

Given all the results, it can be concluded that the applied method of work provided for substantial (statistically significant) progress in pupils' knowledge at all three cognitive levels. In addition to the text about vitamin C, well designed and problem-based experiments and resulting achievement was largely contributed to by the discussion about the role of vitamin C in physiological conditions and as a medication in some pathological states. The entire cognitive process and the theme in itself were highly motivational for pupils (they posed a great number of questions).

CONCLUSIONS

The described method of teaching of vitamin C properties required associating instrumental understanding (knowing how) with all three levels of chemical representation (macroscopic, submicroscopic, symbolic), and it makes relational understanding (knowing why) possible. Considering the results achieved at final testing we note that pupils' motivation for experimental work and scientific literacy improved. Also, it has been demonstrated that this type of lesson can be applied for systematizing the contents of teaching general, organic and inorganic chemistry in upper secondary school.

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Small flame tests intense enough for large audiences

Ensayos a la llama en pequeña escala suficientemente intensos para audiencias grandes

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Abstract

The combustion of wood in an oxygen rich atmosphere provides the energy for the emission of light by some elements in a way that is intense enough to resemble fireworks and easily seen by large audiences. The oxygen rich atmosphere is provided by $KClO_3$ decomposition. The reaction can be handled safely because combustible (wood) and oxidant ($KClO_3$) can be kept separate until the moment of the demonstration.

Key words: flame test, demonstration, general chemistry, introductory / high school chemistry, teaching / learning aids.

Resumen

Se presenta un experimento donde algunos elementos emiten luz gracias a la energía recibida por la combustión de madera en una atmósfera rica en oxígeno producido por la descomposición de clorato de potasio. La emisión de luz es lo suficientemente intensa para parecerse a los juegos pirotécnicos y ser vista por grupos grandes. La reacción es segura ya que combustible y comburente pueden mantenerse separados hasta el momento de la demostración.

Palabras clave: ensayos a la llama, experimentos demostrativos, química general, ayudas para la enseñanza.

INTRODUCTION

Flame tests for certain metals involve much of the chemistry involved in the spectacular fireworks frequently seen on special occasions and at celebrations around the world to the laboratory.

Flame colour and fireworks are due to certain metals emitting energy in the form of light, mainly alkalis and alkaline earths; this energy is taken from other strongly exothermic reactions. The characteristic colour of the light emitted by each metal gives the spectators a glimpse of some of the principles of spectroscopy (from the quantum theory of matter) as well as the atomic structure and the application of these principles to analytical chemistry like atomic absorption spectrometry.

Many demonstrations have been reported, (PEARSON, 1985; BOUCHER, 1986; PEYSER, 1988; GOUGE, 1988; AGER, 1988; MATTSON, 1990; BARNES, 1991; THOMAS, 1992; RAGASDALE, 1992; McRAE, 1994; SMITH, 1995; DALBY, 1996; McKELVY, 1998; BARE, 1998; DRAGOSLOVIC, 1999; JOHNSON, 2001; SANGER, 2004; SANGER, 2004), each having its own particular advantages and disadvantages. Combustion occurs in most demonstrations in a burner in which the fuel is usually propane gas and the oxidant oxygen from the air; the success of the experiment lies in managing to bring solid or dissolved metal salts to the reaction area in the flame in the most efficient way

possible to give it their characteristic color. Aqueous or methanol solutions are thus directly atomized with Li^+ , K^+ , Na^+ , Ca^{2+} , Sr^{2+} , Ba^{2+} and Cu^{2+} ions in the flame in the entry of air to the burner (GOUGE, 1988; MATTSO, 1990; DALBY, 1996; JOHNSON, 2001). The main inconvenience in these demonstrations is the short duration of the coloring and the waste of (sometimes costly) salts, meaning that solutions must be prepared which are not wholly used up; solution which does not reach the flame is also spilled around the burner. The situation becomes worse if solutions containing methanol or heavy metals must be atomized, due to these substances' toxicity paper strips, capillary tubes or cotton swabs have thus been proposed as alternatives for ensuring that the salts reach the flame (PEARSON, 1985; BOUCHER, 1986; BARNES, 1991; McRAE, 1994; SANGER, 2004; SANGER, 2004).

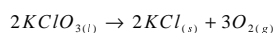
Another frequently used option has been the dissolution of metal salts in methanol to be used as combustible in a burner, or being directly burned in a watch glass, having the advantage that the flame lasts as long as the alcohol in being consumed; however, the color of the flame is extremely subdued (RAGASDALE, 1992; SMITH, 1995; DRAGOSLOVIC, 1999).

Flame color is very faint in all the cases mentioned above and the experiments are not bright or colorful compared to fireworks. Proposals have suggested using a solid combustible, thereby making the assays more spectacular by using nitrocellulose prepared from cotton or filter paper impregnated with metal salts (PEYSER, 1988; THOMAS, 1992) and the demonstration more impressive by using typical pyrotechnical mixtures using combustibles such as sulfur or carbohydrates and oxidants such as alkaline and alkaline earth metal nitrates, chlorates and perchlorates (AGER, 1988).

The latter proposal is interesting since the reaction's intensity makes the light clearly visible, even in outside places. However, this is accompanied by the inconvenience of requiring relatively large amounts (up to 20 grams) of mixtures in which combustibles and oxidants are already in contact, meaning that they are susceptible to react spontaneously and must therefore be handled as explosives and cannot be stored or neglected. All the mixtures produce smoke and gases and therefore require suitable ventilation, especially those containing sulfur as they produce sulfur dioxide which is toxic and an irritant.

This article thus proposes an alternative procedure in which the salt providing the flame colour is mixed with potassium chlorate as oxidants. The reaction is carried out in a test-tube, thereby minimizing risk and, at the same time, reducing expenses and wasted reagents. A wooden stick is used as combustible; it can be kept apart from the mixture for as long as needed and thus allows the reaction to be well controlled and materials for the demonstration to be safely kept and transported.

The present is an experiment adapted from the so-called "glowing splint" (FORD, 1993), whose procedure implies the decomposition of potassium chlorate according to the following reaction:



Potassium chlorate is mixed with small amounts of lithium, sodium, calcium, strontium or barium salts. The reaction providing the energy for

the demonstration is the combustion of the wood in an oxygen-rich atmosphere produced by the decomposition of potassium chlorate. This decomposition is safe and the combustion of the wooden stick produces steam, carbon oxides, soot and smoke giving off a smell of burned wood which can be completely handled by a gas-extraction system. The same reaction has been used with food as fuel for demonstrating its energy-giving content (SULLIVAN, 1992).

Small amounts of substances are used in this demonstration which are completely used up and not wasted. The reaction is carried out in 16 x 150 mm test-tubes, and produces an intense flame of about 10 cm long coming out of the test-tube and lasting for more than 15 seconds.

Flame intensity and duration time are sufficient for the lines of the characteristic colours making up the light of each element to be observed via simple plastic didactic spectrometers available in many laboratories, as proposed by Dalby (DALBY, 1996) or with a multi-channel spectrophotometer (BLITZ, 2006). With the conditions of this demonstration Potassium lines always will appear but they are easily masked to the eyes of spectators by the intensity of the emission of Sodium, Lithium, Calcium, Strontium and Barium.

Materials

An alcohol burner
16x150 mm test-tubes
150 mm long and diameter less than 6 mm wooden sticks as used for the skewers/ toothpicks.
Clamps
Leather gloves
Potassium chlorate
Sodium chlorate or chloride
Calcium chloride or nitrate
Barium chloride or nitrate
Lithium chloride or nitrate
Strontium chloride or nitrate
Safety goggles.

Demonstration

The demonstration is carried out by placing 1.7 g - 1.8 g potassium chlorate and 0.2 g to 0.4 g of the salt of interest in a 16 x 150 mm test-tube. The salts can be previously or directly mixed in the tube with a little shaking. In Table 1 quantities according to desired flame colour and lists the spectral characteristics of the colours produced by each metal are suggested. Chlorides and nitrates work very well, but some salts such as LiCl , SrCl_2 and CaCl_2 are hygroscopic and deliquescent; in such cases the precaution must be taken that, once mixed and put into the test-tubes, they must be kept sealed to avoid absorbing too much water.

Table 1
Mixture composition for Small Flame Test Intense Enough for large Audiences

| Metal | Flame color | Mixture composition | Color of the lines observed | Wavelength (nm) corresponding to each set of lines |
|-------|--------------|---|-----------------------------|--|
| Li | Red-fuchsia | KClO_3 1,7 g | Red | 670.8 very intense |
| Na | Yellow | LiCl 0,3 g NaClO_3 2 g, or, KClO_3 1,7 g + NaCl 0,3 g | Yellow | 589.2 very intense |
| K | Pink-white | KClO_3 2 g | Red | 690 and 750 |
| Ca | Orange- | KClO_3 1,8 g | 2-5 green lines | 550-570 |
| Sr | Pink | CaCl_2 0,1 g | Several orangish colors | 600-650 |
| | Red | KClO_3 1,8 g + SrCl_2 or $\text{Sr}(\text{NO}_3)_2$ 0,2 g | Blue | 460.7 |
| | | | Several yellow-oranges | 595-605 (605 very intense) |
| | | | Several reds | 645-680 |
| Ba | Green-yellow | KClO_3 1,8 g + $\text{Ba}(\text{NO}_3)_2$ or BaCl_2 0,4 g | Blue | 455 |
| | | | Multiple greens | 470-550 |
| | | | Multiple oranges | 600-630 |
| | | | Red | 700 |

The test-tubes are held with clamps and the base of the test-tube is gently heated, using circular movements, until the chlorate melts and starts to bubble. The wooden stick is inserted to the bottom of the test-tube at this point. Small sparks will be observed after a few seconds, followed by the start of the reaction consisting of a vivid and striking flame, very similar to that of a firework, and which will last until all the chlorate has been consumed.

Risks and waste disposal

Gloves and goggles must be worn. The experiment should be carried in a fume hood or outdoors. Potassium chlorate is not combustible but could become dangerous when mixed with reducing agents (YOUNG, 2002), therein lying the advantage and the need to keep the wooden stick apart until the demonstration is about to be begun. The mixture should only occupy 2 cm height in the test-tube to avoid losing chlorate. No loss of reaction mixture by splashing in 16 x 150 mm test-tubes has ever been observed when using the quantities recommended here. Test tubes should be made from a heat resistant glass. The smoke so produced has the typical smell of burned wood so that precautions must be taken to ensure its rapid evacuation and avoiding it being inhaled. The test-tubes will be covered in soot and KCl following the reaction; they can be removed with water and detergent. Barium residues should be handled properly like treating them with soluble sulfate salts to precipitate barium sulfate.

CONCLUSIONS

A safe and intense flame test is presented here; wood combustion in an oxygen rich atmosphere provides the energy for the emission of light by some elements in a way that is intense enough to resemble fireworks and easily seen by large audiences. The raw materials are easily found in a chemistry lab and can be transported and handled safely until the moment of demonstration.

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Interpretation of voltaic cells in chemistry education

Interpretación de las celdas voltaicas en la educación química

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Abstract

The article discusses the ways to improve the knowledge of students when facing this difficult chemistry topic from electrochemistry. Thus, the method for predicting the electromotive force of voltaic cells, and algorithm helping in describing galvanic cells has been proposed.

Key words: chemistry, voltaic cells, algorithm

Resumen

El artículo discute los métodos para mejorar el conocimiento de los alumnos cuando afrontan el difícil tema de la Electroquímica. Así, se propone el método para predecir la fuerza electromotriz de las pilas voltaicas y el algoritmo que ayuda a describir las pilas galvánicas

Palabras clave: química, pilas voltaicas, algoritmo

INTRODUCTION

Electrochemistry is one of the most difficult parts of chemistry among the students. Students at different levels have common misconceptions in electrochemistry. Spontaneous redox reactions taking place in

electrochemical cells are especially difficult for non chemistry students. Aiming to increase the assimilation of electrochemistry material, computer aided programs CROCODILE Chemistry (version 1.53) (Figure 1) and Ecorr (version 1.0) (Figure 2), were used during lectures. The internet can be used during lectures (to see the bibliography), but sometimes it is difficult to connect to it. During lectures students have asked often: "Are these values of potentials and the electromotive forces of voltaic galvanic cells real or virtual?"

METHODOLOGY

Students looked for the answer by performing literature search; Daniel cells were discussed in several articles (OZKAYA, 2003; GOODWIN, 2003; OZKAYA, 2004). SANGER and GREENBOWE (1999) proposed to "calculate cell potentials using difference method ($E_{\text{cell}}^{\circ} = E_{\text{cathode}}^{\circ} - E_{\text{anode}}^{\circ}$) instead of the additive method ($E_{\text{cell}}^{\circ} = E_{\text{ox}}^{\circ} - E_{\text{red}}^{\circ}$)".

We tried to adjust this formula for calculations on Voltaic cells. However, data for the electromotive force E , of voltaic cells calculated using formula $E = \varphi_{\text{cathode}}^{\circ} - \varphi_{\text{anode}}^{\circ}$ (the standard potentials of the metals) differ considerably from experimental data. In addition, using

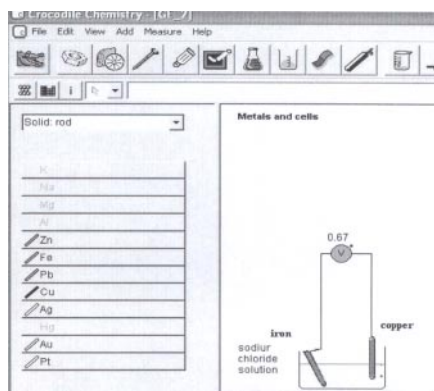


Fig. 1. Part of the Fe-Cu voltaic cell (Crocodile chemistry program)

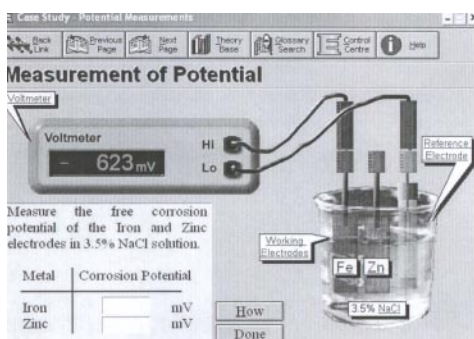


Fig.2. Part of the Fe-Cu voltaic cell (Engineering Corrosion program, version 1.0, Corrosion&Protection centre, UMIST, PO BOX 88, Manchester)

the standard potentials of metals, it is impossible to predict which electrode will be anode and which the cathode and calculate the electromotive force E of a voltaic cell (e.g., Sn/Fe in an alkaline solution and Zn/Al in neutral and acidic solution, where Sn is the anode in first cell and Zn in the second). The table of stationary potentials (Tomilov, 1960) in acidic, alkaline and neutral solutions (Table 1) has been used in the Department of General Chemistry, Kaunas University of Technology. This table enables more precise calculation of E of voltaic cells, even for cells like Sn/Fe in an alkaline solution and Zn/Al in a neutral and acidic solution.

Some experiments were carried out by our freshmen students to determine the E of corrosion galvanic cells using the method of compensation. The electrodes were made from Fe (mark St. 3 - Russia), Al, Cu, Zn, Sn and Mn. The surfaces of the electrodes were pre-treated with fine-grained No. 1 abrasive paper, degreased by Vienna lime and dipped into a 2% solution of sulphuric acid. The ratio of the surfaces of the anode and cathode was 1:1 and the non-working surface of the electrodes was covered with organic glass. Electrodes were fixed to a stand, such that distance between the anode and cathode was 5 mm. Five percent solutions of sulphuric acid (pH 1.03), sodium chloride (pH 6.10) or sodium hydroxide (pH 10.30) were used. Chemically pure substances from "Reakhim" (Russia) and twice-distilled water were used in the preparation of the solutions. The electrodes were immersed into a 250 ml flask containing sulphuric acid, sodium chloride or sodium hydroxide. Measurements were made at 20°C.

The schematic representation of the education information is the effective way to reach the better understanding and learning of the theoretical concepts and practical skills by students (ORLIK & MOZOLEVSKAYA, 1991; ORLIK & MIKHAILOV, 2001). We applied algorithmic-schemas in the first semester of the engineering programs in the Department of General Chemistry, Kaunas University of Technology.

RESULTS AND DISCUSSION

Electromotive force E , calculated using formula $E \cong \phi_{\text{cathode}}^{\text{pH}} - \phi_{\text{anode}}^{\text{pH}}$, were taken as the average of three measurements. In most cases, the calculated data of E_{calc} show good correlation with the experimental values E_{ex} . Values E and E_{ex} are compared in Tables 2 and 3.

Table 1
Potentials of metals in various solutions (vs SHE)

| Electrode | Standard potential ϕ° , V[Mn]=1 mol/l | Stationary potential in solutions | | |
|----------------------|---|-----------------------------------|---------------------|------------------------|
| | | neutral* ϕ , V | acidic** ϕ , V | alkaline*** ϕ , V |
| Li ⁺ /Li | -3.00 | | | |
| Ca ²⁺ /Ca | -2.87 | | | |
| Na ⁺ /Na | -2.71 | | | |
| Mg ²⁺ /Mg | -2.37 | -1.40 | -1.57 | -1.14 |
| Al ³⁺ /Al | -1.66 | -0.57 | -0.50 | -1.38 |
| Mn ²⁺ /Mn | -1.18 | -1.00 | -0.88 | -0.72 |
| Zn ²⁺ /Zn | -0.76 | -0.78 | -0.84 | -1.13 |
| Cr ³⁺ /Cr | -0.74 | -0.08 | +0.05 | -0.20 |
| Fe ²⁺ /Fe | -0.44 | -0.34 - -0.50**** | -0.32 | -0.10 |
| Cd ²⁺ /Cd | -0.40 | -0.53 | -0.51 | -0.50 |
| Ni ²⁺ /Ni | -0.25 | -0.01 | -0.03 | -0.04 |
| Sn ²⁺ /Sn | -0.14 | -0.21 | -0.25 | -0.84 |
| Pb ²⁺ /Pb | -0.13 | -0.29 | -0.23 | -0.51 |
| 2H ⁺ /H | 0.00 | | | |
| Cu ²⁺ /Cu | +0.34 | +0.06 | +0.15 | +0.03 |
| Hg ²⁺ /Hg | +0.79 | +0.30 | +0.33 | +0.16 |
| Ag ⁺ /Ag | +0.80 | +0.23 | +0.28 | +0.25 |

Notes: * - in 0.5 M aerated NaCl solution; ** - in 0.1 M solutions of HCl and HNO₃; *** - in 0.1 M solution of NaOH; **** - depends on grade of steel (the potential value of Russian steel mark St.3 is -0.34 V). Potentials of metals change a little using different concentrations of solutions.

Table 2
Comparison of E and E_{ex} of corrosion galvanic cell

| Galvanic cell | E^* | 5% solution of NaOH | | 5% solution of NaCl | | 5% solution of H ₂ SO ₄ | |
|---------------|-------|-------------------------|----------------------|-------------------------|----------------------|---|----------------------|
| | | E_{calc} **, V | E_{exp} , V | E_{calc} **, V | E_{exp} , V | E_{calc} **, V | E_{exp} , V |
| Al-Cu | 2.00 | 1.41 | 1.24 | 0.63 | 0.66 | 0.65 | 0.58 |
| Al-Fe | 1.32 | 1.28 | 1.00 | 0.15 | 0.29 | 0.18 | 0.13 |
| Fe-Cu | 0.68 | 0.13 | 0.47 | 0.48 | 0.41 | 0.47 | 0.43 |
| Mn-Fe | 0.84 | 0.82 | — | 0.66 | 0.70 | 0.56 | — |
| Mn-Zn | 0.42 | 0.41 | — | 0.22 | 0.285 | 0.04 | — |
| Zn-Fe | 0.42 | 1.03 | — | 0.44 | 0.405 | 0.52 | — |
| Zn-Cu | 1.10 | 1.16 | 1.01 | 0.84 | 0.835 | 0.99 | 0.89 |

*calculated using the standard potentials; **calculated using stationary potentials from Table 1.

Table 3
Comparison of E_{calc} and E_{ex} of voltaic cell

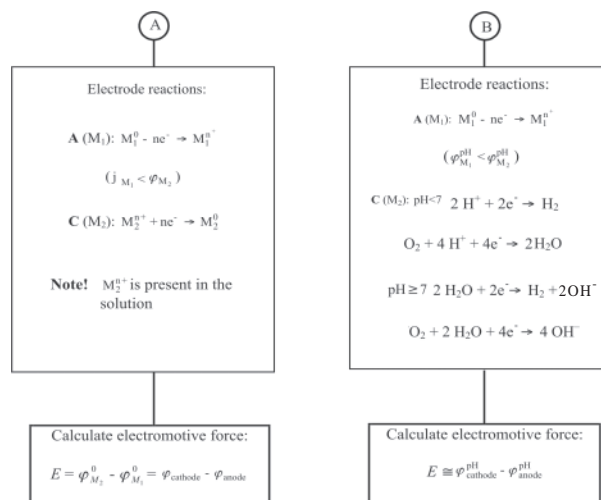
| Voltaic cell | E^* , V | 5% citric acid | | 4.1% citric acid |
|--------------|-----------|-------------------------|-------------------------|--------------------------|
| | | E_{calc} **, V | E_{exp} ***, V | E_{exp} ****, V |
| Zn-Cu | 1.10 | 0.99 | 0.993 | 0.914 |
| Mg-Cu | 2.71 | 1.72 | 1.614 | — |
| Fe-Cu | 0.78 | 0.47 | — | 0.398 |
| Zn-Fe | 0.32 | 0.52 | — | 0.517 |

* calculated using the standard potentials; **calculated using stationary potentials from Table 1 (acidic solution), *** experimental values (Swartling, 1998), **** experimental values (GOODISMAN, 2001)

A measured emf depends on pH of the electrolyte and temperature (SULCIUS, 2003).

On the bases of the data of the experiments carried out by the students during the laboratory session "Galvanic cells", the summarized table (Figure 3) and algorithm helping to master the topic were proposed. The algorithm is given below.

| Metal | Neutral medium | Acidic medium | Basic medium |
|----------------------------------|--|--|---|
| M _I : Zn | $\varphi_{\text{neutr}} = -0,78\text{V}$ anode/cathode (leave the correct word) | $\varphi_{\text{acidic}} = -0,84\text{V}$ anode/cathode (leave the correct word) | $\varphi_{\text{basic}} = -0,13\text{V}$ anode/cathode (leave the correct word) |
| M _{II} : Sn | $\varphi_{\text{neutr}} = -0,21\text{V}$ anode/cathode (leave the correct word) | $\varphi_{\text{acidic}} = -0,25\text{V}$ anode/cathode (leave the correct word) | $\varphi_{\text{basic}} = -0,84\text{V}$ anode/cathode (leave the correct word) |
| E _{calc} , V | 0,57 | 0,59 | 0,29 |
| E _{comp} , V | 0,52 | 0,54 | 0,22 0,32 |
| E _{volts} , V | 0,51 | 0,42 | 0,28 |
| ΔE, V | 0,01 | 0,42 | 0,04 |
| Cell diagram | Zn NaCl Sn ⁺ | Zn HCl Sn ⁺ | Zn NaOH Sn ⁺ |
| Equations of electrode processes | A: $\text{Zn} - 2\text{e}^- \rightarrow \text{Zn}^{2+}$ C: $\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$ | A: $\text{Zn} - 2\text{e}^- \rightarrow \text{Zn}^{2+}$ C: $\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}$ | A: $\text{Zn} - 2\text{e}^- \rightarrow \text{Zn}^{2+}$ C: $\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{OH}^-$ |



CONCLUSIONS

Experiments show that it is possible to use a simplified method and the formula $E \equiv \varphi^{\text{pH}}_{\text{cathode}} - \varphi^{\text{pH}}_{\text{anode}}$ and stationary potentials for calculation of E values for Voltaic cells. It is useful to use the algorithm in order to understand the topic better.

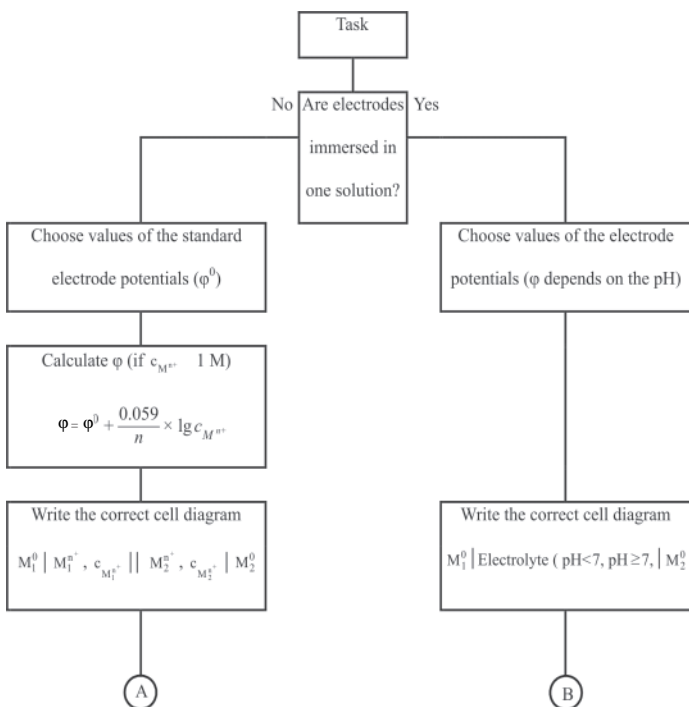
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