Competition *Expert*iment for the Classroom

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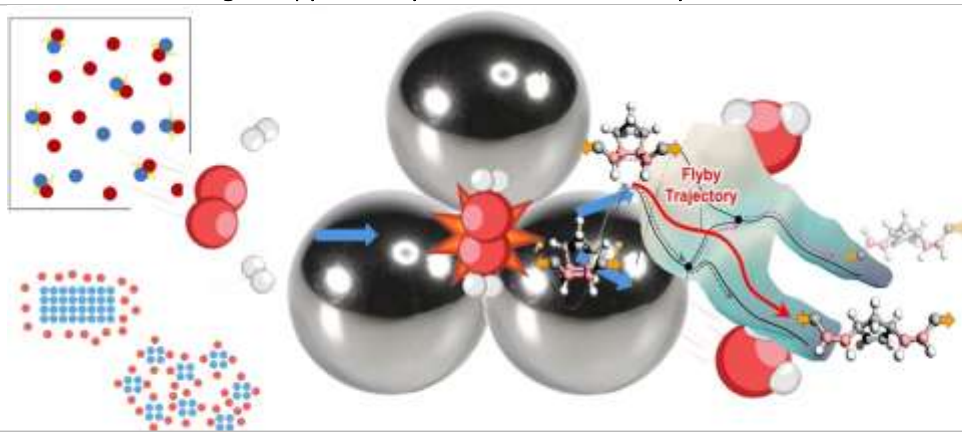
Title of the activity	Mechanochemistry – old new chemistry
Category of the activity	[Multiple answers possible] ☐ Game ☐ Quiz X **Experiment** X **Other: discussion**
Relevant school subjects	[Multiple answers possible] ☐Arts X **Chemistry** ☐Citizenship ☐Geography ☐History ☐Information and Communication ☐Languages ☐Maths ☐Natural sciences ☐Physical Education ☐Physics ☐Religion ☐Technology (including ICT) ☐Other:
Time needed to complete the activity	90 minutes or 2 school hours.
Detailed description of the activity	The purpose of the proposed activity is to introduce the high school students to general principles underlying mechanochemistry. Mechanochemistry, a methodology of prehistoric origin, is described in ancient Greek books. However, it is only recently introduced to contemporary chemical practice,

	gaining the importance in all fields of preparative chemistry. Its inherent ability to conduct chemical reactions entirely in solid state, i.e. without any solvent, makes it one of the green chemistry methods, highly interesting to industry. Thus, it is recognized by IUPAC as one of the chemical methods which will change the world. However, it is still not satisfactory represented in high school chemistry curricula, so this activity will contribute to close that gap. The MSCA action GrindCore, conducted by NB, is devoted to understanding of physico-chemical mechanisms underlying mechanochemical processes. Thus, here proposed activity is naturally linked to that project as one of its communication activities, which will be carried out in interaction with high school teachers and students. The activity is organized in form which simulate the scientific method, going from gaining the general knowledge on the subject, through development of hypothesis, its experimental checking and discussion of the results. The central role Is devoted to students, which conduct the experiments, discuss them and to draw conclusions. The role of teachers is to modulate and moderate the discussion and to supervise the experiments. The activity consists of: 1. **<u>Introduction</u>** to the concepts of mechanochemistry (15 min) – students perform simple examples of reactions in aqueous solution: a) precipitation reaction (yellow PbI_2 from the solution of $Pb(NO_3)_2$ by addition of KI); b) complexation of Cu(II) with 2-methylimidazole (2-MeIm). The chemical equations of the processes are written on board. The experiments are discussed with respect of the concepts of chemical reactivity and the factors underlying it. Teacher's questions will moderate the discussion on chemistry, from general concepts of molecular impacts and statistic nature of chemical systems consisting of large number of moving molecules, as well as the role of chemical environment and outer factors affecting the reactivity (Other details (a)). It ends by the question if the solvents are inevitable for reactions to proceed., and they will be asked if this reaction needs aqueous medium. Through a short discussion, the student are guided to bring the hypothesis that this (and other) reactions can be conducted without any solvent. 2. **<u>Experiments</u>** (45 min) (Other details (b)) – on the basis of the hypothesis brought at the end of introduction, the experiments, representing the most important families of chemical reactions (metathesis, redox, complexation) are designed and conducted. The students will be divided to three groups (not more than 5 students per group). a) **Metathesis** (ion exchange reaction) – (i) lead(II) iodide from potassium iodide and lead(II) nitrate: $Pb(NO_3)_2 + 2KI \rightarrow PbI_2 + 2KNO_3$. 1 eq of $Pb(NO_3)_2$ (white) and 2eq of KI (white) are mixed in mortar with pestle and/or in milling jar with 1 or 2 stainless steel balls. Yellow PbI_2 is produced after short mixing / milling. The reaction is compared with classical precipitation of PbI_2 from aqueous solution. (ii) $Rb_2CuCl_2Br_2$: 2 eq of RbBr (white) is mixed with 1 eq of $CuCl_2$ (brown) or $CuCl_2{\cdot}2H_2O$ (blue) in mortar with pestle. Dark reddish-brown product

	$Rb_2CuCl_2Br_2$ is produced after a few minutes of grinding. The two variants of the reaction are compared with respect of the influence of crystalline water to reaction rate. b) **Redox reaction** – oxidation of oxalic acid ($H_2C_2O_4$) to CO_2 by potassium permanganate ($KMnO_4$). Students must balance the redox equation $2KMnO_4 + 3H_2C_2O_4 \rightarrow 2MnO_2 + 2KOH + 2H_2O + 6CO_2$. The stoichiometric mixture (2 eq. of KMnO4 and 3 eq. of oxalic acid) is ground in mortar with pestle, which quickly results in violent reaction, indicated by release of heat and intense fuming. c) **Complexation** – 1 eq. of copper(II) chloride dehydrate (blue) is ground in mortar with 4 eq. of 2-methylimidazole. After short grinding, violet complex product $Cu(2\text{-}MeIm)_4Cl_2$ appears. The rate of the variant with $CuCl_2$, is compared. Additionally, $CuCl_2$, with addition of small amount of ethanol and some other solvents can be done and the reaction rates can be compared. 3. **<u>Discussion</u>** (30 min) – the results of the experiment will be discussed with respect of basic concepts of chemical reactivity. The conclusions should be based on ideas on transfer of mechanical to chemical energy, various factors affecting mechanochemistry, as well as the influence of added liquids. It ends with brainstorming on applicability of mechanochemistry.
Pictures or illustrations	
Other details	a) Factors affecting chemical reactions (on cards) – aggregate state (molecules are more movable in liquids and gases); concentration or pressure (more particles in given volume); temperature (faster particles at higher temperatures); area (larger surface area suffers more impacts); catalyzers (modification of the reaction pathway). b) Experimental equipment: to safely conduct these experiments, the students will wear the laboratory coats, single-use latex gloves and safety eyeglasses. The experimental equipment consists of spatulas, balance, mortar and pestle, transparent (PMMA) milling jar, a few stainless steel balls (3 or 4 g) and plastic bins for disposal of solid chemical waste.