

# Alternative Electrolytes for Flooded Lead-Acid Batteries, a database of other options

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version 1.5



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This paper is now up to version 1.5, and has come an enormous distance since the first edition. As of this version, I have separated the work into two separate components, this one "*Alternative Electrolytes for Flooded Lead-Acid Batteries*", and a paper that deals specifically with the process of de-sulphation titled "*How can we De-sulphate Lead-Acid Batteries for re-use*".

This has come about due to my exploration of the subject, and my gathering of data to show how different chemical combinations can provide different effects to different degrees, rather than one great holy wonder electrolyte.

So therefore, I have separated the two areas of interest into two separate papers, and this paper will continue to document my work and research into *Alternative Electrolytes for Flooded Lead-Acid Batteries*. As such, this paper will not go into De-sulphation and the chemistry behind it in any great length, you will need to read my other paper "*How can we De-sulphate Lead-Acid Batteries for re-use*".

## ----- QUICK INTRODUCTION AND THANKS -----

Let me say at the outset that I am not professionally trained in Chemistry at all. High-school HSC Chemistry years 11 + 12 was the last time I formally studied and was trained in chemistry, but I have always been fascinated by it, and have continued reading / learning / experimenting / observing / discussing chemistry ever since.

Everything that is in this PDF has come about from my curiosity with my work installing and building off-grid solar power systems over the years, and working with different battery types, and my musings, thoughts, ponderings and bursts of inspiration along the way.

Anyone who puts their attention to this subject would surely have worked all of this out just like I have, and while there is a fair amount of small scale experimenting and articles than can be found searching on the internet about things like "Epsom salts and lead-acid batteries", "Sodium Sulphate and rejuvenating lead acid batteries", etc., I have not been able to find any larger scale university / lab / Corporate funded research paper (surprise surprise) looking in depth at what I have found, nor have I found any databases or tables of experimented findings, calculations, chemistry equations, etc., just mostly a large number of armchair keyboard warriors who are happy to say that things can't work, without actually exploring them themselves, and presenting the chemistry behind it.

For this reason, I became inspired to write this PDF, run workshops for people, put together my theoretical chemical equations and create some basic tables of my findings, so that other people might be able to use it as a starting point in their own experimenting, and it might serve as a reference material for home DIY battery experimenting. :)

I have great thanks and appreciation for all the people of whom I have picked the brain of in helping me to refine my equations and understanding, assist me with chemical suppliers, answer my questions, provide me with huge amounts of free heavily sulphated deep-cycle batteries to run my tests on (Thanks so much Richard and Kaggie), and generally be interested (or at least keep eye contact with me) when making the mistake of asking me about what I'm up to. :), including the hundreds and hundreds of workshop and seminar attendee's, the electric-vehicle and energy-storage groups who have hosted me and my presentations, and the various culture and arts, education and learning festivals around Australia who provide a platform for me to present this work to the public.

Onwards with the focus of this PDF:

# Index:

Introduction and Outline	1 - 2
Index	3
<b>(Basic Into and Walkthroughs)</b>	
Basic Chemistry Info For Lead Acid Batteries	4 - 7
How Discharge Damages Lead-Acid Batteries Using Sulphuric-Acid	7 - 10
<b>(My research notes and main compound Database)</b>	
A key-point summary of important lead-acid chemistry reactions	11
Example of testing efficacy of alternative electrolyte compounds	12
Alternative Electrolytes Database	13 - 20
<b>(A deeper look at the Chemistry)</b>	
Example concentration charts for preparing liquid electrolytes	21
The Role that Hydrogen (H <sup>+</sup> ) is Playing	22
PDF Wrap up Summary + Recommendations	23

# -----Basic Chemistry Intro for Lead-Acid-----

A Basic introduction to Lead-Acid wet-cell Batteries and a simplified outline of the charge/discharge redox reactions (reduction and oxidation).

The standard full cell equation for Lead-Acid wet-cell batteries, using Sulphuric Acid, is:



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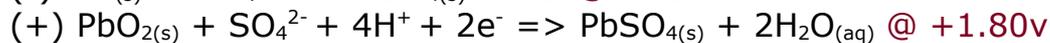
In this full equation, when the traditional lead-acid battery, using an electrolyte of Sulphuric Acid, is fully charged, **the + electrode** (which I will call the **Positrode**, as suggested by Craig Carmichael from Turquoise Energy in the US) is a solid paste of a Lead-Dioxide / Lead-Oxide mix, which is a dark red/chocolate brown colour (called Minium, and the composition quantities vary depending on solution pH, Sulphate-crystal growth and temperature)

**The - electrode (negatrode)**, is a solid paste of pure Lead, which is a dull grey paste-metal colour.

The liquid will be approximately 30-40% Sulphuric Acid and water. The pH of the solution will be low (<1 pH) (very acidic), and the cell will output approx. 2.11 volts.

- Standard Molarity (Concentration) of the Sulphuric Acid for a stationary wet-filled cell is ~4M (calculated to equal roughly 392.32g/L of H<sub>2</sub>SO<sub>4</sub> to Water)
- This is usually noted as varying Specific Density of Sulphuric Acid concentration;
  - ~1.300 g/L = ~ 39% conc.
  - ~1.275 g/L = ~ 36% conc.
  - ~1.250 g/L = ~ 33% conc.
  - ~1.200 g/L = ~ 27% conc.
  - ~1.150 g/L = ~ 21% conc.

Half equations and associated standard electrode potentials will be:



Total nominal cell voltage of ~2.11v

The cell will accept charge up to ~2.40v maximum, after which excessive hydrogen and oxygen gassing will occur.

H<sub>2</sub> and O<sub>2</sub> gassing will begin obviously above ~1.75v

A 2.80v cell charge is listed in some historical notes as the charge voltage required to fully reverse the Lead Sulphate buildup on the Negatrode, however, I have found that while it does have a good effect of cleaning the (-) Negatrode, such a high charge voltage also causes disintegration of the Lead-Dioxide coating of the (+) Positrode, which falls to the bottom of the cell and is no longer useful.

As the battery discharges, the  $O_2$  (oxygen) from the Lead-Dioxide ( $PbO_2$ ) joins with the free  $H^+$  (Hydrogen) from the Sulphuric Acid, to form  $H_2O$  (water). (This actually occurs over a 2 stage process, since Sulphuric Acid deprotonates in water automatically to form a mixture of  **$H^+$  and  $HSO_4^-$** . The  $H^+$  is loosely bound and is responsible for the high-discharge crank capability of Lead Acid cells, and is used up first. The  $HSO_4^-$  comes into play secondarily and is responsible for the longer "stamina" of amp-hour discharge capacity of Lead Acid cells.)

$SO_4^{2-}$  (sulphate ions, or "sulphate potential") joins with the Pb (Lead metal), to form an insoluble compound called Lead Sulphate ( $PbSO_4$ ) which builds up as a thin crystal layer outer coating on both lead-plates. This Lead Sulphate layer can initially be seen as a kind of crystal-glitter spread throughout the plates, but is more commonly seen, when it builds in size, as white/grey crystal build up. This crystal build up is easily removed from the Positrode (+) during charge, but often hardens and seeds more crystal growth on the Negatrode (-) and is not easily removed during normal charge cycles.

**\* Here-in lies the major problem with this version of the Lead-Acid battery. \***

As the battery discharges, both (+) and (-) electrodes become plated with this Lead-Sulphate ( $PbSO_4$ ), and Lead-Sulphate is one of the most insoluble sulphate compounds. This means that the Lead-Sulphate will not readily dissolve back into the solution of its' own accord, to become ionically available, join with free Hydrogen in the solution (mainly produced by electrolysis during charging), and then be able to turn back into Sulphuric Acid ( $H_2SO_4$ ) and Pb /  $PbO_2$  (lead and lead-dioxide).

Although the (+) Positrode more easily releases the  $SO_4^{2-}$  during charging as it undergoes Oxidation and the  $O^2$  takes the place of the  $SO_4^{2-}$  on the Pb (lead), the (-) Negatrode, undergoing Reduction during the charge cycle, does not as readily release the  $SO_4^{2-}$  from the  $PbSO_4^{2-}$  layer.

For this reason it is fairly common to see old lead-acid batteries with heavily sulphated (-) Negatrode plates, and relatively clean (+) Positrode plates. Over time the (-) Negatrode surface area becomes completely covered in the  $PbSO_{4(s)}$  crystals (a white/grey crystal), as well as a more internal version of the  $PbSO_{4(s)}$  crystal within the pores of the Lead (a black, non-light reflecting crystal). Since the Lead plates are semi-porous to the liquid electrolyte, this reduces the available plate area overall, which limits the ion flow and subsequent hydrogen evolution upon charging at the (-) Negatrode (which is required for the reversal of  $PbSO_{4(s)}$  with  $H^+$  to form  $Pb_{(s)} + H_2SO_{4(aq)}$  (sulphuric acid)).

**This is one of the major reasons for Lead-acid batteries having such a shallow depth of total discharge available before you begin to damage the battery and massively reduce it's total number of possible life-cycles.** (That is, the total amount of power you can draw out of the battery, measured in Amp-hours, before you must stop or risk damaging the battery).

The standard maximum available depth of discharge (called **DOD**) for a wet-cell lead-acid battery using 4M Sulphuric Acid electrolyte is 30% of total capacity (rated in Amp hours (Ah) ), and standard maximum DOD for so-called marine or deep-cycle lead acid batteries, often with additives to the liquid electrolyte, such as Sodium Sulphate and Phosphoric Acid, is approx. 50%.

This means, quite literally, that if you have a 12v 100Ah lead acid battery you can only draw 50% of its total capacity, that is, in this example, 50Amp-hours, out of the battery before you must stop, or risk heavily damaging the plates.

(A risk of heavy plate sulphation and possibly, to a much lesser extent, shedding of the active material from the positive + upon next charge at or above 2.4v p/cell, as well as the total reduction of the Positive from  $PbO_2$  to  $PbO$ , although the lower the acid pH towards pH=0, the more easily the conversion from  $PbO$  to  $PbO_2$ , upon next charging).

For a standard car battery, the DOD is only 30%, so for a 12v 50Ah (amp hour) battery, you can only draw 30%, or **15Amps**, total or risk damage to the battery when using Sulphuric Acid as the electrolyte.

In reality, once you draw beyond 50% DOD from a standard lead-acid battery, its' cell voltage drops so much, that it falls below the required voltage to drive the starter motor, or other 12v based appliances, especially devices that draw high amps.

***It is for this reason that we need to massively over-size Lead-Acid battery storage capacity for off-grid houses, to compensate for the fact that we can only draw out, lets say, 30% of the total capacity from the battery bank.***

I am also ignoring the reality that in an off-grid house example, we also need to plan for, usually, a minimum of 3 days of backup battery draw (called autonomy) to compensate for many days of no sun or cloudy weather during winter, as this PDF is not specifically dealing with off-grid solar setups, I will just use our simple example as it could be applied to any lead-acid battery that we assume will be fully charged the following day/use cycle.

## --HOW DISCHARGE DAMAGES LEAD ACID BATTERIES USING SULPHURIC ACID--

As we attempt to draw more power out of the battery, it discharges further, which puts more Lead-Sulphate onto the (+) and (-) plates, of which the  $\text{PbSO}_{4(s)}$  that forms on the (-) Negatode will not totally dissolve back into the solution at the next charge, and the sulphation slowly process begins. (The symptom of this is the slow reduction in total amp-hour capacity of the cell over time).

----DISCHARGE ----->



Ironically, when a standard 12v lead-acid battery has its' voltage drop below 12v, this is usually a sign that more than 50% of its capacity has been drained (since a normal 12v lead acid battery will actually have a voltage of around 12.7v at full 100% State Of Charge), and it will begin to "sulphate" more rapidly, which is a term that describes when the white/grey coloured lead-sulphate crystals begin to build up on the surface of the metallic lead + and - plates. Research data and test results that I have read on lead-sulphate crystal formation actually suggests that the  $\text{PbSO}_4$  crystal begins to "grow" or be precipitated onto the lead electrodes as soon as the total charge voltage drops from its float voltage of **13.3v (2.21v per cell)**.

The more this happens, the less "charge" the lead-acid battery will be able to hold overtime, relative to it's rated capacity, and eventually, it will not be able to sustain the amount of charge it needs to keep its' voltage above 11v when under load, in order to run things like starter-motors in cars, etc., this is because the **Amp-hour capacity of the battery is directly proportionate to the surface area of the lead-plates coming into contact with the electrolyte and the ratio of Negative plate to Positive plate**, (whereby most Lead-Acid cells in production today have 1 extra negative plate compared to the positive plate, such that a cell that has 4 positive plates, will have 5 negative plates, and this helps to reduce hydrogen evolution and gassing at the negatode due to the negatode becoming fully reduced faster than the positrode can become fully oxidised).

The run-away effect of increasing Lead-Sulphate ( $\text{PbSO}_4$ ) crystal buildup, and the lack of ability of normal charge conditions to reverse the compound creation back into Sulphuric Acid ( $\text{H}_2\text{SO}_4$ ) becomes self-evident when you realise that a major player in the **discharge reaction** is Hydrogen ( $\text{H}^+$ ), provided from the  $\text{H}_2\text{SO}_{4(\text{aq})}$  liquid acid electrolyte, which is usually **formed again during the next charge cycle** as Hydrogen ( $\text{H}^+$ ) is produced at the (-) Negatrode from the water through a process known as **water electrolysis**.

When some of that surface area is converted into  $\text{PbSO}_4$  crystal, it stops that portion of the plate from interacting with the electrolyte, and the surface area of the battery has been reduced, thus, the **discharge amp-hour capacity has been reduced also**.

Ironically, the lead-sulphate compound is relatively non-conductive, and it also stops the liquid electrolyte (the  $\text{H}_2\text{SO}_4$  sulphuric acid) from making contact with the metallic lead underneath the layer, effectively stopping the discharge reaction as well as reducing the ability of the (-) Negatrode plate to produce Hydrogen ( $\text{H}^+$ ) during charge under electrolysis.

In this way, if we pull apart an old, heavily sulphated Lead-Acid battery, one that has sat outside and dried out for 10 years for example, we will usually see that beneath the  $\text{PbSO}_4$  crystal layer on the negatrode, the remaining material is still solid/paste metal Lead just as it was produced from the factory, and sometimes I have found this  $\text{PbSO}_4$  layer to sometimes be less than 1mm thick. The (+) Positrode, though often found in a discharged state being heavily covered in white Lead-Sulphate, very easily returns to dark red/chocolate brown colour ( $\text{PbO}/\text{PbO}_2$ ) upon a single charge cycle if put into a beaker with a clean brand new Lead-plate (-) Negatrode.

I generally conclude from this experiment that the main obstacle to a much longer life-span and rejuvenation of the classic Lead-Acid battery is the low-conductivity of the Lead-Sulphate build up on the (-) Negatrode, and that we could conceive of a number of ways to manipulate this condition.

**I propose that alternative liquid electrolytes could be used to allow an appreciable discharge amp-hour capacity, which, during both charge and discharge of the cell, allow the negatrode to continue being in full electrical contact with the liquid and/or, for no insulative Lead-compound to form on the negatrode during discharge.**

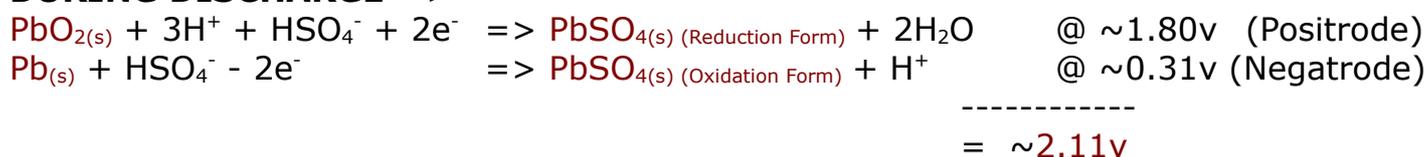
My Experiments and findings to this end are documented in the next pages.

For Reference, before we start, these are the standard average voltages and Specific Gravity values that I have come across in regard to State of Charge (SOC %) of lead-acid batteries using ~4M sulphuric acid electrolyte. This chart only ranges from **2.12v to 1.8v**, and covers most batteries used for deep discharge cycles such as forklifts and off-grid systems.

SOC %	Per Cell (2v nominal)	X6 cells (Standard 12v Batt)	Specific Gravity using 4M H <sub>2</sub> SO <sub>4</sub> Electrolyte (g/L) + acid conc. @ 20*c
100	2.12v	12.72v	1.300 (39% conc.)
90	2.10v	12.62	1.275 (36% conc.)
80	2.08v	12.48	1.250 (33% conc.)
70	2.06v	12.37	1.225 (30% conc.)
60	2.04v	12.24	1.200 (27% conc.)
50	2.01v	12.06	1.185 (25% conc.)
40	1.99v	11.94	1.160 (22% conc.)
30	1.96v	11.76	1.150 (21% conc.)
20	1.89v	11.34	1.120 (17% conc.)
10	1.80v	10.81	1.070 (10% conc.)

There are 2 different chemical reactions occurring in the lead-acid battery during discharge which each give us different electro-negative potential values (voltages) at each terminal/electrode.

#### **DURING DISCHARGE -->**



The bulk of the discharge capacity (the amount of amp-hours we can usually draw from the cell) occurs between the cell voltages of ~2.11v to ~1.80v, and then the cell's capacity drops very quickly along with its' cell voltage.

We can observe this when looking at standard discharge curves for Lead-Acid batteries.

This shows us that the reaction which is providing the bulk of the amp-hour capacity in the discharge of the cell is most notably that which is occurring at the negative electrode, the conversion of Pb (Lead) to PbSO<sub>4</sub> (Lead Sulphate, Oxidation Form), and that the process of the reaction at the Positrode (the conversion of Lead Dioxide to Lead Sulphate, Reduction Form / Lead Oxide) is providing a much smaller amount of the total charge capacity in amp-hours, but is required to provide a closed circuit for the plate discharge reaction to take place and give us a relative voltage.

**If we, therefore, were to change the reaction occurring at the negatrode, then we should expect to drastically change the total cell amp-hour capacity, as well as alter the overall cell voltage characteristics.**

PbSO<sub>4</sub> has been shown also to be formed as two different varieties on the lead plates depending on the route of formation, whether through Oxidation (Discharging of the Negatode) or through Reduction (Discharging of the Positrode). This is discussed in a brilliant research paper titled "**Transformation of inert PbSO<sub>4</sub> deposit on the negative electrode of a lead-acid battery into its active state**". The paper can be found by following this URL:

[https://www.researchgate.net/publication/245108620\\_Transformation\\_of\\_inert\\_PbSO\\_4\\_deposit\\_on\\_the\\_negative\\_electrode\\_of\\_a\\_lead-acid\\_battery\\_into\\_its\\_active\\_state?enrichId=rgreq-612c990b6bce108547add1385f508780-XXX&enrichSource=Y292ZXJQYWdIOzI0NTEwODYyMDtBU](https://www.researchgate.net/publication/245108620_Transformation_of_inert_PbSO_4_deposit_on_the_negative_electrode_of_a_lead-acid_battery_into_its_active_state?enrichId=rgreq-612c990b6bce108547add1385f508780-XXX&enrichSource=Y292ZXJQYWdIOzI0NTEwODYyMDtBU)

The consequence of this discovery is that depending on the route of PbSO<sub>4</sub> formation, that one form (particularly the Reduction form PbO<sub>2</sub> → PbSO<sub>4</sub>) is shown to be more highly electro-conductive than the other.

In a simple overview, the PbSO<sub>4</sub> that is formed on the Positrode during discharge will be more electro-conductive and will form H<sub>2</sub>SO<sub>4</sub> from the available liquid electrolyte more readily during charge than the Negatode.

Secondarily, more brilliant research has shown that PbO<sub>2</sub> exists as two possible crystal forms named PbO<sub>2</sub> (alpha) and PbO<sub>2</sub> (beta).

This is mentioned in the above research paper, but also in more experimental depth in a paper titled "**Lead Acid Battery Formation Techniques**" by Dr. Reiner Kiessling (you will need to search google for this paper), where-in the author demonstrates their research showing that PbO<sub>2</sub> (alpha) is formed most usually in neutral or alkaline pH environments, and goes through a reduction process at a much slower rate than PbO<sub>2</sub> (beta). PbO<sub>2</sub> (alpha) only allows a low sustained Ah discharge rate. It does however provide a more "glued" base for the Positrode during discharge, as it sheds active material less than the beta version.

PbO<sub>2</sub> (beta) is formed most usually in acidic environments, and goes through a reduction process at a much faster rate than PbO<sub>2</sub> (alpha), and provides for an ability to deliver a more sustained large-Ah discharge rate, however it sheds active material at a much greater rate. Spiral / Tubular wound cells would be able to negate this issue to a large extent, so that the downside of the PbO<sub>2</sub> (beta) particle shedding could no longer be a major player.

These pieces of information above can guide us in our search and research for alternative electrolytes for Pb/Pb Batteries and help us to theorise basic discharge rates / capacities as well as charge reversability.

## We can summarise all of the above into this super useful dot point list:

- The Lead/Lead acid cell voltage is a product of the reactions at both electrodes
- Changing/stopping the reaction at the Negatrode should alter the cell voltage
- The formation of either  $\text{PbO}_2$  (beta) or  $\text{PbO}_2$  (alpha) will depend on the electrolyte pH and will alter the "cranking" discharge capabilities of the cell
- The crystal form shape of the  $\text{PbSO}_4$  is physically different on either electrode due to the route of formation (oxidation or reduction)
- Due to the greater formation of  $\text{PbO}_2$  (beta) in a more acidic pH electrolyte, the Positrode may disintegrate at a faster rate
- A higher pH and lower acid concentration will form more  $\text{PbO}_2$  (alpha) and the Positrode may disintegrate at a slower rate, but the cell will have a lower "cranking" discharge ability and a lower total cell capacity.
- A lower acid concentration will cause a slower  $\text{PbSO}_4$  sulphation of the (-) Negatrode over time, but the cell will have a lower total cell capacity.
- $\text{PbSO}_4$  crystal forms on both electrodes during discharge using  $\text{H}_2\text{SO}_4$  electrolyte
- The majority of the cell amp-hour discharge capacity comes from the reaction at the (-) Negatrode **(this is important!)**, and is responsible for  $\sim 0.310\text{v}$  difference from 2.11v to 1.80v in a cell using  $\text{H}_2\text{SO}_4$  electrolyte.
- Upon charging, the (+) Positrode will form different Lead compounds depending on the electrolyte pH (mostly  $\text{PbO}_2$  in low pH (acid),  $\text{PbO}/\text{PbO}_2$  in mid pH (mildly-acid),  $\text{Pb}(\text{OH})_2$  in high pH (alkaline))
- The ability for the  $\text{PbSO}_4$  to become  $\text{H}_2\text{SO}_4$  again during re-charge depends on an available cation in the electrolyte to receive the  $\text{SO}_4^{2-}$  from the Lead plates, such as other metal cations ( $\text{Na}^+$ ,  $\text{Pb}^+$ ,  $\text{Mg}^{2+}$ , etc..) or  $\text{H}^+$
- Upon charging,  $\text{H}^+$  is produced at the (-) Negatrode due to electrolysis of the water electrolyte, and is then available as a cation to bond with the  $\text{SO}_4^{2-}$
- If we reduce the  $\text{H}^+$  production (such as by reducing surface area of the (-) Negatrode), then we reduce the ability for  $\text{PbSO}_4$  to be removed from **both plates**
- $\text{PbSO}_4$  is more able to be converted to  $\text{H}_2\text{SO}_4$  in an electrolyte that is less acidic **(how ironic!)**
- Lead electrodes (Paste or Plate) are usually various alloys of Lead, such as Lead/Tin, Lead/Antimony, Lead/Calcium, and the alloy metal will also take part in the various charge/discharge reactions
- In-organic Lead compounds are generally insoluble, except for Lead nitrates (Nitric Acid compounds) while **organic Lead compounds are generally highly soluble (and therefore dangerous)** such as Lead acetates (vinegar compounds) and Lead citrates (lemon juice compounds)
- $\text{PbO}_{2(s)}$  is a relatively powerful oxidising agent, and will be reduced by a range of impurities and contaminates in the electrolyte
- If the solid lead-compound that forms during discharge could be made to be highly conductive, then the Lead/lead acid cell could last for decades, instead of years.

## -----AN EXAMPLE OF MY ALTERNATIVE ELECTROLYTE EXPERIMENTS-----

This is a short example of my research direction, and demonstrates some of the difficulties I have come across in researching and discovering possible alternative electrolytes that could alter the chemical process of the Lead/Lead cell.

In one experiment, where I setup a test cell in a beaker of two thin Lead plates in a maximum saturated solution of Zinc Sulphate ( $ZnSO_4$ ) at 3.33M concentration, and charged and discharged it, I could visually watch  $Zn(s)$  metal plating onto the Lead negatode, and then be mostly removed again into solution upon discharge. (There is already a patent for this style of Lead-cell where a Zn negatode is used instead of Lead), as well as the formation of dark red Lead(IV) oxide / clay coloured orange Lead(II) oxide.

As a reference, the test cell gave  $\sim 150mAh$  capacity using 5M Sulphuric Acid as the electrolyte.

I removed the  $ZnSO_4$  electrolyte and poured it into a beaker, which I then mixed with an equal concentration of 3.33M of Sulphuric Acid (I was intending to create a solution of Zinc Bisulphate ( $Zn(HSO_4)_2$ ), and I then re-poured this new solution back into the lead-cell test beaker and charged it using the same apparatus as before. (4v DC @ 2Amp)

*To my surprise, there was no visible Zinc plating on the negatode that I could see. Absolutely no change of colour (since Zinc is a more bright grey colour than Lead) occurred that I could see.*

Attempting to discharge the cell gave almost nothing, as the voltage dropped immediately below usable limits once the charge source was removed. (0.2v)

*Somehow, the change from Zinc Sulphate to Zinc Bisulphate was stopping the Zinc from coming out of solution and plating onto the negatode during charge, as well as stopping the Hydrogen from reducing the Positrode to  $PbO$ .*

I repeated this style of test using the same Lead electrodes, and Sodium Bisulphate, which I had obtained in pure granular form from a local pool chemical supply store.

Again, I found that the test cell barely performed at all using just the Sodium Bisulphate solution, and that when I removed the lead electrodes, and placed them into a beaker of Sodium Sulphate instead, that the cell would be able to accept some charge, and be discharged to a similar degree that I had observed in my initial experiments desulphating old car batteries. (In my research I have found that I can use Sodium sulphate as the electrolyte to act more as a capacitor rather than a battery, more on this later).

***These experiments and the results have led me to assume that, because  $Pb^{2+}$  is a much weaker oxidising agent compared to the metal ions of the compounds I have been using (Sodium, Potassium, Aluminium, Magnesium, etc..) that the  $SO_4^-$  and possibly  $H^+$  ions in solution will not effectively move out of bound solution and interact with the Lead (e.g.  $MgSO_4$  and  $Mg(HSO_4)_2$  wont easily interact with the  $Pb + PbO_2$  )***

-----ALTERNATIVE ELECTROLYTES DATABASE-----

This chart below is a basic summary and database of my experiments using all kinds of different electrolytes, both liquid and solid-saturated, to observe simple changes and effects, as well as to report on initial charge/discharge capacity testing and attempt to gain understandings of the chemical processes occurring in each change of electrolyte.

Most of the following tests charged cells over many hours at between 1-5Amp, pushed cell voltage up to between 2.4-3.5v (depending on half-cell equation standard potentials) under charge to force formation of PbO<sub>2</sub> on positrode. Tests used either new clean Lead electrodes in beakers, or previously fully De-sulphated Lead-Acid cells of pasted Lead Positrodes and plate/pasted Lead Negatodes as noted in the test descriptions.

Discharge capacity tests were generally conducted at a C/20 (0.05C) rate (relative to the rated capacity of the test cell when using 4M H<sub>2</sub>SO<sub>4</sub>)

**Note:** Fields left blank indicate that the compound should at least be testable, but that no test has yet been completed by me at the publishing of this version of this paper.

SULPHATE COMPOUNDS		
Compound @ max saturation in pure water		Observations
Sulphuric Acid	H <sub>2</sub> SO <sub>4</sub> (Conc. of this for testing was 4M)	100Ah "rated" cell gave ~101Ah capacity discharge. During Charge, Positrode becomes dark red PbO <sub>2</sub> , negatode becomes pure grey Lead. Both plates form white PbSO <sub>4</sub> upon discharge, though Positrode also forms PbO (brick orange coloured solid) <b>REFERENCE FOR SULPHATES</b>
Magnesium Sulphate	MgSO <sub>4</sub>	Identical test cell was "rated" at 3Ah using 4M H <sub>2</sub> SO <sub>4</sub> . Clean Lead plates used. 1.26M MgSO <sub>4</sub> (concentration). Charging at 3.3v causes + plate to form PbO/PbO <sub>2</sub> layer (orange and dark brown). - Plate builds up a "cloud" of opaque white suspension that marks the inside walls of the plastic case. Cell rest voltage sits at ~1.9v. DC Load of 1Amp pulled cell from 1.9v to 1.73v, then dropped to 0.266v with a total Ah drawn of 154mAh. (~5% of rated cell capacity). A secondary charge cycle gave 355mAh of capacity (~11.8% of rated cell cap). Subsequent charge cycle gave similar capacity, but the voltage range covered is almost unusable for most purposes (from ~1.9v to 0.25v). Follow up test drawing 0.5Amp from the cell from 1.73v to 1.49v gave ~73mAh. (2.4% of rated cap). Discolouration of plastic case can be scrubbed off almost completely. The opaque cloud only gathers around the Negative electrodes. Apart from opaque cloud, the lead negatode shows almost no white crystal buildup upon discharge to 0.2v
Magnesium	Mg(HSO <sub>4</sub> ) <sub>2</sub>	100Ah "rated" cell gave ~5Ah capacity discharge. (5%

Bisulphate		capacity) However, drawing cell to 0.1v caused only small amounts of PbSO <sub>4</sub> to form on negatrode, and It would accept charge again slowly to provide a second discharge capacity of ~5Ah again. This test was only performed 3 times.
Zinc Sulphate	ZnSO <sub>4</sub>	Solid Zinc could be seen plating onto Pb negatrode under charge, then dissolving off again during discharge. 2 lead plate beaker test. Forms PbO <sub>2</sub> on positrode, negatrode becomes zinc plated. Cell voltage at rest = , Discharge capacity =
Zinc Bisulphate	Zn(HSO <sub>4</sub> ) <sub>2</sub>	No Zinc could be seen plating, cell had almost no discharge capacity
Sodium Sulphate	Na <sub>2</sub> SO <sub>4</sub>	Cell voltage = ~1.85v , cell discharge showed a large instantaneous CCA, but a very small overall cell capacity. I theorise that the Sodium is acting through electro-static forces to be casually held to the negatrode, and provide a large discharge amp-flow in the style of a large capacitor. This works really well as a car starter battery, however as the seasons change and ambient temperature drops, I have found that the solubility changes and the conc. reduces, which also seems to reduce the discharge capacity.
Sodium Bisulphate	NaHSO <sub>4</sub>	WRITE UP OF DATA WILL COME IN NEXT REVISION
Aluminium Sulphate	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	(conc. = max saturated at 20*c) Pb negatrodes changed to very dull pasty grey colour under charge (Aluminium plating?) cell rest voltage = ~1.835v Using a 100Ah "rated" cell with clean plates, a 5A DC load was applied and cell voltage immediately dropped to ~1.10v and gave 2.0Ah capacity from 1.101v to 1.009v. (voltage drop was suprisingly stable at first), (2% of rated cell capacity, but at a much lower cell voltage than the usual Pb/Pb operating voltage of 2.11v-1.8v) Upon Charge, gas bubbles don't appear on either plates until cell voltage reaches ~2.90v. <b>(Discharge capacity from this cell was easily and instantly increased upto ~60% of rated cell cap, See notes below on Sodium-Aluminium-Sulphate)</b>
Aluminium Bisulphate	Al(HSO <sub>4</sub> ) <sub>3</sub>	Similar to Zinc Bisulphate, Upon charge, no visible Aluminium can be seen plating negatrode, and discharge produces almost no amp-hour capactiy. Cell voltage drops immediately to around 0.3v once charge source is removed.
Potassium Sulphate	K <sub>2</sub> SO <sub>4</sub>	WRITE UP OF DATA WILL COME IN NEXT REVISION
Potassium Bisulphate	KHSO <sub>4</sub>	WRITE UP OF DATA WILL COME IN NEXT REVISION
Calcium	CaSO <sub>4</sub>	<b>NOT SOLUBLE IN WATER, perhaps try this as a super-</b>

Sulphate		saturated-wet-paste electrolyte instead?
Copper (II) Sulphate	CuSO <sub>4</sub>	Max concentration (1.44M). Blue colour of solution recedes upon charging (1.9v, higher amp charge kept pushing cell voltage higher and higher without limit up to 8v) orange coloured Copper plates onto Lead negatrode and will not return under discharge (lower electro-negativity than Pb). 3Ah "rated" cell gave approx. 159mA discharge capacity from 1.23v to 0.560v (5.3% of rated cap). Upon next charge more Cu <sub>(s)</sub> plated onto Negatrode until plates shorted out. <i>The Test should be run again by plating Cu onto Pb negatrode during first charge, then remove all CuSO<sub>4</sub>, refill with other compounds and test again. This would have the effect of creating a Cu- /Pb+ battery, possibly just using H<sub>2</sub>SO<sub>4</sub> to strip Cu back off negatrode during discharge, and re-plate copper onto lead negatrode during charge cycle. Could also use Carbon or Aluminium negative plates.</i>
Copper (I) Sulphate	Cu <sub>2</sub> SO <sub>4</sub>	
Iron (II) Sulphate	FeSO <sub>4</sub>	Liquid solution is light green coloured when fresh. Upon charging green colour fades, liquid becomes totally transparent. Cell rest voltage = 1.40v
Iron (II) Bisulphate	Fe(HSO <sub>4</sub> ) <sub>2</sub>	
Iron (III) Sulphate	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	
Lithium Sulphate	Li <sub>2</sub> SO <sub>4</sub>	
Nickel (II) Sulphate	NiSO <sub>4</sub>	
Nickel (III) Sulphate	Ni <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	
Tin (IV) Sulphate	Sn(SO <sub>4</sub> ) <sub>2</sub>	
Ammonium Sulphate	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	
Cobalt (III) Sulphate	Co <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	
Chromium (III) Sulphate	Cr <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	
Manganese (III) Sulphate	Mn <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	
Manganese (II)	MnSO <sub>4</sub>	Mn ions react upon contact with PbO <sub>2</sub> to form Permanganates (MnO <sub>4</sub> <sup>2-</sup> ), assuming production of Lead

Sulphate		Permanganate ( $\text{Pb}(\text{MnO}_4)_2$ ) or Permanganic Acid and Lead Sulphate ( $\text{H}_2\text{MnO}_4 + \text{PbSO}_4$ ). Both Lead plates became covered in black/purple powder and no amount of charging would grow $\text{PbO}_2$ back onto positive, and cell gave no discharge capacity of any value. Is there a metal that could form an oxidised positive that won't be attacked by the $\text{MnO}_4^-$ ?
Titanium (IV) Sulphate	$\text{Ti}(\text{SO}_4)_2$	Will it form Lead Titanate? $\text{PbTiO}_3$ on the negative? $\text{Ti}(\text{SO}_4)_2$ is a clear/yellow coloured oily liquid made using $\text{H}_2\text{SO}_4$ liquid and electrolysis with Titanium plates
Barium Sulphate	$\text{BaSO}_4$	<b>NOT SOLUBLE IN WATER, perhaps try this as a dry-paste electrolyte instead?</b>
Cadmium Sulphate	$\text{CdSO}_4$	TOXIC, will not test
Silver Sulphate	$\text{AgSO}_4$	
Mercury Sulphate	$\text{HgSO}_4$	TOXIC, will not test
Tungsten (VI) Sulphate	$\text{W}(\text{SO}_4)_3$	
Tungsten (IV) Sulphate	$\text{W}(\text{SO}_4)_2$	

### DOUBLE METAL BOUND SULPHATES (CALLED ALUMS)

Though these compounds are still Sulphates, they are special compounds between a metal ion in a 3+ state and another in a 1+ state. They have the formula:  **$\text{AM}(\text{SO}_4)_2$**  where **A=1+ metal ion and M=3+ metal ion**

I have had the best success in the Sulphate Compound family by using Alums. The same processes might also work for Phosphates ( $\text{PO}_4$ ), Selenates ( $\text{SeO}_4$ ) and Borates ( $\text{BO}_3$ ).

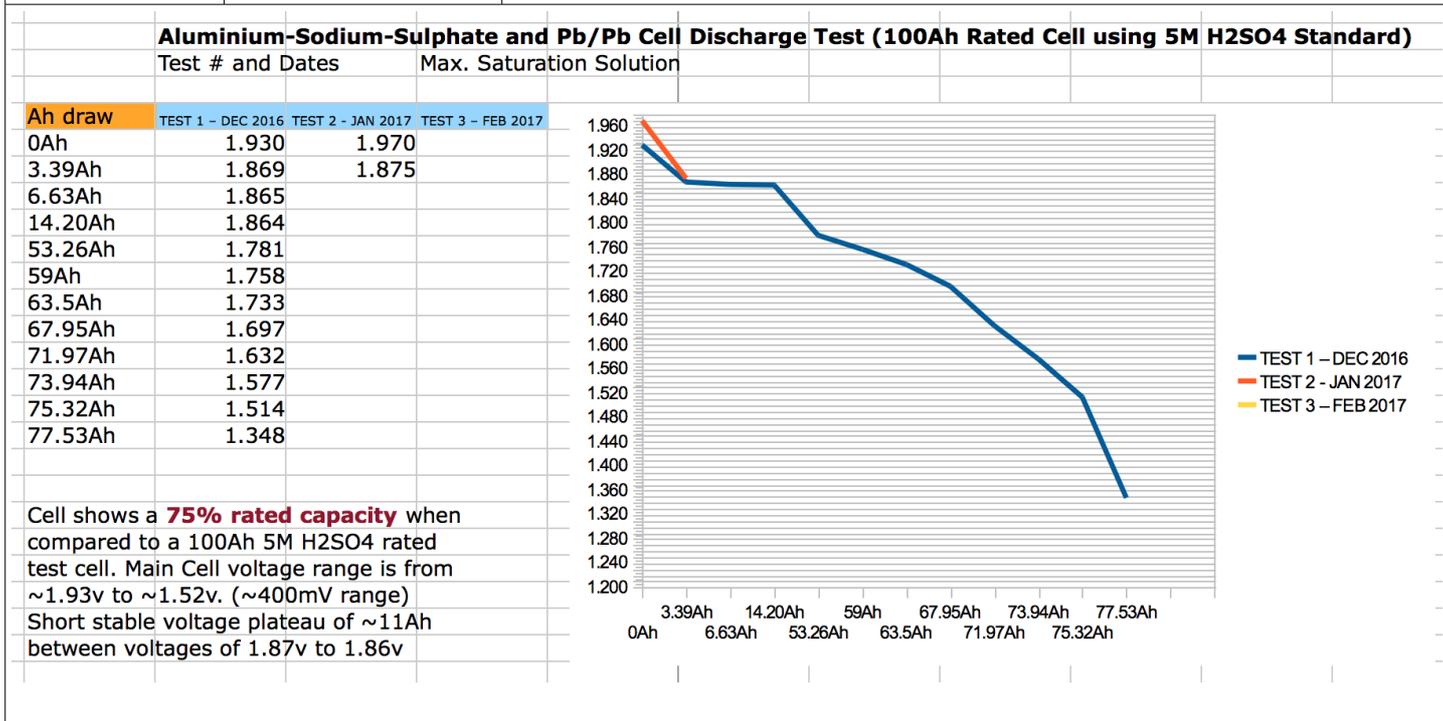
Double Metal Salts are different to Complexes in that upon being dissolved in water, Double Metal Salts fully dissociate to give the corresponding ions, whereas Complexes remain intact upon dissolving.

The properties of the Double Metal Sulphates are usually different to the properties of either individual salt.

Double Metal Sulphates seem to generally exhibit low pH values and colour litmus paper red upon exposure. Perhaps they are able to effectively reduce the  $\text{PbO}_2$  on the positive during discharge?

Potassium Aluminium Sulphate (ALUM)	$\text{KAl}(\text{SO}_4)_2$	100Ah rated cell gave ~45Ah discharge capacity between voltages ~1.45v – 1.01v. Low spark when terminals short-circuited, large amp-flow though as 8gauge cables heat and melt. (A 45% rated cell capacity) Cell rest voltage - ~1.45v charging voltage = ~2.6v
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Sodium Aluminium Sulphate (ALUM)	$\text{NaAl}(\text{SO}_4)_2$	Voltage range from $\sim 1.90\text{v}$ to $\sim 1.50\text{v}$ gave an Ah capacity of $\sim 75\text{Ah}$ (in a 100Ah rated cell ( $\text{H}_2\text{SO}_4$ )). <b>This gives us a 75% rated cell capacity.</b> The discharge voltage curve was consistent and steep, with one short sustained plateau. Cell resting voltage = $\sim 1.93\text{v}$
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Iron(III) Chromium Sulphate (ALUM)	$\text{CrFe}(\text{SO}_4)_2$	
Iron(II) Ammonium Sulphate (ALUM)	$(\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2$	
Iron(III) Ammonium Sulphate (ALUM)	$\text{NH}_4\text{Fe}(\text{SO}_4)_2$	
Potassium Chromium Sulphate (ALUM)	$\text{KCr}(\text{SO}_4)_2$	

**NITRATE COMPOUNDS**

Cannot test, since Lead Nitrates ( $\text{PbNO}_4$ ) are soluble, and will form an electroplating cell, rather than a battery.

## PHOSPHATES COMPOUNDS

Ortho-Phosphoric-Acid

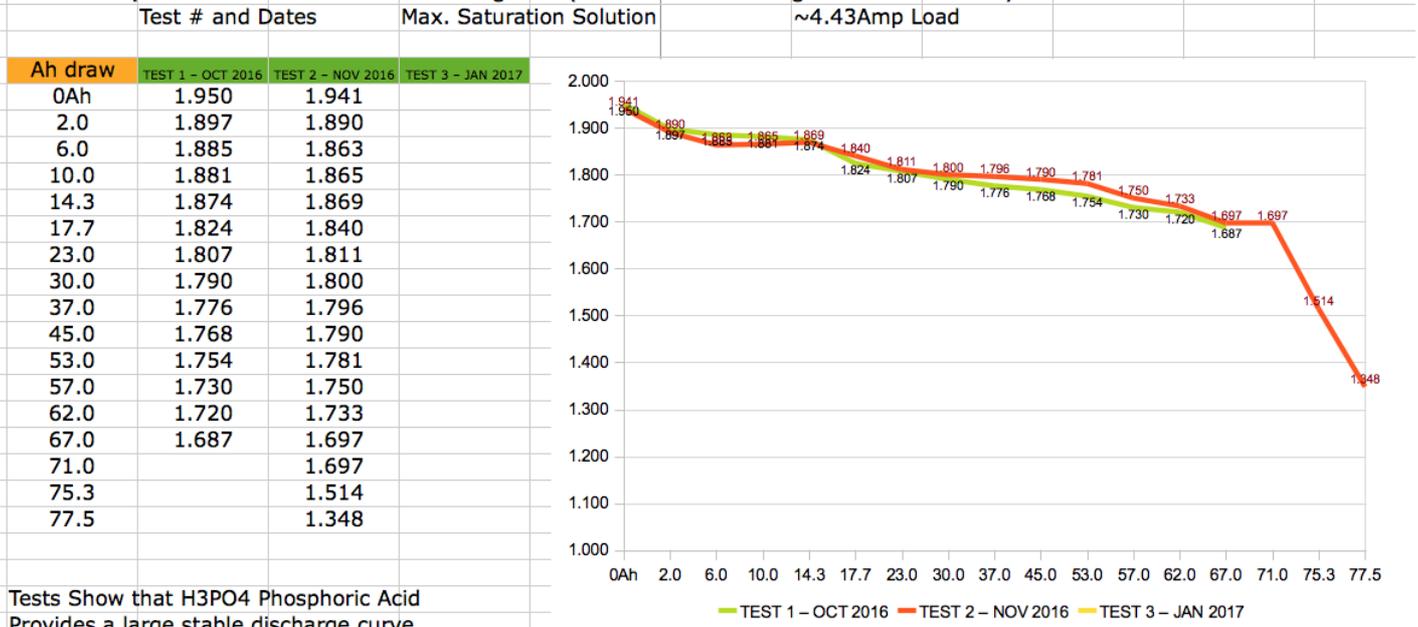


100Ah "rated" cell gave ~70Ah capacity discharge. (70% of rated capacity).  
 Voltage discharge range was ~1.90v to ~1.70v (200mV range)  
 Resting cell voltage = ~1.95v  
 Discharge voltage curve was remarkably flat with two main plateaus, 0-14Ah (from voltages 1.90v to 1.87v), and then 30-62Ah (from voltages 1.79v to 1.72v). Cell voltage dropped rapidly from ~1.68v.

### REFERENCE FOR PHOSPHATES

While this electrolyte works extremely well as a replacement Lead-Acid cell electrolyte in terms of Ah capacity compared to the use of 4M Sulphuric Acid, upon discharge to below 1.7v the Lead-Phosphate compounds that form create translucent crystals that grow enormously (mainly upon the Negatrotode). These crystals grow beyond the negative plates, and form solid transparent crystals that grow up into the electrolyte reservoir space above the plates. These crystals dissolve completely upon charging the cell, however it is possible that the Lead-Phosphate crystal growth could puncture the plate-separators and cause shorting to the cells or damage to thin lead-plates potentially?, Would the  $PbPO_4$  crystals conduct between the plates and cause a high self-discharge rate?

**H3PO4 Phosphoric Acid in a Pb/Pb Cell – Discharge Test (100Ah Rated Cell using 5M H2SO4 Standard)**

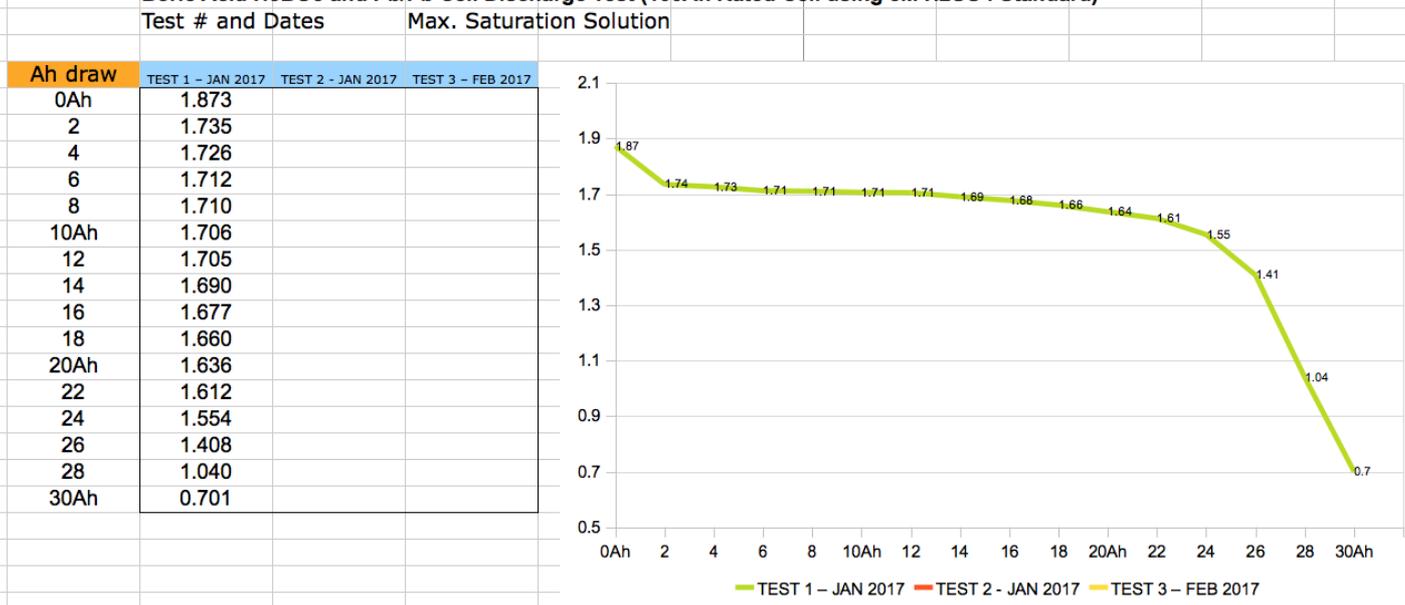


Tests Show that H3PO4 Phosphoric Acid Provides a large stable discharge curve and provides ~71Ah over a 200mV range from 1.90v to 1.70v. This represents a Discharge Ah capacity of ~70% of the rated cell capacity of 5M H2SO4.

## BORATE COMPOUNDS

Boric Acid	$H_3BO_3$  or $B(OH)_3$	100Ah "rated" cell gave ~24Ah capacity discharge ( <b>24% of rated capacity</b> ) between cell voltages of ~1.80v to ~1.50v (300mV range) (@ Max. Saturation). Cell rest voltage = ~1.87v Discharge cell to 0.6v showed no white-crystal growth on negatrode, positrode remains dark red/dark brown (assumed to be $PbO_2$ ?) Negatrode colour darkened to dark grey/black. Theorise this to be some form of Lead (II) Borate solid ( $Pb_3(BO_3)_2$ )? References for Lead Borate state a white powder? ( $Pb(BO_2)_2$ ) is this a Lead (IV) compound? <b>REFERENCE FOR BORATES</b>
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**Boric Acid H3BO3 and Pb/Pb Cell Discharge Test (100Ah Rated Cell using 5M H2SO4 Standard)**



Test 1 shows that the cell gives its' greatest stable Ah capacity between **1.75v and 1.55v** (a 200mV range) and equals **~24Ah capacity** from a test cell that is rated as 100Ah capacity using 5M H2SO4 as a standard.  
 This cell therefore gives **26% of the rated capacity** of Pb/Pb H2SO4

Borax (Disodium Tetraborate)	$Na_4HBO_3$ ?	Borax showed to be highly capable of stripping lead-sulphate crystal growth away from the negative electrode, effectively cleaning the Negatrode to a dull grey colour. WRITE UP OF MORE OF THIS DATA WILL COME IN NEXT REVISION (use of Borax as a daily cyclic electrolyte)
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## OTHER MISC. COMPOUNDS

Hydrochloric Acid	HCL	(conc=9.05M) Dark red $PbO_2$ on positrode was changed to white pasty $PbCl_{2(s)}$ Lead(II) Chloride. Liquid became yellow and oily ( $PbCl_{4(aq)}$ ) Lead Tetrachloride, and slowly went clear again over time. Gassing of $Cl_{(g)}$ could be
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		<p>smelled (Highly Dangerous) and Positrode turned a dull white/grey colour (PbCl<sub>2</sub>). No real amount of discharge power usable. Is this because PbCl<sub>2(s)</sub> is actually an electrical insulator?. Subsequent charges required cell voltages over 5v to realise even a few milliamp of charge. Due to Lead becoming soluble at PbCl<sub>4</sub> and then reducing to Pb on negatrode during charge, the cell shorted out after a few charge cycles, and there was never any great output, cell voltage dropped to 0.2v almost immediately. PbCl<sub>2</sub> solid that forms on Positrode can be reversed to PbO by filling the cell with NaOH and charging. Assumed reaction was: PbCl<sub>2(s)</sub> + NaOH<sub>(aq)</sub> =&gt; PbO<sub>(s)</sub> + NaCl<sub>(aq)</sub> + H<sub>2</sub>O</p>
Sodium Hydroxide	NaOH	<p><b>Interestingly, this cell will discharge a very high amp-hour output, but only if the PbO<sub>2(s)</sub> is formed before hand in another acidic cell, using sulphuric acid, for example.</b> Negatrode remains clean. Trying to re-form PbO<sub>2(s)</sub> on the positrode in the NaOH electrolyte did not work. Perhaps the NaOH reduces the PbO<sub>2(s)</sub> to PbO<sub>(s)</sub> and destroys the potential power output very quickly? (high self discharge). Charging forms a slimy dull yellow layer on positrode (Pb(OH)<sub>2</sub>?). It is also possible also that upon charge in such an alkaline environment that the form of PbO<sub>2</sub> is of the (alpha) type, with no (beta) type created, leading to a very low-Ah discharge capacity/rate.</p>
Magnesium Hydroxide	Mg(OH) <sub>2</sub>	
Copper Hydroxide	Cu(OH) <sub>2</sub>	
Calcium Hydroxide	Ca(OH) <sub>2</sub>	
EDTA 4Na (Tetra-sodium Ethyl-d-t-acetate)		<p>The use of this compound is mentioned in automotive and battery forums across the internet with reports of hugely varied experience. I was contacted via email by a man from France, "Pierre Yves Thomas" , and asked to comment on the use of EDTA to desulphate Lead-Acid cells. This information is now in my "Desulphating" paper, and I thank him for the prompt!. I chose not to use EDTA as an alternative electrolyte for charge/discharge cycles due to massive solubility of lead/antimony-acetate, as I theorise that this would slowly but consitently dissolve lead particles into solution as PbAcetate, and simply erode the plates.</p>

## ---EXAMPLE CONCENTRATION CHART FOR PREPARING LIQUID ELECTROLYTES---

The following are examples of calculating molarity (concentration values) for some of the alternative electrolyte compounds noted in this paper. This should provide the reader with enough information to create standard preparations of the listed compounds for their own testing.

<b>Na<sub>2</sub>SO<sub>4</sub></b> (Sodium Sulphate)	<b>@ 20*c</b>	<b>@ 40*c</b>
max. solubility p/L H <sub>2</sub> O	195g/L	488g/L
molar weight (to make 1M)	142.04g/L	142.04g/L
Max. concentration p/L H <sub>2</sub> O	1.37mol	3.43mol

<b>K<sub>2</sub>SO<sub>4</sub></b> (Potassium Sulphate)	<b>@ 20*c</b>	<b>@ 40*c</b>
max. solubility p/L H <sub>2</sub> O	111g/L	148g/L
molar weight (to make 1M)	174.26g/L	174.26g/L
Max. concentration p/L H <sub>2</sub> O	0.63mol	0.85mol

<b>MgSO<sub>4</sub></b> (Magnesium Sulphate)	<b>@ 20*c</b>	<b>@ 40*c</b>
max. solubility p/L H <sub>2</sub> O	351g/L	447g/L
molar weight (to make 1M)	120.36g/L	120.36g/L
Max. concentration p/L H <sub>2</sub> O	2.91mol	3.71mol

<b>Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub></b> (Aluminium Sulphate)	<b>@ 20*c</b>	<b>@ 40*c</b>
max. solubility p/L H <sub>2</sub> O	364g/L	458g/L
molar weight (to make 1M)	342g/L	342g/L
Max. concentration p/L H <sub>2</sub> O	1.06mol	1.34mol

<b>KAl(SO<sub>4</sub>)<sub>2</sub></b> (Potassium Alum)	<b>@ 20*c</b>	<b>@ 50*c</b>
max. solubility p/L H <sub>2</sub> O	140g/L	368g/L
molar weight (to make 1M)	258.19g/L	258.19g/L
Max. concentration p/L H <sub>2</sub> O	0.54M	1.42M

<b>ZnSO<sub>4</sub></b> (Zinc Sulphate)	<b>@ 20*c</b>	<b>@ 40*c</b>
max. solubility p/L H <sub>2</sub> O	538g/L	705g/L
molar weight (to make 1M)	161.45g/L	161.45g/L
Max. concentration p/L H <sub>2</sub> O	3.33M	4.36M

-----THE ROLE THAT HYDROGEN IS PLAYING-----

The following chart is looking at the estimated values for the **“total available hydrogen”** for some of the listed alternative electrolyte compounds, to help give us an idea of the “Reduction potential” of the liquid electrolyte on the Positrode (during Discharge).

Since H<sup>+</sup> is required to reduce the Positrode during normal Discharge, yielding H<sub>2</sub>O<sub>(aq)</sub> in the process, then I reason that the greater availability of H<sup>+</sup> overall (per/Litre) should relate to a greater discharge capacity of the Positrode.

Compound Name	Bisulphate Compound Formula	Per/molecule H <sup>+</sup> count	Max. Molar concentration p/L based on solubility @ 20*c	Available H <sup>+</sup> per L/electrolyte
Sulphuric Acid	H <sub>2</sub> SO <sub>4</sub> (for reference)	2	4M (reference of most used conc.)	8g/L
Sulphuric Acid	H <sub>2</sub> SO <sub>4</sub> (for reference)	2	5M (example of higher conc.)	10g/L
Aluminium Bisulphate	Al <sub>2</sub> (HSO <sub>4</sub> ) <sub>3</sub>	3	1.45M	* 4.37g/L
Sodium Bisulphate	NaHSO <sub>4</sub>	1	2.06M	2.06g/L
Potassium Bisulphate	KHSO <sub>4</sub>	1	3.56M	3.56g/L
<b>Magnesium Bisulphate</b>	<b>Mg(HSO<sub>4</sub>)<sub>2</sub></b>	<b>2</b>	<b>2.04M</b>	<b>* 4.09g/L</b>
Potassium Aluminium Bisulphate	KAl(HSO <sub>4</sub> ) <sub>4</sub>	4	0.52M	* 2.11g/L

**Note: Hydrogen has a molecular weight of 1 gram (rounded down from 1.008g)**

-----**WRAP UP SUMMARY OF THE PDF AND RECOMMENDATIONS**-----

Lastly on this topic, I am making specific assumptions that, for the majority of the Amp capacity of the battery, it is the availability of the dissolved Hydrogen in the solution that is the limit for the amp-hour capacity of the cell, not just the Oxygen attached to the Positrode, nor specifically just the plate surface area overall, as well as the crystal type/morphology of the  $\text{PbO}_2(s)$  of the Positrode. (Although it is true that the plate surface area will determine the amount of Oxygen available at the Positrode, **and the amount of  $\text{H}^+$  generated under charging at the Negatrode**).

I need to confirm this with more testing, but I am fast coming to this conclusion.

So, to wrap this PDF all together, if we take the 4M sulphuric acid concentration as an example, and we have calculated that we could have up to 8g/L in electrolyte of available Hydrogen, then we could theoretically reduce up to 4g/L of oxygen from the Positrode (given that the water molecule is  $2\text{xH}^+$  and  $1\text{xO}^{2-} = \text{H}_2\text{O}$ ).

Given my idea (**it may be wrong, but I am interested in the  $\text{H}^+$ /amp-hour relationship and am open to being more enlightened on the subject**), let's say that in our 12v 100Ah battery, that 100Ah capacity is a representation of the 8g/L  $\text{H}^+$  from the 4M sulphuric acid, so theoretically, every 1g  $\text{H}^+$  could be used to represent every 12.5Ah of capacity.

Given that, in most Sulphuric Acid based Flooded Lead Acid Batteries, we want to only consume a total of 30% to 50% maximum capacity, before recharging, to keep to our max. DOD for long(ish) life cycles. Then we can consider this instead to be a **total amount of "useable"  $\text{H}^+$  of 3.75g/L to 6.25g/L**. Effectively making the total usable Amp-Hour capacity of our Lead-Acid battery to be **12v 30Ah or 12v 50Ah respectively**.

**Sulphuric Acid = 3.75g/L of "useable"  $\text{H}^+$                       (12v @ 30.0Ah) = 30% DOD**  
**Sulphuric Acid = 6.25g/L of "useable"  $\text{H}^+$                       (12v @ 50.0Ah) = 50% DOD**

**Please take nothing that I discover as fact, experiment with it for yourself.**

I have provided the basis to doing all of your own experimenting of this process, and no doubt others will be able to test other compounds that I have not even thought of yet. Let's share this information together, rather than arguing about expected outcomes based on information that we receive from battery companies.

The best thing to do is to experiment. If you can get your hands on any second hand lead-acid wet cell batteries that have probably only worn out due to sulphation, not mechanical stress, and ideally not shorted out cells due to dendrils and shedding, then this could be a brilliant way to rejuvenate deep-cycle batteries, making them work better than designed in the first place, and power your solar / wind / off-grid system for almost no cost.

Alternatively, if you were to purchase a brand new lead-acid wet-cell battery, you could immediately dump out the sulphuric acid into a tub and neutralise it using Sodium Bicarb or Sodium Hydroxide (so that it can then be safely poured down the sewer/drain), and then fill your new battery with one of these pre-made compounds.

I'd hedge my bets that it would extend the life span of an average car starter battery from 3 years to over 7 years, and for deep-cycle spiral wound batteries, maybe it would take their life span up to over 20-30years, up from the nominal 10-14yrs if only 30% DOD is drawn.

I drive around quite happily with my 2.5L diesel van, and both starter batteries have been emptied and filled with my Sodium Sulphate solution and the engine starts happily every time. When the temperature changes from Summer to Winter, the cranking power drops substantially, but the engine still turns round. (I assume this is due to the solubility of the compound reducing in the colder temperature, and precipitating out of solution?).

Voltage drop is much less than it was with sulphuric acid under the starter motor pull. The batteries themselves probably have less Amp-hours available now, given that Sodium Bisulphate generates less Hydrogen per mol and provide a higher pH than Sulphuric Acid, but still, for testing, when I replace the fuel filter on the van, and put in a new one, I need to crank the engine for up to 40seconds to pump the diesel through the filter and get the engine going again, and routinely, the starter batteries drop from about 11.7v to around 9v and stay there the whole time, not dropping further under the load like sulphuric acid batts do.

Best of luck! In your own battery research and experimenting. ^\_^

**For the assistance of all the humans of Earth and the sustainable development of human societies.**

Lots of Love,  
© Sylph Dominic Hawkins

\*1<sup>st</sup> Version was originally published November 2015\*

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