a battery be completely discharged by being acci-

dently short circuited and left, care should be taken in bringing it back to full charge. If the rate of discharge was much above normal rate the plates are liable to be warped and should be examined to see that they do not touch. Charge at about one-half normal rate of current if this amount may be forced thru without overheating as the cell temperature should not exceed 90 degrees Fahr.

After cell has been nearly charged and allowed to stand until the gas has nearly all left the plates, they may be taken out and straightened by pressing the plates out between soft pine or other soft wood boards. Never handle the plates when nearly discharged as the active material is expanded and brittle and may be easily broken off. The solid form of the plate is alloyed with antimony to harden it and is rather brittle and should be bent as little and as slowly as possible.

Replace plates and continue charge until both plates give off gas, discharge down to 1.75 volts and charge again. If positive take their color of brownish red, the battery is very likely in good shape although it may require several cycles of charge and discharge to reduce all of the sulphate to active material.

To put a battery out of use, charge up to maximum or over-charge and then give a slight discharge to make the composition of the plates as nearly uniform as possible. The slight discharge causes the gas to leave the surface.

Remove from electrolyte and dry as quickly as possible to prevent oxidation of the surface of the plates, meanwhile keep-

ing the positive and negative plates separated to prevent local short-circuits.

When wanted, all that is necessary is to add electrolyte and give an overcharge. The cell will be sluggish at first, but will soon reach its normal capacity if constantly used.

G. P. Berger,
H. H. Momyer,
'08.