STUDYING THE TEMPERATURE DEPENDENCE OF THE SPEED OF CHEMICAL REACTIONS

Katalin Radnóti[1], Mária Nagy[2], Mária B. Németh[3]

[1] Institute of Physics, Faculty of Science, Eötvös Loránd University,
[2] Faculty of Science, Eötvös Loránd University,
[3] MTA-SZTE Research Group on the Development of Competencies

The poster shows an example of an IBL activity requiring the students to discover the relationship between temperature and the speed of chemical reactions, integrating the curricula of chemistry, physics and mathematics.

Features of the activity

For physics and chemistry subjects
For ages 17-18, working in groups of 3-4
Time to process: 2 x 45 minutes

The task is aimed at the fostering of the following inquiry skills

planning experiments, hypothesis,
scientific inquiry process, developing scientific thinking
graphical representation of the measurement data.

The students study the problem through the reaction of sodium thiosulphate and hydrochloric acid. The series of measurements can be carried out easily with only a few pieces of equipment, and at the same time the result is spectacular.

$Na_2S_2O_3 + 2HCl = 2NaCl + H_2O + SO_2 + \underline{S}$

During the reaction, non-water soluble sulphate colloids develop that allowing the measurement of time.

Carrying out the series of measurements is very simple, it requires only a few pieces of equipment but it is very spectacular. It can be observed clearly that in a cool environment, for example at 10 degrees Celsius, the process takes place very slowly, while in a water bath of 60 degrees Celsius it happens instantaneously. Consequently, the chemical reactions take place much more slowly in a cool environment. This is why for example we can store food much longer in a fridge.

Steps of the process

- Summing up student' prior knowledge in connection with the conceptual content of the text (chemical reactions).
- Observing the reaction between sodium thiosulfate and hydrochloric acid at room temperature.
- Planning an experiment in order to observe the temperature dependence of reaction rate in the above process.
- Carrying out the measurements.
- Representation of data on paper or by computer with the help of spreadsheet program.
- Analysis of the graphs, comparing them with the hypothesis.
- Making a report.
- Making the report actually begins in the planning phase.
- Groups present their work.
- Why the acquired knowledge is important for everyday life?

Pour 5 cm³ of fixing salt and 5 cm³ of hydrochloric acid into the test tubes placed on the test tube rack. Pour water of the same quantity but of different temperatures into big beakers. (In laboratories this is called a waterbath.) Pour enough water into the beakers so that it covers the solutions in the test tubes but does not get into them. Put two test tubes into each beaker one containing fixing salt and another containing hydrochloric acid for 2-3 minutes so that they reach the required temperature. Then pour the hydrochloric acid into the fixing salt. During the chemical process a substance gets precipitated (sulphur), the small grains of which make the liquid opalescent. This shows us that the process is complete.

Handle the solutions carefully; make sure they do not squirt onto your skin or into your eyes!

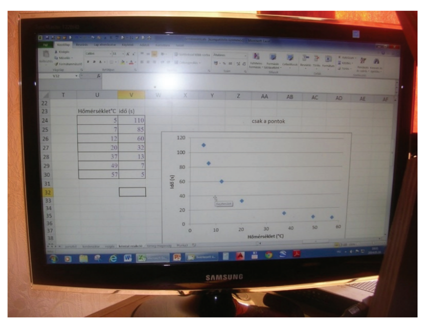
The students are given the table below only if they fail to plan measurement process on their own.

The results of a possible measurement

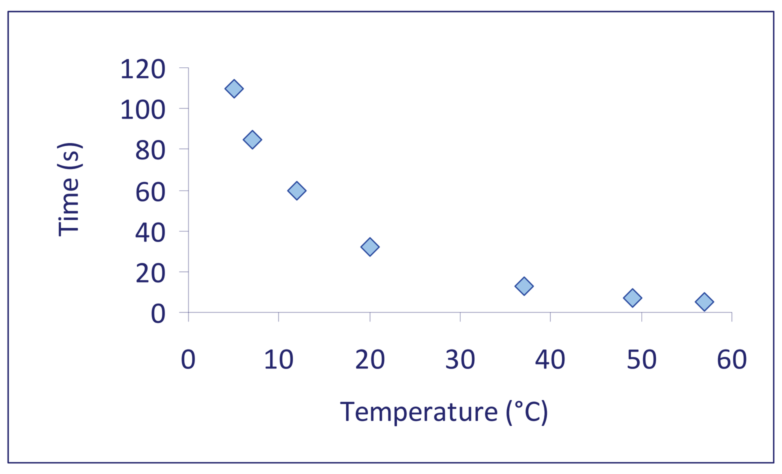
Temperature of the water bath (°C)	Time needed for precipitation of sulphur (s)
5	110
7	85
12	60
20	32
37	13
49	7
57	5

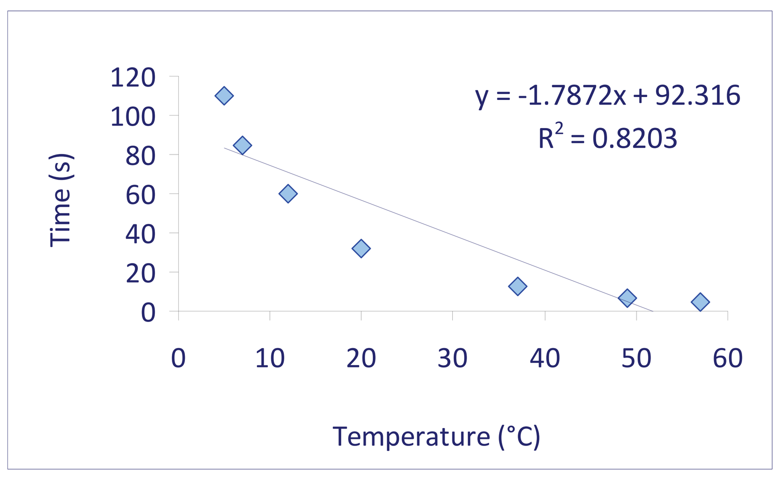
The students may illustrate the data directly measured, for example reaction time as a function of temperature. It is apparent from the measurement points that contrary to what most students expected, the relationship is far from being linear. The measurement marks cannot be linked by a straight line, but by only a curve.

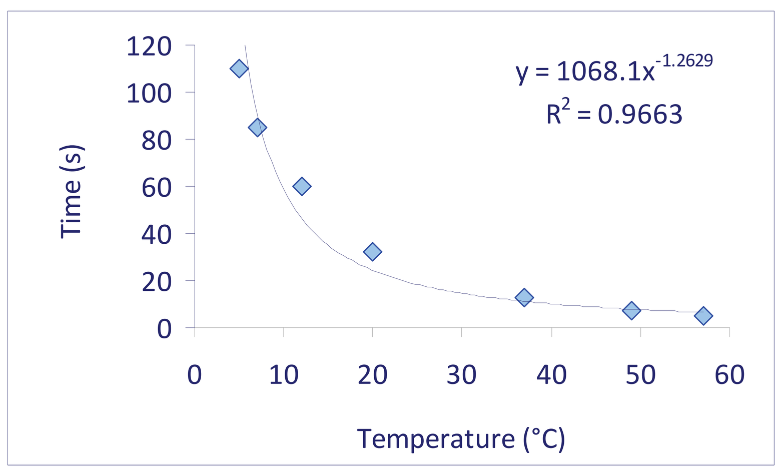
If it is possible to use a spreadsheet program and the students (not necessarily all) like to use one, a curve should be fitted. Furthermore, students can look for the most appropriate function that fits the data the best, about which the value of R^2 provides information. It would also be important to look up a function that describes the curve constructed from the data.

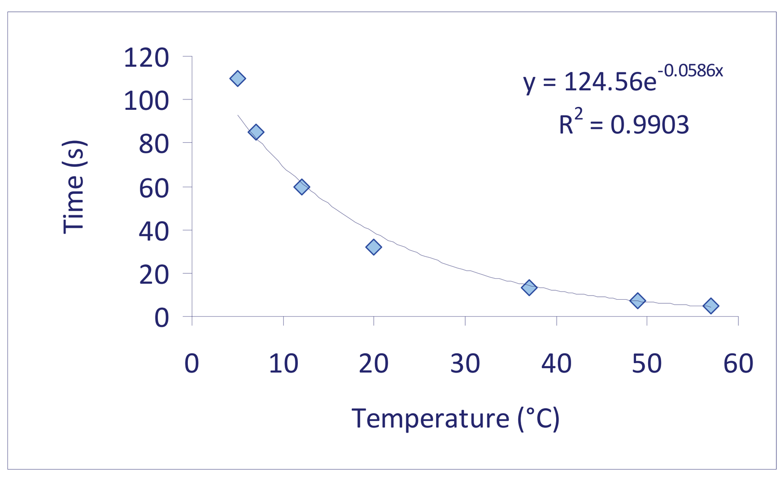


From measurement data to the exponential function







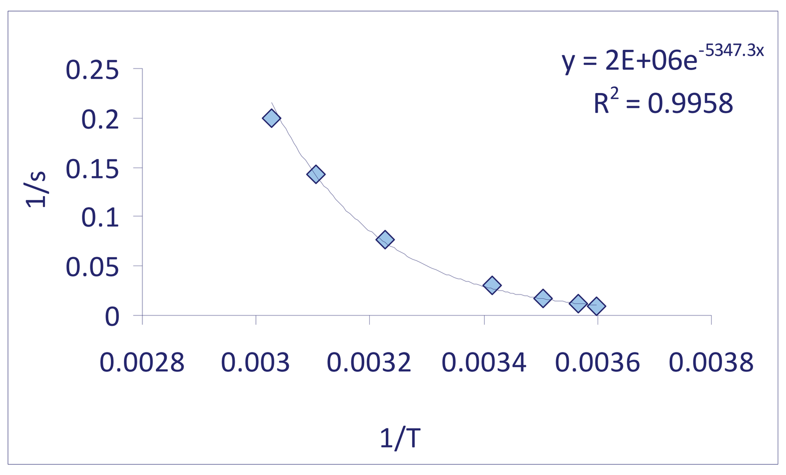


However, we would get k only via chemical calculations, which is not the topic of a physics class. Still, we know that the constant for reaction time is a proportional factor in the form describing the instantaneous speed of the chemical reaction:

$$\text{something} * k = \upsilon = \frac{d\,(\text{concentration of original material})}{dt}$$

The concentration changes are the same if we mix solutions of the same volume, so the reaction speed will be proportional to the reciprocal reaction time.

T (K)	1/T	reciprocal (1/s)
278	0.0036	0.0091
280	0.0036	0.0120
285	0.0035	0.1700
293	0.0034	0.0310
310	0.0032	0.0770
322	0.0031	0.1430
330	0.0030	0.2000



The form of the Arrhenius equation containing the molar (m) activation energy is (R=8.314J/molK, the universal gas constant):

$$k = Ae^{-\frac{(E_a)_m}{RT}}$$

The molar activation energy:

$m = -E_a/R = 5347$

$(E_a)_m = -mR = -(-5347)\ 8.314 \approx 45$ kJ/mol

Further discussion of the topic is recommended in specialized groups in differentiated processing. During the testing this part of the activity also took place. The activation energy of the reaction can be estimated with further analyzing the mathematical description. The studied problem is a good example for the Boltzmann-distribution.
Knowing the Arrhenius-equation we can calculate activation energy as well.

References

Nagy, M. & Radnóti, K. (2013). Problem solving in the topic of the Boltzmann-distribution. *Fizikai Szemle, 63*(7–8), 257–261. http://wwwold.kfki.hu/fszemle/archivum/fsz130708/nagy130708.html
Radnóti, K. (1982). The application of the Boltzmann-distribution in chemistry tasks. *Fizikai Szemle, 32*(5), 178–182.
Radnóti, K. & Tóth, E. (1986). *Teacher's handbook. Grammar School, Physics IV.* Budapest: Tankönyvkiadó.
Tóth, E. (1982). *Physics IV.* Budapest: Tankönyvkiadó.

CONTACT: rad8012@helka.iif.hu

SAILS Strategies for Assessment of Inquiry Learning in Science

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 289085