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The Chemistry Associated with an Exploding Lead-Acid Battery

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Abstract: On April 25, 1997, the Plaintiff was testing an automotive battery with a battery tester when it exploded. He was following his usual practice of ensuring that the battery in a vehicle for sale at his retail store would be sufficiently charged to start the engine. The contact of the inputs from his battery tester to the posts on this battery created a spark that resulted in an explosion. The explosion described by the Plaintiff is indicative of hydrogen gas (H_2) being ignited by available oxygen (O_2) and an ignition source or spark. The force of this explosion was loud enough to cause the Plaintiff's permanent hearing loss.

Key Words: Lead/Acid battery, Hydrogen explosion.

INTRODUCTION

On April 15, 1997, the Plaintiff (of Evans City, PA) went to retrieve an automotive battery (type 24F-50, distributed by MM Battery, Inc.). He placed it on the floor and tested it with a battery tester. As the owner of a retail establishment selling motorized equipment, the Plaintiff generally checked the charge on a battery prior to putting the battery into service. He wanted to ensure that when a customer turned the ignition key, the engine on the purchased vehicle started.

The battery blew up (exploded).

The battery explosion described by the Plaintiff is indicative of hydrogen gas (H_2) being ignited by available oxygen (O_2) [present in ambient air and/or produced with hydrogen by the electrolysis of water (H_2O) in the battery] and an ignition source or spark. The contact of the battery tester inputs to the actual battery's posts could produce a spark causing hydrogen to explode.

Fundamental Explosion/Flammability Science

Hydrogen is extremely flammable. Two key terms are the lower explosive limit (LEL) and the upper explosive limit (UEL). For hydrogen, the LEL is 4.1% by volume and the UEL is 74.2% by volume. [1] When hydrogen is in this large 70.1% by volume flammability envelope, in the presence of oxygen and an ignition source or spark, it can explode. This scenario is identified in a Material Safety Data Sheet (MSDS) issued by Johnson Controls, the parent company of Interstate Battery. (Table 1)

Table 1. Flammability Properties for Lead/Acid Battery (Wetcell)

Flashpoint (for H_2)	N/A as this is a gas (Test Method: N/A)
Autoignition Temperature (for H_2)	580°C
Flamable Limits (for H_2)	LEL - 4.1 UEL - 74.2
Extinguishing Media	Dry chemical, foam, or CO_2
Special Fire Fighting Procedures	Use positive pressure, self-contained breathing apparatus.
Unusual Fire and Explosion Hazard	Hydrogen and oxygen gases are produced in the cells during normal battery operations, hydrogen is flammable and oxygen supports combustion. These gases enter the air through the vent caps. To avoid the chance of a fire or explosion, keep sparks and other sources of ignition away from the battery.

Important Chemical Reactions

The chemical reactions for the lead (Pb) storage battery occur via electron transfer. Important definitions are: an oxidized element has lost electrons and a reduced element has gained electrons.

The oxidation reaction for a Pb storage battery is given in equation (1):

$Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2e^-$ (1)

The reduction reaction for a Pb storage battery is given in equation (2):

$PbO_2(s) + SO_4^{2-}(aq) + 4\,H^+(aq) + 2e^- \rightarrow$
$PbSO_4(s) + 2\,H_2O(l)$ (2)

When these chemical reactions are summed, equation (3) results:

$Pb(s) + PbO_2(s) + 2\,SO_4^{2-}(aq) + 4\,H^+(aq) \rightarrow$
$2\,PbSO_4(s) + 2\,H_2O(l)$ (3)

The electrochemical potential or voltage from equation (1) is 0.356 Volts, the electrochemical potential or voltage from equation (2) is 1.685 Volts, and the sum in equation (3) is 2.041 Volts. A battery containing six cells as described can produce 6 x 2.041 Volts or 12.246 Volts. Equation (3) is the discharge reaction in a 12 Volt lead storage battery. [2]

Where: Pb = lead (0) or elemental lead, (s) = solid, SO_4^{2-} = sulfate ion, (aq) = aqueous or water-based solution, $PbSO_4$ = lead (II) sulfate, e^- = electrons transferred, PbO_2 = lead (IV) oxide, H^+ = hydrogen ion, and (l) = liquid. The chemical reaction in equation (3) as written is favorable since it produces a positive electrode potential or number of Volts. Equation (3) is an example of a galvanic cell chemical reaction.

This also means that, eventually, all of the lead and lead oxide initially present in the battery plates are converted to lead sulfate. At this point, the battery is completely discharged. What makes the lead storage battery unique is that the application of an external electrical source, such as an alternator or generator, reverses the direction in equation (3). The reverse reaction is what happens when a car is running. This is called an electrolytic cell chemical reaction and is shown in equation (4).

$2\,PbSO_4(s) + 2\,H_2O(l) \rightarrow$
$Pb(s) + PbO_2(s) + 2\,SO_4^{2-}(aq) + 4\,H^+(aq)$ (4)

Importance of Sulfuric Acid (H_2SO_4) Electrolyte

Sulfuric acid is a very strong acid. This means that it breaks down efficiently to hydrogen ions and sulfate ions as shown in equation (5).

$H_2SO_4(aq) \rightarrow 2\,H^+(aq) + SO_4^{2-}(aq)$ (5)

The breakdown of sulfuric acid to its component ions also renders sulfuric acid a strong electrolyte. In the absence of an external source (e.g., alternator or generator), the chemical reaction summarized in equation (3) takes place. The hydrogen ion from the acid reacts with the oxygen from the lead oxide to form water and the sulfate ion from the acid reacts with both lead and lead oxide to form lead sulfate.

It is very important that the battery does not fully discharge. A fully discharged battery has all of its sulfate present in the lead sulfate. Sulfuric acid must be present for the battery to work properly. This is often tested with a hydrometer or density gauge.

The hydrometer is a syringe with several floating balls. The objective is to draw sulfuric acid into the syringe and to observe how many balls float. The number of floating balls is indicative of the specific gravity of the sulfuric acid.

The specific gravity of water is defined as 1.0 (based on a density of 1.0 gram/milliliter) and the specific gravity of sulfuric acid is about 1.8 (based on a density of 1.8 grams/milliliter). The specific gravity of battery acid is typically in the 1.2 to 1.3 range, indicating that the percent sulfuric acid is about 33%. [1](Table 2)

Battery Charging Can Lead to an Explosion

A charged battery will have water available [on the left side in equation (4)]. The application of electricity from an external source (e.g., alternator or generator) can electrolyze or split water into its component gases hydrogen (H_2) and oxygen (O_2). This chemical reaction is shown in equation (6).

$2\,H_2O(l) \rightarrow 2\,H_2(g) + O_2(g)$ (6)
where: (g) = gas.

The cells in a battery are designed to vent gases such as hydrogen and oxygen. This system works well until more gas molecules are produced than can be safely vented.

The resulting pressure build-up can (unfortunately) be relieved by a relatively minor jolt, leading to a spark. In the presence of oxygen and a spark (source of ignition) between posts, the hydrogen can explode.

The force of the explosion is sufficient to blow the top off of the battery case. Pieces of the battery case are discharged like shrapnel. The rapid release of hydrogen produces a sound similar to a bomb explosion. [2,3].

Table 2. Physical and Chemical Properties for Lead/Acid Battery (Wetcell)

Physical State	Battery is solid case with solid and liquid internal components.
Appearance and Odor	
Battery Electrolyte (acid)	Clear to cloudy liquid with slight acidic odor.
Acid saturated lead oxide	Dark reddish-brown to gray solid with slight acidic odor.
pH	
Electrolyte	1.0
Boiling Point	
Lead	1755°C
Electrolyte	110-112°C
Melting Point	
Lead	327°C
Solubility in Water	
Electrolyte	100%
Coefficient Water/Oil	N/A
Specific Gravity	
Electrolyte	1.210-1.300
Vapor Pressure	
Electrolyte	11.7
Vapor Density	
Electrolyte	3.4
Percentile Volatile	Not determined
Evaporation Rate	Not determined

DISCUSSION

It is important to have as complete a history of a battery as possible. A discharged battery's plates will contain deposits of lead sulfate. The formation of lead sulfate is indicated in equation (3). While the application of an external electrical source reverses equation (3), the efficiency of equation (4) is reduced. The charging reaction produces fewer electrolytes (sulfate).

The process of lead sulfate plate depositing is called *sulfation*. [4] The problem with sulfation is that the longer the battery sits (without being in service), the more likely equation (3) will proceed; since it is favorable in the absence of an external source of electricity. The effort to recharge the battery can then lead to the explosive scenario previously described. The author of the carblog reference indicates that a consumer should never purchase a battery if it is more than 6 months old. It is unclear whether anyone knows how much time had elapsed from the time of battery manufacture to April 15, 1997, the date of this incident. Due to the ample available knowledge that battery explosions constitute a known hazard scenario, there should have been a manufacture date stamped on the battery, which would have enabled more accurate and precise record-keeping.

CONCLUDING THOUGHTS

To a high degree of scientific certainty, the explosion on April 15, 1997 resulted from the ignition of hydrogen gas in a battery of type 24F-50. The Plaintiff was following his usual practice of ensuring that the battery in a vehicle for sale at his retail store would be sufficiently charged to start the engine. The contact of the inputs from his battery tester to the posts on this battery created a spark that resulted in an explosion.

The force of this explosion was loud enough to cause the Plaintiff's permanent hearing loss, confirmed in a report by Douglas A. Chen, M.D. [5] The explosion seemingly blew the top off of the battery case; a liquid (most likely battery acid) was released onto the floor. A hole was observed in the battery case, presumably from the escaping hydrogen gas. It is helpful to have photographs of the battery in question, but it would have been more helpful to actually have had the opportunity to inspect the battery in question. This is a chain of custody issue. By not adequately maintaining chain of custody, the defendant(s) is (are) unable to determine where the actual battery is located.

There is a record-keeping issue involving the age of the battery. The sulfate, initially present as sulfuric acid and converted upon discharge to lead sulfate, may not have been recharged to a sufficient concentration of electrolyte.

Battery acid is approximately two-thirds water and one-third sulfuric acid on a specific gravity basis. Maintaining the flow of electrons in a recharged battery can electrolyze water. The conditions required for a hydrogen explosion are well known and, to a high degree of scientific certainty, are met in this incident.

There are several possible defects that may contribute to a battery explosion. We are unable to confirm how these possible defects could have contributed to the explosion at *the Plaintiff's* location. Without the benefit of examining and testing the battery, we can never know if a possible defect could have contributed to the explosion. To a reasonable degree of scientific certainty, the explosion of the battery would not have occurred in the absence of a defect in the battery and/or negligence by the suppliers/manufacturers of the battery. [6]

The Plaintiff was, to a reasonable degree of certainty, counting on the battery to be fresh and not sulfated. He certainly could not have reasonably foreseen that the contact of the battery tester's inputs to the battery posts would have resulted in the hydrogen explosion.

The hydrogen concentration had increased to a level above the battery's pressure venting capacity. Available oxygen and an ignition source (spark) would suffice to create the bomb-like explosion noted by the Plaintiff.

One of the Defendants (owner and president of MM Battery, Inc.) in his Deposition [7] referred to this explosion as a "staged event." The explanations provided in this report indicate, to a high degree of scientific certainty, that a fully charged battery and the subsequent electrolysis of water will produce hydrogen quantities that fall within the 4.1% to 74.2% by volume flammability envelope.

The finding of a hydrogen explosion is a well-established scenario. The Defendant(s) should have identified a possible defect in the now-exploded battery via the age of the battery from the date of manufacture through the date of the explosion.

If there was any doubt about the age of the battery and the potential for an explosion upon charging, the battery should have been removed from the Plaintiff's inventory during "normal" pick-up and delivery "rounds" by one of the Defendant's personnel.

There wasn't any way for the Plaintiff to know that hydrogen was building up inside the battery. As a result, a preventable incident occurred and a man sustained permanent hearing loss. While the Defendant is not a scientist, he should have been aware of the explosion risk associated with hydrogen generation in lead storage batteries and he should have acted in accordance with that knowledge. He failed in his duty to notify the Plaintiff of the explosion risk and he also failed to mitigate this risk through timely removal of the battery from the Plaintiff's inventory. An event like this one did not need to be staged.

This case was settled favorably for the Plaintiff.

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REFERENCES

1. Interstate Battery MSDS for Wetcell. http://corporate.interstatebatteries.com/msds/msds_wetcell_US.pdf (10/19/2008)
2. Answers.com – Lead Acid Battery. http://www.answers.com/topic/lead-acid-battery-1 (10/20/2008)
3. Morr, Tom. Battery Bombs: Explosives under your hood. http://www.valvoline.com/car-care/automotive-system/electrical/dsm20020301bb (10/20/2008)
4. Strong, Allen. A Crash Course on Battery Sulfation. http://xanderrazheil.blogspot.com/2008/12/crash-course-on-battery-sulfation.html (10/20/2008)
5. Reports from Douglas A. Chen, M.D., dated January 19, 2005 and February 15, 2000, concerning injuries sustained by Mr. Lower
6. Wikipedia – Car Battery. http://en.wikipedia.org/wiki/Car_battery (10/19/2008)
7. Deposition transcript of Michael McKibben

