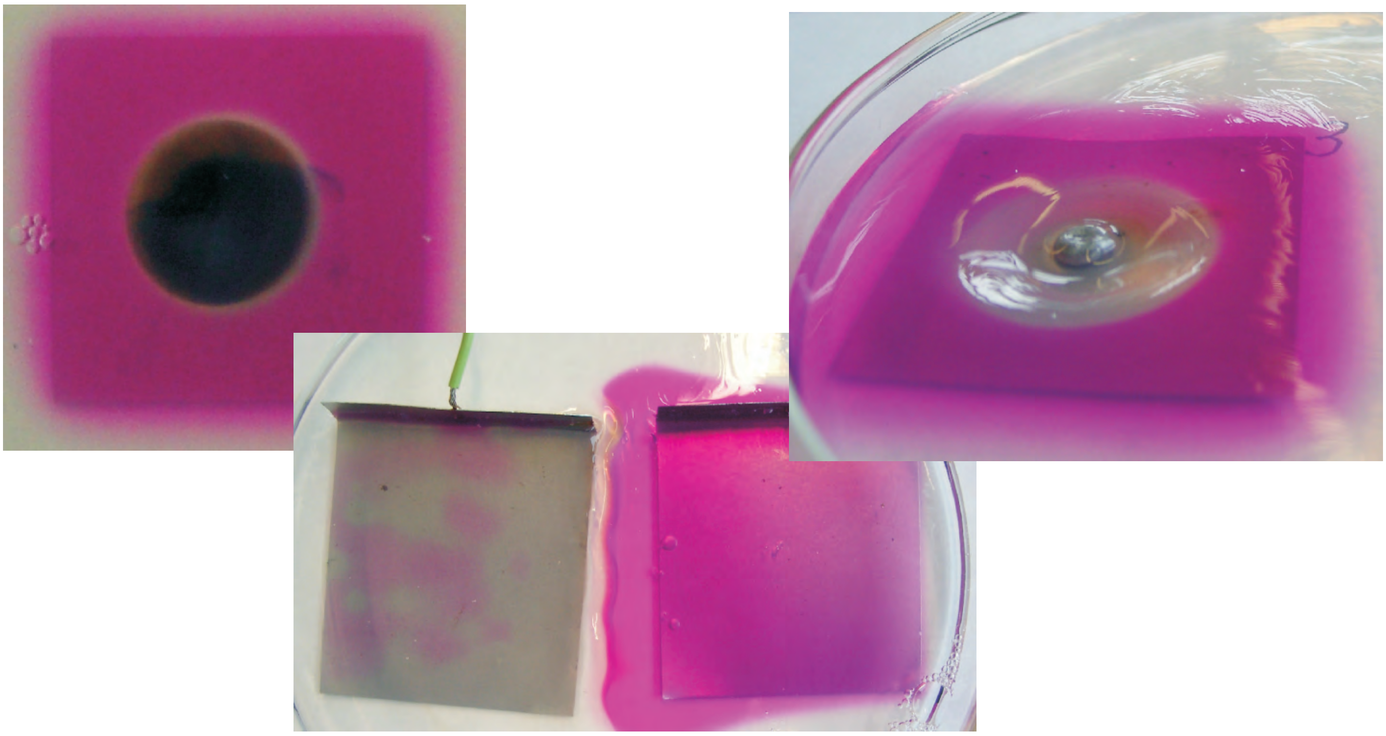
Georg Kerschensteiner Gymnasium
Müllheim

An Object Teaching Lesson about Corrosion



presented by

Julius Goldmann
Max Winkelmann

CEFIC Science Education Award 2002

2nd Edition 2008 by Stefan Müller and Otto Schäfer

30 Jahre

jugend forscht

1978-2008

an der Georg-Kerschensteiner Schule

Technisches Gymnasium Müllheim

TABLE OF CONTENTS

1. INTRODUCTION

For the past 25 years the Georg-Kerschensteiner-Gymnasium in Müllheim has been involved – under the supervision of ist senior chemistry teacher Mr Otto Schäfer – in scientific individual and team project work. These projects have always been open to interested students from other scools in the area.

At present 10 students are working on 5 different projects, one of them being the project with which the Georg-Kerschensteiner-Gymnasium Müllheim is applying for the CEFIC Science Education Award 2002 entry.

The theme of this particular project originated in the idea of one of the team project members whose father is interested in sailing and sailing boats. It was through him that the student became aquainted with corrosion: A friend of his father's had specially had the body of his boat rebuilt from stainless steel (Nirosta steel) in order to avoid corrosion. To his great surprise, however, the body of the boat rusted unusually fast. This story got the student and some of his fellow students interested in the phenomenon of corrosion and the chemical processes involved in it to such an extend that they decided to work on this topic in a project team.

2. BASICS OF CORROSION

The term *corrosion* is derived from the Latin verb ***corrodere***. It denotes the reaction of a metallic material with the environment. The reason for this observable fact is a variety of electrochemical processes.

Metals are characterised by their readiness to release an electron from a neutral atom which turns into a positively charged ion according to:

$Me \leftrightarrow Me^{n+} + ne$ (where n = 1,2,3, ...) [I]

Due to this reaction the metal is „dissolved“.

By means of our experiments one can discern the onset of this process before corrosion can actually be seen. As mentioned above during corrosion metals release electrons. As a result of this, a metal wafer will be negatively loaded and the charges on its surface shared equally. Water molecules in the air moisture „grasp“ the free electrons accordingly to the following formular:

$2\,H_2O + 2e \rightarrow 2\,OH^- + H_2$ [II]

The OH^--ions produced by reaction [II] give rise to an alkaline media in the neighbourhood of the metal surface. This fact can be detected using phenolphthalein as an indicator. In the presence of OH^--ions in the thin layer encapsulating the metal surface the added phenolphthalein solution will be of a reddish colour.

If the metal is iron (steel) the following reaction is valid:

$Fe \rightarrow Fe^{2+} + 2e$ [III]

In this case the metal wafer will also be negatively charged and by applying phenolphthalein solution the whole surface reveals a red colouring.

The Fe^{2+}-ions resulting from [III] react with OH^{-}-ions (see [II]) and a slightly soluble $Fe(OH)_2$ compound occurs. The colourless $Fe(OH)_2$ is oxidized to the brown $Fe(OH)_3$ (the precursor of rust) by oxygen in a very short time (see [IV]).

$$2Fe^{2+} + \tfrac{1}{2}O_2 + H_2O \rightarrow 2Fe^{3+} + 2OH^{-} \qquad [IV]$$

On a smooth or polished iron (steel) surface rust stains appear. From the corrosion centre the Fe^{3+} ions are by diffusion transported to the periphery. It seems that the *in statu nascendi* ferric hydroxide is amorphous and therefore a concentric structure similar to the well known Liesegang's rings emerges. This phenomenon customarily accompanies the growth of various crystal species in gel media. An Agar gel sheet, covering the investigated metal surface causes a retardation effect on the mobility and partition of Fe^{3+}-ions.

3. PURPOSE OF THIS PROJECT

In our project we wanted to develop simple experiments for the chemistry lesson at schools, who make the distinct processes in connection with corrosion visible.
The different corrosion processes should be detectet with following methods:

- OH^{-}-ions can be make visible by using the indicator phenolphthalein to give a red colour

- dissolving Fe-Ions on a metal surface can be detected by using $K_4Fe(CN)_6$ to give an intense blue colour

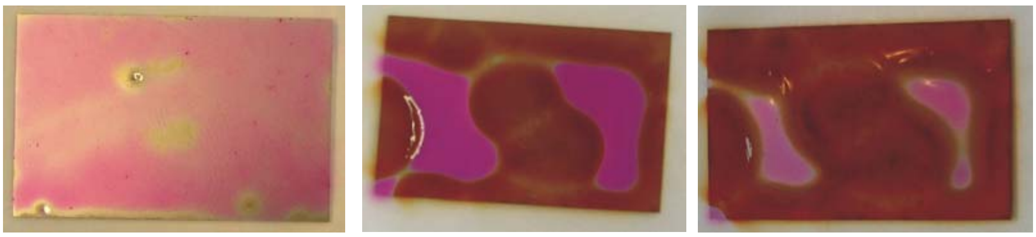
4. RESULTS

All experiments was made in an agar gel (1 %) with the additives mentioned above. An agar gel can easily be made by dissolving dry agar in hot water and let cool down to room temperature. Agar gel is also a non-toxic gel that could be handled by pupils and is biologically dedradable. In the gel the Ions have a small mobility, so the diffusion is very small. This circumstance causes that the ions coud be detectet in a very small room segment where the ions are created by corrosion processes. An other advantage of the gel is the fact that the corrosion processes could be observed over an longer period of time (weeks).

- Corrosion of steel

  In this experiment it could be shown that steel in an agar gel undergo corrosion. A steel plate lying in a agar gel that contains phenolphthalein and in one case no further additive (pict. 1) and in the other case NaCl as additive (pict. 2). The corrosion of the steel in this experiment is after a short time visible. The created OH^{-}-ions was detected with phenolphthalein and provided a red colour. In a period of 48 hours the red colour disappeared in the case of the gel who contain NaCl completely. In the case of the gel who doesn't contain NaCl the red colour was disappeared not completely. This shows that the corrosion speed is in presence of NaCl faster than without NaCl.

Picture 1: A plate of steel in an agar gel who contain phenolphthalein.



t = 0.2 h t = 24 h t = 48 h

Picture 2: A plate of steel in an agar gel who contain phenolphthalein and NaCl.

t = 0.2 h t = 24 h t = 48 h

- Interaction of other metals with steel

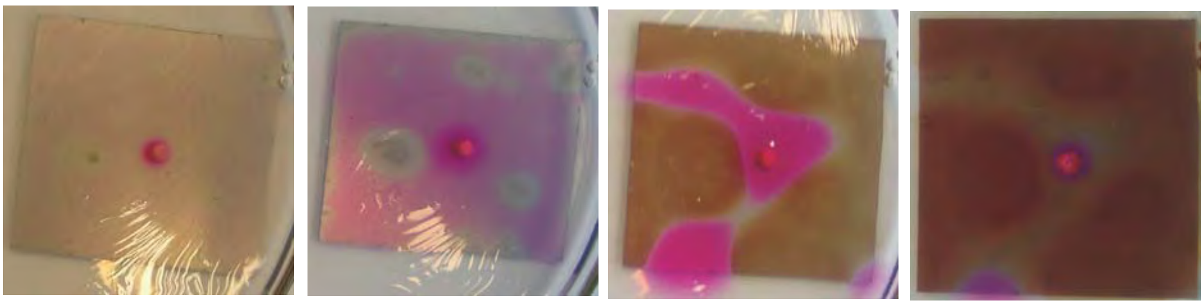
  In this experiment could be show that metals who are more noble than iron (e.g. copper) causes fast corrosion of a steel plate in an agar gel, when the other metal have a direct contact to the steel. Is the steel plate in contact with an metal that is less nobel than iron (e.g. zinc), the corrosion in the area around the less noble metall protect the iron from corrosion. As additive in the gel serves phenolphthalein for the detection of the created OH^--ions by occurrence of a red colour.

  We have develop an experiment for both cases mentioned above. In one case we layed a pice of copper (pict. 3) and in the other case a pice of zinc (pict. 4) on a steel plate and add a hot solution of agar in water containing phenolpthaleine.

  - copper on steel:

  After a short period of time (1.5 h) at the surface of the steel plate occurred a red colour that shows OH^--ions has been created. In the area around the copper piece the red color became more intense with the time, because the copper is charged with electrons provided by the steel. The elektrons react with the water in the gel to OH^--ions (see [II]). The red colour on the surface of the steel plate disappeare with time. After 50 h the steel plate is overcoated with rust and the area around the piece of copper stay red.

Picture 3: A pice of copper on a plate of steel (5 cm) in an agar gel who contain phenolphthalein.

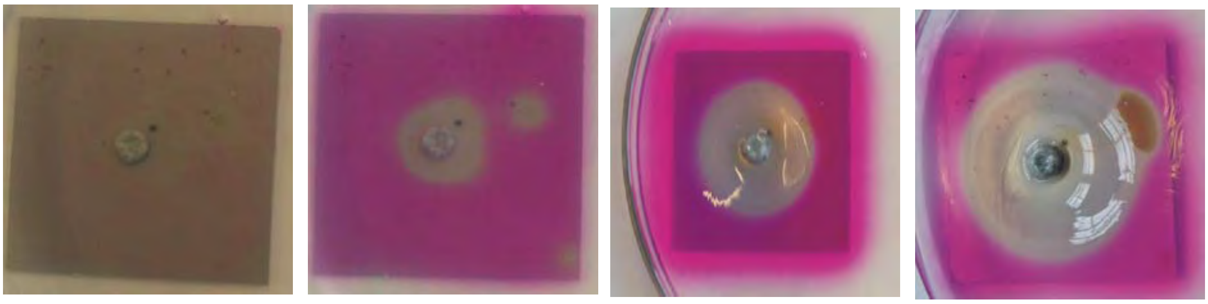


t = 0 h | t = 1.5 h | t = 24 h | t = 50 h

- zinc on steel:

In the case when zinc is lying on a steel plate it occurred the red colour at the surface of the steel plate after 1.5 h. In this case the steel is charged with electrons from the zinc and the zinc undergo corrosion. In a period of about 50 h the area around the piece of zinc is becoming more and more colourless. This is caused through the creation of colourless zinc hydroxide around the zinc that consumed the created OH^{-}-ions.

Picture 4: A pice of zinc on a plate of steel (5 cm) in an agar gel who contain phenolphthalein.

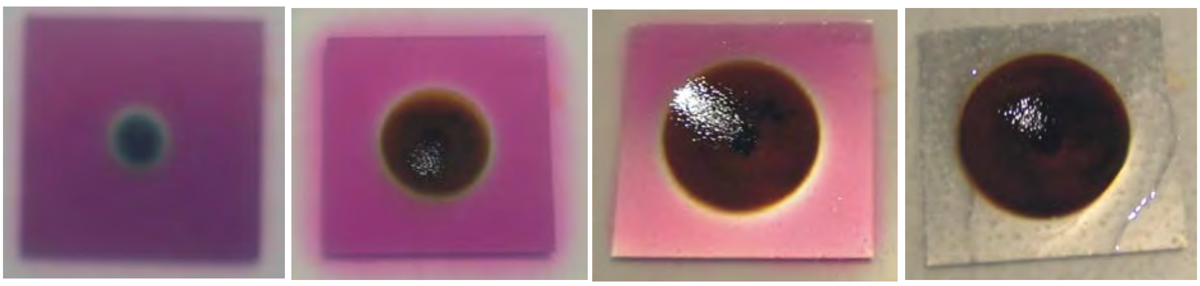


t = 0 h t = 1.5 h t = 24 h t = 50 h

- Corrosion of a piece iron on a surface of stainless steel

We layed a piece of iron on an plate of stainless steel in an agar gel who contain phenolphthalein and $K_3Fe(CN)_6$. We observed the occurrence of a reddish colour on the steel surface. This colour occurred, because the plate is charged with electrons from corrosion of the iron piece who release Fe^{2+}. The Fe^{2+}-ions were oxidized by oxygen to Fe^{3+}-ions and after 24 h a ring of the blue precipitate of Berlin blue caused from Fe^{3+}-ions is visible (pict. 5). The red colour diappear after a period of 120 h and the ring is grown and become brown from the precipitate of brown $Fe(OH)_3$. The stainless steel behaves under these conditions indifferent.

Picture 5: A pice of Fe_3O_4 on a plate of stainless steel (5 cm) in an agar gel who contain phenolphthalein and $K_4Fe(CN)_6$.

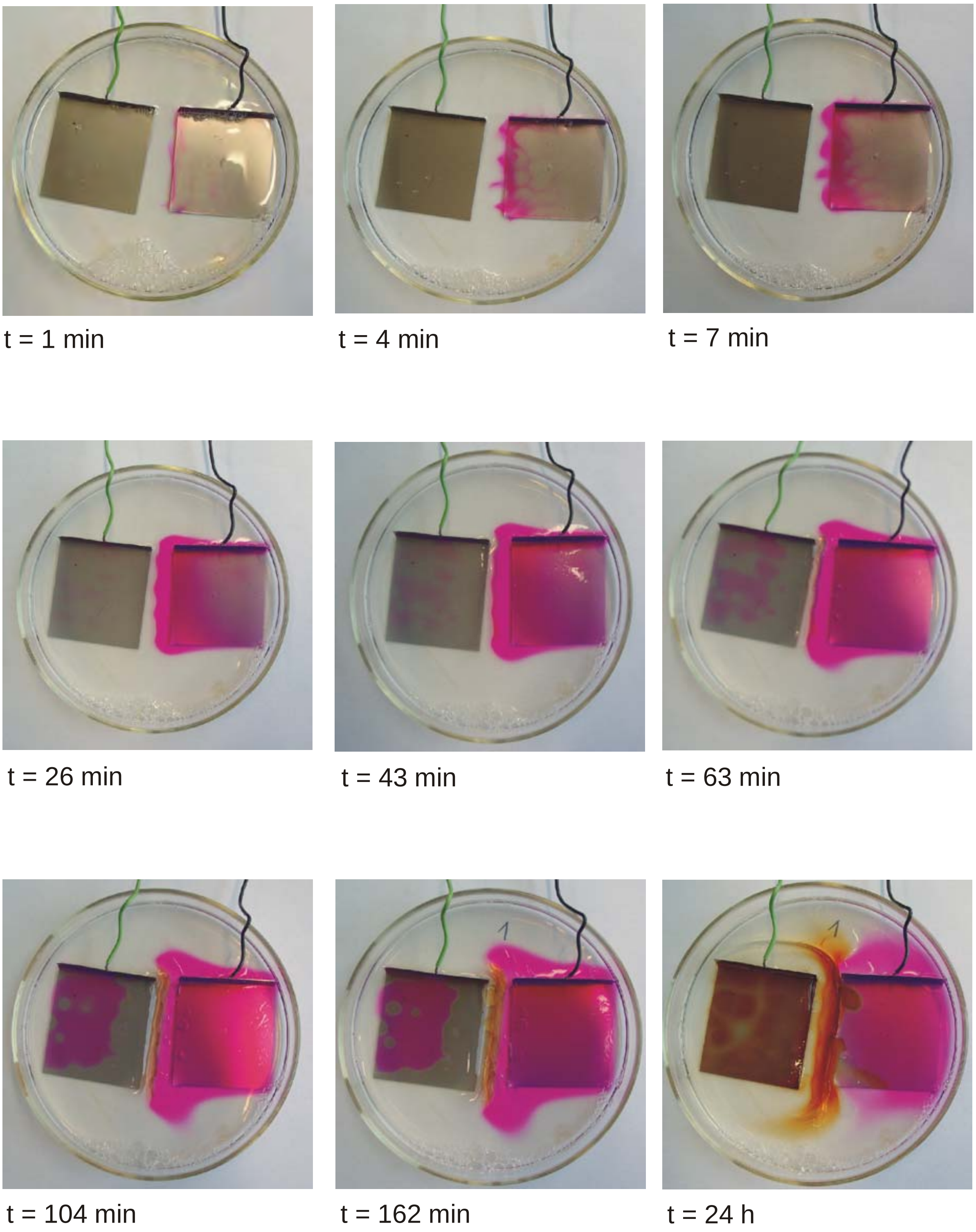


t = 24 h t = 48 h t = 72 h t = 120 h

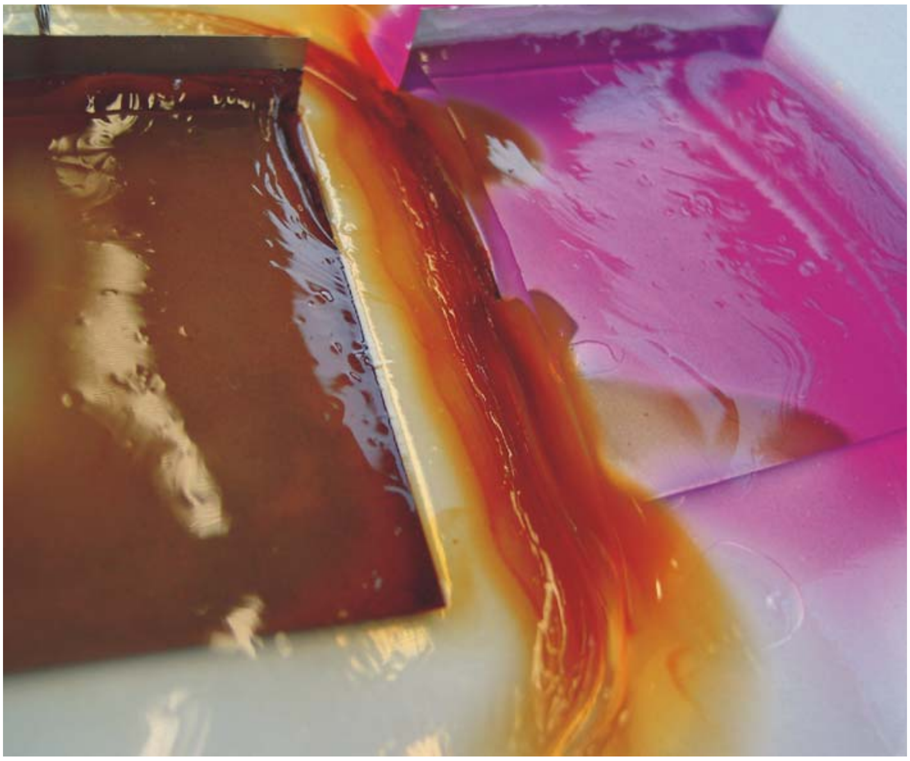
- Corrosion by electricity

Corrosion can be caused by electricity. We develop an experiment who show that fact. We layed two steel plates in an agar gel who contains phenolphtalein. Each of the steel plates were connected to a pole of a battery (1.5 V)(pict. 6). At the plate connected with the –-pole we could observe the occurrence of red colour. This colour is caused by the creation of OH^{-}-ions through the negative charged steel plate. At the other pole we observed no colour on the surface of the steel plate. The Fe^{2+}-ions released by the positive charged plate moved along the electric field in direction of the negative pole. Between the two steel plates the Fe^{2+}-ions met the OH^{-}-ions who moved in direction of the positive pole. This caused after oxidation of the Fe^{2+}- to Fe^{3+}-ions by oxygen the precipitate of slightly soluble and brown $Fe(OH)_3$. After 24 h in the between the two plates we observed a deep crack coloured dep brown by $Fe(OH)_3$. The crack in the gel was presumably caused by the moving of water in the gel along an concentration gradient (pict. 7).

Picture 6: Two pices of steel plates in an agar gel each connected with an pole of a baterry (left: +-pole, right: —-pole, 1.5 V, time after connection with the battery)



Picture 7: Observed crack between the two plates



5. SUMMARY

We have developed a set of simple and non-toxic experiments which can make distinct processes of corrosion visible. With our experiments teachers could demonstrate diffrerent chemical and physical principles. And pupils are fronted to special phenomena and could make own hypotheses.

Following phenomena can be observed with our experimens:

- creation of OH^--ions by the colour of deprotonated phenolphthalein
- diffusion of ions by indicators
- creation and un-solubility of $Fe(OH)_3$
- moving of ions in an electric field
- moving of water along an concentration gradient

6. ACKNOWLEDGEMENT

We thank Mrs Beate Wagner the headmistress of the Georg-Kerschensteiner-Gymnasium who make this project possible. A special thank goes to Mr Otto Schäfer and Mr Dipl. chem. Stefan Müller for the support of our work.