CHEMICAL SAFETY
Investigating health and safety in the laboratory

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Languages available
English, Slovenian, Hungarian

Summary
Chemical safety encompasses a broad area of knowledge and legislation. A key part of this is about safeguarding everyone's health and safety. As scientists, we particularly come into contact with chemical safety issues when working in a chemical laboratory or in an industrial plant.

However, we should not forget safety rules when we buy commercial chemical products and use them at home. Knowledge about chemical safety helps us to handle such chemicals properly. There are other situations in every day life where such knowledge is beneficial, as well. For instance we may be a witness or be involved in a chemical or traffic accident, an explosion, a chemical spillage into water and/or soil or it may simply prevent us from inhaling carbon monoxide from incomplete combustion.

The aim of this activity is to take safety culture to a higher level. It is limited to school laboratories and chemicals. It cannot replace appropriate literature, part of which is cited later in the text.

Activity type **C**
Use of scientific knowledge and understanding to solve problems
Working in teams to solve problems
Time and workload management

Techniques
Filtration

Field
Health and safety
Environmental

Time
Practical lessons: 90 minutes
Theory lessons: 150 minutes
Out of class time: 60 minutes

StandardBase procedures
None

StandardBase techniques
None

Other resources
Literature:
A) Keith Furr, ed., CRC Handbook of Laboratory Safety, 4th Ed., 1995, CRC Press (783 pages, all inclusive book on safety for chemical lab work.)
B) John Timbrell, The Poison Paradox: Chemicals as Friends and Foes, 2005, (paperback ed. 2008) (Very useful stories of many chemicals.)
C) Louis J. Ling et al., Toxicology Secrets, 2001, Hanley & Belfus, Inc. (Written as questions "you will be asked" with clear answers about chemicals and drugs.)

Websites:
http://www.ilpi.com/safety/explosion.html (A case of mixing chemicals)
www.osha.gov (Occupational Safety & Health Administration OSHA)
http://physchem.ox.ac.uk/ (Chemical and other Safety Information)
http://ec.europa.eu/environment/chemicals/reach/reach_intro.htm (REACH about chemicals)
http://www.who.int/ipcs/en/
http://www.who.int/ipcs/publications/ehc/ehc234.pdf (WHO Publication on Human Health Assessment)
http://en.wikipedia.org/wiki/Risk_and_Safety_Statements
http://www.ilpi.com/msds/faq/parta.html#whatis (MSDS - Materials Safety Data Sheets - basics)
http://www.oecd.org/document/46/0,2340,en_2649_34379_37795981_1_1_1_1,00.html (CAS basics)
http://www.ase.org.uk/htm/book_store/detail.php?SIID=238 (Safeguards in the School Laboratory 11th edition, 2006, a basic booklet as the publisher ASE says: "*Safeguards in the School Laboratory* is the only complete textbook on health and safety in science for secondary schools")
http://www.hanford.gov/rl/?page=516&parent=506 (Important source for analysis of accidents)
http://www.uwm.edu/Dept/EHSRM/LAB/index.html (Laboratory safety programme, structured, recommended)
http://www.uwm.edu/Dept/EHSRM/EHS/LAB/reactivechemicalslists.pdf (List of reactive chemicals: chemical incompatibilities, peroxidisable compounds, potentially explosive compounds, explosives)

Student’s document

CHEMICAL SAFETY: Investigating health and safety in the laboratory

You start work in a chemical laboratory. In order to keep yourself healthy and safe, the first task you have in this job is about chemical safety.

This activity will help you to develop the following skills:
- Using scientific knowledge and understanding to solve problems
- Working in teams to solve problems
- Time and workload management

There are millions of chemical substances. Moreover, their quantity or their concentration creates an enormous range of possible values, from micrograms per litre and traces to tonnes, all of which may have a different effect, depending on their environment. Some molecules are lethal in small concentrations, others are vital for our health. The same holds for plants and animals.

Depending on the amount or concentration, the same component can be useful or harmful for living organisms and the environment – e.g., several chemical elements are essential for life in small amounts and highly toxic in excessive concentrations (e.g. selenium). For a brief overview of elements in the human body, see:
http://chemistry.about.com/cs/howthingswork/f/blbodyelements.htm
Notice that elements are generally not in an elemental state in the human body, but bonded to other elements or as ions in a solution. For example, chlorine is not found as a dissolved gas in blood but as a chloride ion, coming from table salt or other food or drink.

Your brief
This activity enables you to employ best practice and obtain data on chemical safety issues, both for working in a chemical laboratory and for everyday life situations.

The first rule of safety in chemistry is that your safety is your responsibility. So, it is important that you know what impact the chemicals you are using will have on your health.

You will improve your knowledge through this activity by carrying out:
- practical work with hazardous chemicals
- web data search for hazards with chemicals
- web data search for accidents with chemicals.

Remember, a risk assessment must be made and agreed before carrying out any practical work.

Your investigation

Task 1: Laboratory and chemicals safety issues in practice

(See details in **Student sheet**: *Preparation of copper powder*.)
Working in a development laboratory, you are asked to prepare a copper powder from copper strip, using a recipe. Later on, this preparation will become routine at the laboratory, so missing data are needed.

- Gather data on the safety measures to be respected at work.
- Measure the time needed for the preparation as a whole and for each step and estimate the workload.
- Follow the procedure.

The estimated time for this is 2 x 45 minutes

Task 2

(See details on **Student sheet**: *Searching for hazards with chemicals*.)
There are times when you need answers on safety data for a chemical. For example, as a chemist you may be asked for advice about whether a certain chemical is dangerous to health or not. There may be times when you need to know for yourself. At another time, new chemicals may come to your laboratory and their safety data must be found. Perhaps you want to send a chemical by cargo airmail. You will need to fill out a form called a Material Safety Data Sheet (MSDS) for the chemical. Where to find the data?

To get you started, there is an example to help you.
Time for the actual search is limited to about 30 minutes.

Task 3

(Details in **Student sheet**: *Searching for accidents involving chemicals, to learn from them*)
Read the example and then find the list of accidents on the website given below. Choose one to present to your group or, alternatively find examples of particular types of chemical accident. Discuss your chosen example with your group and present it to other groups.
http://www2.umdnj.edu/eohssweb/aiha/accidents/ (Laboratory safety incidents, sorted)

The time for this is about 45 minutes.

Task 4: Organisation of the teamwork

Review how you worked as a group for the practical work and collected information. Complete the self-assessment and the questions related to the subject.

Allow 45 minutes for this.

Task 5

Write up your final report, including an evaluation of results.

The estimated time is 60 minutes.

Your findings

1. Preparation of copper powder

The outcome is your report on managing the time for the preparation of copper powder as defined in ***Task 1*** and the **Student sheet**. Note the slowest phases in the procedure. Estimate the time and workload for this laboratory work.

2. Searching for hazards with chemicals

Report on your findings. List websites that describe hazardous chemicals and the chemicals you discussed with your group. Briefly describe the content of your chosen websites.

3. Searching for accidents involving chemicals, to learn from them

Discuss your findings. Select one case from among those looked at in detail by group members; present and compare this with other groups. Report on the accidents discussed. List other websites found.

Student self assessment

Complete the checklist below. If there are more than three "NO" answers, please consult your teacher.

Using scientific knowledge and understanding to solve problems

1. Can you search information after putting in a keyword on the Internet?
2. Have you found useful information other than the suggested articles and websites?
3. Can you write the reaction equation for copper(II) ions and zinc?
4. Do you know what the colour is of copper(II) ions in aqueous media?

Also, use the file *Evaluating skills.doc* from the ProBase website.

Student sheet: Preparation of copper powder

Do not start work until you have your teacher's permission. This is for your safety and to ensure that the laboratory work is properly organised. It will also help in ensuring that the time is well managed.

Follow the procedure and answer the questions.

Procedure

1. Into a 250 mL beaker weigh about 0.5 g of copper strip or scrapings, to an accuracy of 0.01 g. In a fume hood, add 4 mL concentrated nitric acid (65% by mass).

- What are the fumes that are coming out? Are they toxic? What are the safety measures?

At the end of the reaction, add distilled water to half-fill the beaker.
Note: **In good practice you should always add concentrated acid to water.** However, in this experiment, it is acceptable if a large volume of water is added quickly to the very small volume of acid, because the heat generated is dissipated quickly in the water.

2. Add 30 mL 3 mol/dm^3 NaOH. The $Cu(OH)_2$(s) formed will settle out.

- What is the general name for this kind of reaction? Why does it happen?

3. Add 2-3 pieces small boiling chips to agitate boiling and stir the contents continuously until it boils. You will notice that $Cu(OH)_2$(s) will convert to black CuO(s).

- Do you know of any other copper oxide?

4. Let the CuO settle and filter the solution. Wash out with 200 mL very hot distilled water.

5. Add 45 mL 6 mol/dm^3 H_2SO_4 to convert CuO(s) to $CuSO_4$(aq).

- What colour would you expect the solution to be after adding the acid?

6. Add 4 g Zn powder (in a fume hood), and some more if needed, and stir continuously until the liquid over the settled copper Cu(s) is clear and colourless. When hydrogen ceases to evolve, decant the solution.

- Is hydrogen gas dangerous? What happens to the zinc? What kind of reaction is taking place in the copper solution?

7. Still in a fume hood, first add 5 mL water, then 10 mL concentrated HCl (36% by mass) to react with a residual Zn(s). When hydrogen nearly ceases to evolve, heat to near boiling and stop heating with the burner.

- What happens now to the zinc?

8. When no more hydrogen is detected evolving, decant and transfer the suspension (Cu) to a weighed porcelain dish.

9. Wash with 5 mL distilled water and decant. Repeat this once more.

10. Wash the suspension with 5 mL methanol (Safety! No flames nearby!), wait until it settles again and decant. Now wash it with 5 mL acetone (Safety! No flames nearby!), wait for it to settle again and decant.

- Why should there be no flames nearby with methanol and acetone?

11. Put a dish into a water bath and leave the product to dry out.

- Why do we use a water bath here and not direct heating with a burner?

12. Remove the boiling chips from the dish and again weigh the dish with its contents.

13. If there is enough time, repeat step 11 and 12 until the mass is constant.

- From the mass of the copper scrap and the mass of copper powder, calculate the yield.

Additional safety notes

Safety gloves and safety glasses are to be used when handling nitric, sulfuric, and hydrochloric acids and the sodium hydroxide. Pour them first into small beakers and not directly from heavy bottles. Preferably use pipettes.

Summary

Write down your data on the masses of the Cu. Calculate the yield (see the formula below).

A. Results
1. Mass of copper scrap
2. Mass of copper powder
3. Yield η

$$\eta = \frac{m(\text{Cu powder})}{m(\text{Cu scrap})} \times 100\%$$

B. Answers to questions

Write down your answers to the questions posed in procedure above. Compare your answers with the rest of your group.

C. Write a report with your results and answers.

Student sheet: Searching for hazards with chemicals

Stage 1
Is a chemical you work with hazardous? In a system to answer such questions properly, a good starting place is the MSDS (Materials Safety Data Sheet) data.

Example story
Your girlfriend got a job at a dry cleaners'. She saw part of a label saying *trichloroethylene* on a container of chemical used to fill the machine. She noticed a smell in the air she was breathing by the machine and asked you if it could hurt her, as she will spend hours at the machine.

Start the search with, for example http://physchem.ox.ac.uk/
Scroll down to *Local Resources*, click *MSDS database*, scroll down to *MSDS* and try *T*. Next look at *Tr*. When you find trichloroethylene and click, the MSDS page opens. Under Toxicology you will find:
"Carcinogen. Mutagen. Toxic. Possible teratogen. Human mutagenic data. May cause systemic effects if swallowed or inhaled. May be addictive. Harmful if swallowed, inhaled or absorbed through skin. Narcotic. Severe irritant. May cause dermatitis. Typical STEL 150 ppm. Typical LTEL 100 ppm. Carcinogen category 3."

Are you able now to tell her why she should avoid breathing the vapour?

Stage 2
Find out the meanings of the terms met in *Stage 1* using additional searches! Better hits will lower your search time and improve control of your time.

An MSDS contains written or printed material concerning a hazardous chemical as prescribed by law. It contains basic information needed to ensure the safety and health to the user at all stages of manufacture, storage, use and disposal of the chemical. The MSDS information system was developed using chemical data sheets that chemists have been using for the past one hundred or more years.

Stage 3
Go to *Risk Phrases* on the sheet, to see what kind of risk she is exposed to.
→ They are: R20 R21 R22 R40 R52 R53. Click for the *meanings*.
The answer about breathing is R20 = *Harmful by inhalation*!

How should she protect herself?
Look at *Safety Phrases*.
→ They are: S23 S36 S37 S61.
The answer is: S23 = *Do not breathe vapour*!

Your girlfriend will need protection.

You should be able to find similar lists in your laboratory, usually together.

Stage 4
Go through the same procedure for the chemical of your choice.

Student sheet: Searching for accidents involving chemicals, to learn from them

Stage 1: Learn from stories

Example story
You are training to become a vocational chemist. A friend of yours asks you to go with him to look at some old chemicals that he had uncovered in a cellar in his family house. His grandfather had been an apothecary. You take a look at those bottles and suddenly notice that picric acid is written on the label. In the early 20th century, picric acid was stocked in pharmacies as an antiseptic and as a treatment for burns, malaria, herpes, and smallpox. See:
http://en.wikipedia.org/wiki/Picric_acid
You also notice that there is almost no liquid in the bottle. As a chemist, you know it is a chemical trap. Opening it could explode nicely! Turning a stopper might crush dry crystals of picric acid captured between stopper and bottleneck. Explosion of the crystals could trigger the rest of the acid to explode, too.
Look at a similar story: http://ehs.memphis.edu/news/aug98/.

Modern safety precautions recommend storing picric acid wet. When picric acid is dry, it is relatively sensitive to shock and friction, so laboratories that use it store it in bottles under a layer of water, rendering it safe.
http://en.wikipedia.org/wiki/Picric_acid
http://www.cci.ca.gov/Reference/PICRIC.pdf

http://www.hanford.gov/rl/?page=516&parent=506 lists and sorts accidents.
See an example from 2001: Peroxide Forming Chemical Not Checked as Required

Stage 2
Discuss the findings of this report. Choose one accident from the list and prepare a presentation. Each group should select one for comparison with other groups.

Chemists know that certain chemicals should not be mixed together. They are known under the name incompatible chemicals. This also holds for household chemicals. Could you imagine that mixing bleach and vinegar will produce a poisonous gas − chlorine! Use the links bellow to read a full story.
http://chemistry.about.com/b/2003/07/08/mixing-bleach-and-vinegar-always-a-bad-idea.htm
http://chemistry.about.com/b/2007/09/26/the-killing-power-of-bleach-and-vinegar.htm

This goes for other acids as well. Visiting websites that list incompatible chemicals could be very interesting and also somewhat surprising. Here are two:
http://www.uwm.edu/Dept/EHSRM/EHS/LAB/reactivechemicalslists.pdf
http://chemistry.about.com/cs/toxicchemicals/a/aa603003a.htm

Less known, but even more dangerous is another type of chemical: chemicals that can form peroxides on aging. This also occurs in well-known diethyl ether. Such chemicals could surprise us with explosions. Testing for peroxide should be carried out. For example:
http://www.ab.ust.hk/hseo/chem_info/peroxide-test.htm
http://safety.nmsu.edu/policies/policy_peroxide_former.html

Teacher's document

Overview
The aim of this project is to bring chemical safety issues and knowledge to its potential user, to lower the probability of harm from working in chemistry. Also of importance is basic chemical knowledge in everyday life. It is suggested that examples are discussed with students.
The activities offer three different ways of encountering chemical safety. All three activities will also develop time and workload management skills.

1. Preparation of copper powder
An experiment is carried out such that many safety issues are present and must be considered, for example handling of highly concentrated acids and bases, inflammable solvents, evolving toxic or combustible gases (nitrogen oxides, hydrogen). With all this in mind, the experiment has the aim of becoming a standard procedure for the production of copper powder from scrap copper, in a small-capacity laboratory. This provides an opportunity to develop time and workload management skills. The time for each step is measured and the sum calculated for each group. The number of students working on each step is also noted and whether the number of students could be reduced.

The total time for the production is the sum of times for all the steps in the process. Different groups may get different times, and these can be compared.

Yield (η) in % is calculated as normal:

$$\eta = \frac{m(\text{Cu powder})}{m(\text{Cu scrap})} \times 100\%$$

The chemistry for each step:

1. reaction between copper and nitric(V) acid gives blue/green copper ions
   $Cu(s) + 4HNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2NO_2(g) + 2H_2O(l)$
   deep brown NO_2 is in balance with colourless N_2O_4

2. light blue copper hydroxide settles with NaOH
   $Cu(NO_3)_2(aq) + 2NaOH(aq) \rightarrow Cu(OH)_2(s) + 2NaNO_3(aq)$

3. heating copper hydroxide yields black precipitate CuO
   $Cu(OH)_2(s) \rightarrow CuO(s) + H_2O(l)$

4. copper(II) oxide reacts to blue copper(II) ions with sulfuric acid
   $CuO(s) + H_2SO_4(aq) \rightarrow CuSO_4(aq) + H_2O(l)$

5. copper(II) ions transforms to metallic copper using zinc powder
   $CuSO_4(aq) + Zn(s) \rightarrow Cu(s) + ZnSO_4(aq)$

6. excess of zinc reacts with hydrochloric acid to evolve hydrogen gas
   $Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2$

Students should also be asked to write the equations in ionic form.

2. Searching for hazardous chemicals
It is important to stress that the database will give students, and later as employees, a means of checking data on the hazards and risks posed by chemicals.

The MSDS is designed to provide both workers and emergency personnel with the proper procedures for handling or working with a particular substance. MSDS has a long history:
http://jrm.phys.ksu.edu/Safety/kaplan.html

A quiz that could be used to master chemical safety knowledge is given in:
http://www.ilpi.com/msds/quiz/part1.html
It has seven parts. In each part, the students read some background material and then answer some questions. If the answers are correct, the students can go on to the next part. If not, they can try again until they get the correct answer.

The story of the dry cleaners′ is included to help students master both the ability to answer such questions and to do so quickly. They learn how to search for relevant data and manage their time. Two key parts of the learning are familiarisation with R and S statements and their meanings, and symbols for hazards, as also found on commercial products in everyday use.

A very important regulation which came out in 2007 is REACH.
REACH is a new European Community Regulation on chemicals and their safe use (EC 1907/2006). It deals with the **R**egistration, **E**valuation, **A**uthorisation and Restriction of **Ch**emical substances and came into force on 1 June 2007.
The aim of REACH is to improve the protection of human health and the environment through the better and earlier identification of the intrinsic properties of chemical substances.
Students should be aware of this regulation. It is suggested to open:
http://ec.europa.eu/environment/chemicals/reach/reach_intro.htm

3. Searching for accidents to learn from them
Give students a time limit for their search. Students compare their findings firstly in their groups and then with the rest of the class. When evaluating the results, there is an opportunity to select the most interesting accidents.

Developing students' skills
1. The main aim of this activity (besides learning about health and safety) is to develop students′ time and workload capability. Guide the students with suggestions, but leave them to manage their work independently.

2. For the **Student sheet**: *Preparation of copper powder*, suggestions might include advice on efficient equipment use, for example a funnel, but leaving students to distribute the work (who will do what). It is suggested that the time taken for each step is also recorded and an estimate made, at the end of the task, of the total number of students (workers) that would be needed in a commercial situation.

3. For **Student sheet**: *Searching for hazards with chemicals*, other chemicals than those mentioned could be suggested, for example, methoxyethane (ethyl methyl ether).

4. For **Student sheet**: *Searching for accidents involving chemicals*, no further suggestions should be needed.

Organising and managing the class

The minimum group size is 3, preferably working in 3 or more groups.
With more than 2 groups, communication between the groups is essential.
Each student in a group carries out web search tasks, then the teacher facilitates the exchange of data and information gathered. The experiment is carried out by the group.

Working environment and conditions inside school:

- laboratory
- computers (with Internet access)
- library

Every student should take part in planning, the practical activity and the report.

Teachers should help with advice on key words, searching the web and in discussions.

Session plan for teachers

- Teacher gives introduction to chemical safety issues with interesting examples (30 minutes)
  - Outline the purpose of the project
  - Statement of expected output (content, format)
  - Organisation of the teamwork
- Searching for hazardous chemicals (30 minutes)
- Searching for accidents to learn from them (45 minutes)
- Collecting information and self-assessment with questions related to the subject (45 minutes)
- Practical work in groups making copper powder (90 minutes)
- Making final report, evaluating results (60 minutes)

Technical notes

Preparation

The activity needs a laboratory with a fume hood and computer room with Internet access.

Equipment and materials

Materials and their CAS numbers

Name	Grade	CAS-No.
nitric acid (65% by mass)	Reagent	7697-37-2
sodium hydroxide	Reagent	1310-73-2
sulfuric acid	Reagent	7664-93-9
zinc powder	Reagent	7440-66-6
methanol	Reagent	67-56-1
hydrochloric acid concentrated	Reagent	7647-01-0
acetone	Reagent	67-64-1

Glassware and other equipment

- 250 mL beaker
- 400 mL beaker for water bath
- plastic dripping-tube
- glass rod for mixing
- boiling chips (ceramic or glass) for agitating boiling
- porcelain dish, R = 80 mm
- tripod with gauze
- burner
- balance
- funnel
- graduated cylinder

TESTING PRIOR KNOWLEDGE

Select the correct answer.

1. What is the highest concentration in percent by mass of HCl(aq) usually held in stock in a laboratory?
   a. 96%
   b. 65%
   c. 37%
   d. 25%

2. How should you dispose of bottles of acetone, ether, methanol, ethanol when empty?
   a. throw away somewhere and forget
   b. fully fill with water, empty, dry and put in stock or put with glass waste
   c. put in stock or put with glass waste
   d. dry and put in stock or put with glass waste

3. Hydrogen peroxide, highly concentrated (30% by mass), is packed in bottles that have small holes in the stopper. Why?
   a. because of the technology for producing stoppers
   b. hydrogen peroxide needs fresh air to stabilise it
   c. hydrogen peroxide slowly decomposes and the gas needs releasing
   d. we pour the hydrogen peroxide through these holes

4. If you see **T+** above a hazard symbol, what does it mean?
   a. Throwaway chemical
   b. Toxic chemical
   c. Very toxic chemical
   d. Ready for Transport

5. When highly concentrated acids or bases are diluted with water, what is a safe method of dilution?
   a. pour water into acid or base
   b. pour acid or base slowly into water
   c. pour acid or base and water together into a beaker
   d. freeze water first and pour acid or base on ice

Note: Correct answers are given in red. These need to be changed to black before the test is used.

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