



# Journal of Applicable Chemistry

2013, 2 (1): 107-112

(International Peer Reviewed Journal)



## A total experimental study of electrolysis based on precise observation and analysis of products (color, solubility)

Parantap Nandi

Email: [nandiparantap@gmail.com](mailto:nandiparantap@gmail.com)

Received on 06<sup>th</sup> January and finalized on 18<sup>th</sup> January 2013

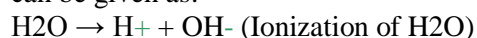
### ABSTRACT

*Electrolysis of salts is mainly used for electroplating and electro refining. For this acidic solutions are used (chiefly dilute H<sub>2</sub>SO<sub>4</sub>). Alkaline solutions are hardly used because metal hydroxides are formed which are mostly insoluble. But precise experiment shows that alkaline solutions can significantly help in metal deposition at cathode as seen case of SnCl<sub>2</sub>.2H<sub>2</sub>O and (CH<sub>3</sub>COO)<sub>2</sub>Pb.3H<sub>2</sub>O and help in the formation of salts like (CH<sub>3</sub>COO)<sub>2</sub>Cu which can not be synthesized generally. Organic compounds like alcohols can form salts by this process salts containing RO- (R being an alkyl group primary or secondary). If acidic alcohols are electrolyzed, aldehydes and carboxylic acids are formed. So the difference can be easily noticed. Highly covalent aromatic compounds like benzene, toluene e.t.c. can accelerate some reactions, retard some and some times change the products. In this Paper it has been discussed about the electrolysis of Ca(NO<sub>3</sub>)<sub>2</sub>.4H<sub>2</sub>O, SnCl<sub>2</sub>.2H<sub>2</sub>O, (CH<sub>3</sub>COO)<sub>2</sub>Pb.3H<sub>2</sub>O in alkaline medium and how organic compounds like benzene can affect the products.*

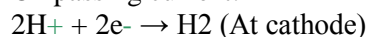
**Keywords:** Ca(NO<sub>3</sub>)<sub>2</sub>.4H<sub>2</sub>O; SnCl<sub>2</sub>.2H<sub>2</sub>O; (CH<sub>3</sub>COO)<sub>2</sub>Pb.3H<sub>2</sub>O; C<sub>6</sub>H<sub>6</sub>; 2 Butanol; NaOH.

### INTRODUCTION

The primary idea of electrolysis comes from the electrolysis of acidulated water with dilute H<sub>2</sub>SO<sub>4</sub> and inert electrodes like Platinum, graphite (carbon) which gives O<sub>2</sub> at anode and H<sub>2</sub> at cathode. The reaction can be given as:-



On passing current:-



Bubbles are formed at both electrodes due to the liberation of gases. But as  $d[\text{H}_2]/dt = 2d[\text{O}_2]/dt$ , bubbles of O<sub>2</sub> are formed at a slower rate. Principle applications of electrolysis include electro refining and electroplating in which cathode and anode are both metals. For instance for electroplating of copper, CuSO<sub>4</sub> solution is taken as electrolyte. Sometimes dilute H<sub>2</sub>SO<sub>4</sub> is added to increase conductivity. When salt solutions having cations of high reduction potential like Ca<sup>2+</sup> are electrolyzed using inert electrodes like graphite, H<sub>2</sub> is liberated at cathode (because the other cation has more negative reduction potential than H<sub>2</sub> which is 0V). At anode O<sub>2</sub> is released but it corrodes graphite into tiny particles. The cathode reaction remains same in all cases. But if metallic electrodes are used, two cases arise:

If anode is inert like platinum, O<sub>2</sub> is released. But anode does not corrode. Only a thin coating of oxide develops.

If anode is reactive like copper, O<sub>2</sub> is not obtained. Cu ionizes into Cu<sup>2+</sup> and combines with OH<sup>-</sup> to form pale blue Cu(OH)<sub>2</sub>. Consequently no bubble is observed.

So if pure salt solution is used, anode ionizes if it is not inert in to hydroxides and H<sub>2</sub> is liberated at cathode. Even if a salt containing a cation having low negative reduction potential like Sn, Pb is used the respective metals can not be deposited at cathode. H<sub>2</sub> is formed which causes formation of bubbles at cathode. If Sn has to be deposited, SnCl<sub>2</sub> solution must be acidified using a suitable acid like HCl.

Experiment reveals that alkalis like NaOH, Ba(OH)<sub>2</sub>.8H<sub>2</sub>O can change the cathode reaction resulting in more than one product at cathode (like H<sub>2</sub> and Sn as will be discussed in this paper).

## MATERIALS AND METHODS

**Symbols used:** Black colored plus (+) indicates addition while sea green (+) ones represent charges on the respective ions.

**\*\*\* In this paper the research has been done with anode and cathode made of Cu (copper).**

### Salts studied:

Ca(NO<sub>3</sub>)<sub>2</sub>.4H<sub>2</sub>O, SnCl<sub>2</sub>.2H<sub>2</sub>O and (CH<sub>3</sub>COO)<sub>2</sub>Pb.3H<sub>2</sub>O, Ba(NO<sub>3</sub>)<sub>2</sub>.

### Standard reduction potentials of various ions studied:

Pb<sup>2+</sup> + 2e<sup>-</sup> → Pb (-0.13V)

Sn<sup>2+</sup> → Sn (-0.14V)

2H<sup>+</sup> + 2e<sup>-</sup> → H<sub>2</sub> (0.00V)

Cu<sup>2+</sup> + 2e<sup>-</sup> → Cu (0.34V)

SnCl<sub>2</sub>.2H<sub>2</sub>O

1. A mixture of the salt and 4-5 pellets of NaOH were diluted with H<sub>2</sub>O.
2. It was electrolyzed using Cu electrodes.
3. Slowly black mass was formed at cathode
4. Cu gradually corrodes.
5. Ba(OH)<sub>2</sub>.8H<sub>2</sub>O if used instead of NaOH, it only slows down the reaction and substantial black mass at cathode is not formed.

Ca(NO<sub>3</sub>)<sub>2</sub>.4H<sub>2</sub>O

1. A mixture of Ca(NO<sub>3</sub>)<sub>2</sub>.4H<sub>2</sub>O and NaOH was diluted with H<sub>2</sub>O and boiled.
2. The boiling solution was diluted to about 100m.l. and electrolyzed.
3. Bright blue mass forms at anode and H<sub>2</sub> is liberated at cathode.
4. After some time bubbles start forming at anode while formation of the bright blue mass almost stops.

(CH<sub>3</sub>COO)<sub>2</sub>Pb.3H<sub>2</sub>O (4 separate experiments were performed with this salt)

### Experiment a:

1. A solution of lead acetate and NaOH was electrolyzed.
2. Black mass is deposited at cathode which reduces the conductivity of Cu.
3. Slowly a clear blue solution forms.
4. Anode corrodes and no bubbles are observed.

### Experiment b:

1. Ba(OH)<sub>2</sub>.8H<sub>2</sub>O was used instead of NaOH in experiment (a).
2. No blue solution was formed.
3. Pale blue Cu(OH)<sub>2</sub> was formed which is insoluble .
4. No Black mass was obtained at cathode. Formation of bubbles indicated the production of H<sub>2</sub> at a slow rate.

### Experiment c:

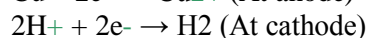
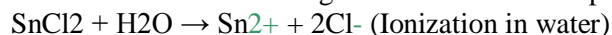
1. About 20 m.l. alkaline solution of (CH<sub>3</sub>COO)<sub>2</sub>Pb.3H<sub>2</sub>O (alkali used was NaOH) was boiled with 2 butanol for 5 minutes.
2. The hot solution was diluted to about 100 m.l. and electrolyzed.
3. Bright green mass forms at anode which slowly dissolves to form a green solution.

- This color strictly varies from the one obtained in experiment (a).

**Experiment d:**

- $(\text{CH}_3\text{COO})_2\text{Pb} \cdot 3\text{H}_2\text{O}$  and  $\text{C}_6\text{H}_6$  were boiled.
  - Two layers of liquids are formed.
  - The hot liquid is poured in a beaker.
  - In the same test tube an equal volume (10m.l.) of  $\text{NaOH}$  is added and boiled.
  - A brick red mass is formed
  - It is poured in the beaker, diluted to about 60m.l. and electrolyzed.
  - Very quick deposition of black mass at cathode occurs.
  - Anode corrodes very slowly and need not be replaced for a long time. Bubbles are formed at anode.
- A.  $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$
- The salt in its pure state is heated till it melts and starts to boil.
  - To the boiling mass  $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$  is added and heated.
  - The mixture swells and foams and turns yellow.
  - Little  $\text{NaOH}$  is added and allowed to react.
  - After 5 minutes the mass is diluted to 100m.l. and electrolyzed.
  - Light green mass forms at anode.
  - It is allowed to stand for about 12 hours. The entire green mass changes to brick red.
  - Bubbles are formed at cathode.
- B.  $\text{Ba}(\text{NO}_3)_2$
- Alkaline solution of the salt was electrolyzed.
  - The solution shows very poor conductivity.
  - A little blue mass at anode is formed.  $\text{H}_2$  bubbles at cathode.
- C.  $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$
- Calcium nitrate is heated till it melts and starts boiling.
  - $\text{C}_6\text{H}_6$  of an equal volume as the molten salt was mixed with it and boiled.
  - The boiling mass was diluted and with  $\text{H}_2\text{O}$  electrolyzed.
  - The reaction was slower than the electrolysis of pure calcium nitrate solution.
  - Though bubbles were seen forming at cathode, the anode reaction could hardly be detected. This is very different from pure calcium nitrate solution where a pale blue mass of  $\text{Cu}(\text{OH})_2$  can be detected within about 10 minutes of switching ON the current.

**Contrast noticed when pure salts are used:**  $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$  in its neutral solution state gives  $\text{H}_2$  at cathode and the anode corrodes to give insoluble mass of pale blue  $\text{Cu}(\text{OH})_2$ . Also the reaction is very slow.



Every other salt mentioned in this paper shows the same reaction. The only difference lies in their conductivities i.e. calcium nitrate has very high conductivity while lead acetate and stannous chloride show very poor conductivity.

**RESULTS AND DISCUSSION****Experiment A**

$\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$  is fairly soluble in water at S.T.P. Its ionization occurs as:

$\text{SnCl}_2 + \text{H}_2\text{O} \rightarrow \text{Sn}^{2+} + 2\text{Cl}^-$ . As aqueous solution is used,  $\text{H}^+$  is also present.  $\text{Sn}^{2+}$  has more negative reduction potential than  $\text{H}^+$ . So cathode reaction is self explanatory, i.e.  $\text{H}^+$  is reduced in preference to  $\text{Sn}^{2+}$ .

$\text{Cu}$  has lower oxidation potential than  $\text{OH}^-$ . So  $\text{Cu}^{2+}$  and combines with  $\text{OH}^-$  to give pale blue  $\text{Cu}(\text{OH})_2$ . When  $\text{NaOH}$  is added  $\text{Na}^+$  and  $\text{OH}^-$  increase the conductivity.  $\text{Cl}^-$  and  $\text{OH}^-$  migrate to anode. But they have higher oxidation potential than  $\text{Cu}$ . So anode reaction does not change. But at cathode the reaction gets altered. The ionization of  $\text{SnCl}_2$  increases in presence of  $\text{NaOH}$  as the salt gets hydrolyzed to form

$\text{Sn(OH)}_2$ . In the solution  $\text{Sn}^{2+}$  gets oxidized to  $\text{Sn}^{4+}$  which has a positive reduction potential of 0.15V. So it is easily reduced to  $\text{Sn}^{2+}$  at first and finally to Sn.

### Experiment B

Both  $\text{Ca(NO}_3)_2 \cdot 4\text{H}_2\text{O}$  and NaOH are strong electrolytes. When boiled with water  $\text{NaNO}_3$  and  $\text{Ca(OH)}_2$  are formed which are also strong. In case of a pure NaOH solution concentration of  $\text{OH}^-$  is very high. So Cu can not be oxidized.  $\text{OH}^-$  is oxidized in preference to Cu owing to its high concentration.

For Pure  $\text{Ca(NO}_3)_2 \cdot 4\text{H}_2\text{O}$  concentration of  $\text{OH}^-$  is not increased.  $\text{NO}_3^-$  has high oxidation potential and so Cu ionizes to  $\text{Cu}^{2+}$ .

When a mixture of both is used, the solution contains  $\text{H}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Na}^+$ . The reduction potential of  $\text{Na}^+$  and  $\text{Ca}^{2+}$  is very high as compared to  $\text{H}^+$ . So  $\text{H}_2$  is liberated at cathode and bubbles are observed.

At anode initially Cu ionizes to form bright blue  $\text{Cu(OH)}_2$ . Though the said hydroxide is slightly soluble, it increases the concentration of  $\text{OH}^-$  such that  $\text{OH}^-$  is oxidized at anode and  $\text{O}_2$  is formed.  $4\text{OH}^- - 4e^- \rightarrow 2\text{H}_2\text{O} + \text{O}_2$ . Now bubbles are seen forming at anode.

### Experiment C

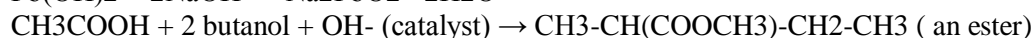
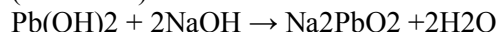
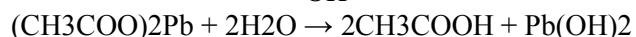
**Exp a :**  $(\text{CH}_3\text{COO})_2\text{Pb} \cdot 3\text{H}_2\text{O}$  in an alkaline medium (NaOH solution) gets hydrolyzed to form  $\text{CH}_3\text{COOH}$  (a weak organic acid) and  $\text{Pb(OH)}_2$ .

The valency of Pb is  $2+$  and that of Cu is also  $2+$ . At anode Cu usually forms  $\text{Cu(OH)}_2$ .  $\text{Cu(OH)}_2$  is a base. So it reacts with  $\text{CH}_3\text{COOH}$  to form Blue solution of  $(\text{CH}_3\text{COO})_2\text{Cu}$ . At cathode  $\text{Pb}^{2+}$  is deposited as a black mass. The solution contains  $\text{Cu}^{2+}$  coming from  $(\text{CH}_3\text{COO})_2\text{Cu}$  and  $\text{Pb}^{2+}$  ( $\text{Pb(OH)}_2$  is amphoteric, so it reacts with NaOH to form  $\text{Na}_2\text{PbO}_2$ ). But concentration of  $\text{Cu}^{2+}$  is negligible as compared to  $\text{Pb}^{2+}$ . So  $\text{Pb}^{2+}$  gets reduced in preference to  $\text{Cu}^{2+}$ .

If neutral lead acetate is use, hydrolysis is not possible. So at anode  $\text{Cu(OH)}_2$  is obtained and  $\text{H}_2$  is liberated at cathode. The  $\text{H}^+$  (for  $\text{H}_2$ ) and the  $\text{OH}^-$  for  $\text{Cu(OH)}_2$  comes from  $\text{H}_2\text{O}$ . The charges are balanced which need not be explained.

**Exp b :**  $\text{Ba(OH)}_2 \cdot 8\text{H}_2\text{O}$  is a weak alkali as compared to NaOH. So hydrolysis of  $(\text{CH}_3\text{COO})_2\text{Pb} \cdot 3\text{H}_2\text{O}$  can not take place. Consequently  $\text{Pb}^{2+}$  can not be deposited and blue solution of  $(\text{CH}_3\text{COO})_2\text{Cu}$  is not formed. (In reality it is formed but to such a nominal amount that it can be ignored).

**Exp c :-**  $(\text{CH}_3\text{COO})_2\text{Pb} \cdot 3\text{H}_2\text{O} + \text{NaOH} + \text{CH}_3\text{-CH.OH-CH}_2\text{-CH}_3$  makes the solution both alkaline as well as alcoholic. The following reactions are expected:-



Also on boiling with strong alkali like NaOH 2butanol gets partly ionized to form 2butoxide ion i.e.  $\text{H}^+$  gets separated from OH to give negative charge on O ( it is not possible to draw a very neat structure in MS Word). So  $\text{Cu}^{2+}$  combines with the said ion to form  $(\text{CH}_3\text{.CHO.CH}_2\text{.CH}_3)_2\text{Cu}$ . CHO is not aldehydic group. Here oxygen and carbon are linked by single bond and Oxygen bears a negative charge. This Oxygen links with Cu. An equilibrium is established between the alcohol and the Cu salt.

**Exp d :-**  $(\text{CH}_3\text{COO})_2\text{Pb}$  on heating with  $\text{C}_6\text{H}_6$  melts and gets denatured. Now when a little amount of concentrated NaOH is added and the mixture is boiled, as usual hydrolysis occurs to give  $\text{CH}_3\text{COOH}$  and  $\text{Pb(OH)}_2$ . Now due to the presence of  $\text{C}_6\text{H}_6$  which acts as catalyst  $\text{Pb}^{2+}$  gets farther oxidized to  $\text{Pb}^{4+}$  to give brick red  $\text{PbO}_2$ .  $\text{Pb}^{4+}$  has a strong tendency to get reduced (much greater than  $\text{H}^+$ ,  $\text{Na}^+$  which are also present in the solution. So it migrates to cathode readily and gets reduced to  $\text{Pb}^{2+}$ . As the concentration of  $\text{Pb}^{2+}$  becomes high around the cathode, it is reduced to neutral Pb.

$\text{C}_6\text{H}_6$  being a dielectric increases the concentration of  $\text{OH}^-$  at the anode which consequently gets oxidized to  $\text{O}_2$ . This  $\text{O}_2$  tends to convert  $\text{C}_6\text{H}_6$  into  $\text{C}_6\text{H}_5\text{OH}$ . Thus anode corrodes at a very slow rate. Hence it is seen that suitable treatment of alkaline lead acetate with highly covalent compound like  $\text{C}_6\text{H}_6$  not only

speeds up the cathode reaction but alters the anode reaction too. But if compounds containing oxygen is present, it ionizes and therefore can not act as dielectric. So this reaction does not occur for alcohols.

### Experiment D

Both  $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$  and  $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$  contain water of crystallization. When heated  $\text{H}_2\text{O}$  becomes free.  $\text{SnCl}_2$  produces  $\text{HCl}$  which reacts with  $\text{NO}_3^-$  from  $\text{Ca}(\text{NO}_3)_2$  to liberate  $\text{NO}_2$  (yellow). The reaction is similar to synthesis of  $\text{HNO}_3$  by laboratory method using  $\text{H}_2\text{SO}_4$  and  $\text{KNO}_3$ . Here some of the  $\text{HNO}_3$  decomposes to give  $\text{NO}_2$  which remains soluble imparting yellow color.

On addition of  $\text{NaOH}$  the solution starts to neutralize. Thus the yellow color disappears. When it is diluted the solution contains  $\text{Na}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{H}^+$  and  $\text{Sn}^{2+}$ . Here  $\text{H}_2$  is liberated at cathode just as electrolysis of neutral salt solution. Now in case of alkaline  $\text{SnCl}_2$  solution (without  $\text{Ca}^{2+}$  and  $\text{NO}_3^-$ )  $\text{Sn}$  was deposited as was seen in Experiment A. So the presence of these two ions stops the reduction of  $\text{Sn}^{2+}$  at the cathode.

Anode corrodes into  $\text{Cu}(\text{OH})_2$  for sometime. After that  $\text{OH}^-$  due to excessive concentration starts to get oxidized at anode liberating  $\text{O}_2$ . But corrosion of anode doesn't totally stop. Since  $\text{OH}^-$  is getting oxidized,  $\text{Cu}$  is no longer able to hold 2 hydroxide ions. So it decomposes to form unstable  $\text{CuOH}$  which changes to brick red  $\text{Cu}_2\text{O}$  and settles at the bottom. It is insoluble and after about 5 days gets oxidized to black  $\text{CuO}$ .

### Experiment E

Pure solution of  $\text{Ba}(\text{NO}_3)_2$  has very poor conductivity. On mixing  $\text{NaOH}$ ,  $\text{NaNO}_3$  and  $\text{Ba}(\text{OH})_2$  is formed to some extent. Hence conductivity increases slightly.  $\text{OH}^-$  can not be oxidized because  $\text{Ba}$  has great affinity for it.  $\text{Ba}(\text{OH})_2$  is more soluble than  $\text{Ca}(\text{OH})_2$ . All these factors do not let  $\text{OH}^-$  be oxidized at anode. So anode corrodes slowly to pale blue  $\text{Cu}(\text{OH})_2$  and  $\text{H}_2$  liberates at cathode. This  $\text{OH}^-$  and  $\text{H}_2$  come from water.

### Experiment F

$\text{Ca}(\text{NO}_3)_2$  is a very good oxidizing agent as it contains  $\text{NO}_3^-$  ion. Boiling it with benzene does not produce any considerable reaction. Conductivity of  $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$  is very high. But Presence of viscous  $\text{C}_6\text{H}_6$  slows down the movement of ions. It does not allow  $\text{Cu}(\text{OH})_2$  settle down and so products are not noticeable for a substantial amount of time.

Reduction potential of  $\text{Cu}^{2+}$  is .34V and that of  $\text{H}^+$  is 0.00V. So it is evident that  $\text{Cu}$  can not displace  $\text{H}_2$  from acids. When neutral solutions of salts of alkali metals, alkaline earth, or transition metals like  $\text{Zn}$  are electrolyzed using  $\text{Cu}$  electrodes, in each and every case anode corrodes into pale blue insoluble  $\text{Cu}(\text{OH})_2$  and  $\text{H}_2$  is produced at cathode. The salts used as electrolyte i.e.  $\text{Ca}(\text{NO}_3)_2$ ,  $\text{Ba}(\text{NO}_3)_2$ ,  $\text{SnCl}_2$ ,  $(\text{CH}_3\text{COO})_2\text{Pb}$  remain unchanged in mass and composition. If acidic solutions containing  $\text{HCl}$ ,  $\text{H}_2\text{SO}_4$  are used  $\text{Cu}(\text{OH})_2$  gets dissolved to give  $\text{CuCl}_2$  or  $\text{CuSO}_4$ .

But electrolysis of alkaline solutions using strong alkalis like  $\text{NaOH}$  can affect the products to a great extent. The principle effects include:-

Deposition of metal at cathode as in case of alkaline  $\text{SnCl}_2$  and  $(\text{CH}_3\text{COO})_2\text{Pb}$  which does not occur if neutral solutions are used.

Synthesis of compounds like  $(\text{CH}_3\text{COO})_2\text{Cu}$  and  $(\text{CH}_3.\text{CHO}.\text{CH}_2.\text{CH}_3)_2\text{Cu}$  which can not be obtained normally.

Farther the reaction can be accelerated, retarded, and anode products can be altered by addition of covalent organic compounds like  $\text{C}_6\text{H}_6$  e.g. alkaline  $(\text{CH}_3\text{COO})_2\text{Pb}$  gives blue solution of  $(\text{CH}_3\text{COO})_2\text{Cu}$  but suitable treatment with benzene gives  $\text{O}_2$  at anode.

Though electrolysis of  $\text{CH}_3\text{COOH}$  and alcohols can be done, to obtain salts but the reaction is very slow. It results in the evaporation of alcohols because they are highly volatile.

### APPLICATION

The Paper has discussed about the electrolysis of  $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$ ,  $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$ ,  $(\text{CH}_3\text{COO})_2\text{Pb} \cdot 3\text{H}_2\text{O}$  in alkaline medium and is useful for knowing how organic compounds like benzene can affect the products.

### CONCLUSION

If electrolysis of salt solutions is carried out using metallic electrodes (like Cu as discussed in this paper) give metal hydroxides at anode which are mostly insoluble. On the other hand if inert non metal graphite is used,  $\text{O}_2$  is liberated at anode but it breaks the graphite anode into tiny carbon particles. Hence it has to be periodically replaced. If acidic salt solution along with Cu electrodes is used,  $\text{Cu}(\text{OH})_2$  dissolves to give salt of Cu. Electrolysis of alkaline solution of weakly electropositive metals like Pb, Sn, can cause deposition of the metal at cathode (explanation already given). Not only this, proper treatment with covalent compounds like  $\text{C}_6\text{H}_6$  can improvise the reaction to a great extent by altering speed and anode products. The color of precipitated mass is different for each neutral solution due to absorption of different wavelengths which is beyond the scope of this paper. The effect of alkalis on solutions is best noticed for metals having negative reduction potential close to zero e.g. Pb, Sn.