Workshop on Friction Connecting School Students' Everyday Life to Recent Fundamental Research

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Abstract

The Collaborative Research Centre (CRC) 1073 "Atomic Scale Control of Energy Conversion" at the University of Göttingen aims to contribute to a sustainable energy future by providing guidelines for technical innovations which allow a clean, efficient, and sustainable generation and storage of electric energy. Since a large proportion of e.g. wind energy is converted into heat by friction occurring in bearings of wind turbines, the CRC project A01 tries to disentangle the process of converting kinetic energy into heat in a sliding contact. It has already contributed to a better understanding and thus to the discovery of control tactics of dry friction at the atomic scale. Nevertheless, the fundamental causes of friction are still not fully understood, even though it is all around us. At the macroscopic scale, friction is often described by simple empirical laws, but those cannot be applied at the atomic scale. The CRC enables high school students to discover this scale dependency themselves experimentally during the "Hands-On Energy Science Workshop" presented here. The workshop starts with everyday life friction phenomena. Afterwards, the students apply normal forces F_N and measure the corresponding friction forces F_R between two materials at the macroscopic scale. By using the Atomic Force Microscope of the CRC, students can then perform an analog experiment at the nanoscale, but the plot of the nanoscale friction forces vs. the nanoscale normal forces shows that the simple law $F_R = \mu \cdot F_N$ taught in school does not fit. This creates a cognitive conflict. When comparing this plot with the one of the forces they measured at the macroscopic scale they recognize that they do not have to change their pre-conceptions of friction, but that they need to extend it: Size must be considered. They finally understand why CRCs energy conversion studies at the atomic scale are required, in particular because components of technical innovations become smaller and smaller.

Keywords: friction, energy science, fundamental research

1. Introduction

Europe targets a cleaner and more sustainable energy future [1]. Therefore, physicists and chemists in the Collaborative Research Center (CRC) 1073 work together on tactics to control elementary steps of energy conversion at the atomic scale. In this way, the CRC researchers contribute to appropriate answers to central questions of our future energy supply: How can energy losses be reduced? (Researcher group A) How can the enormous power of the sun be efficiently converted into electric power? (Researcher group B) Since power is also needed when the sun is not shining: How can power be stored? (Researcher group C)

Researchers in project A01 aim to control friction losses in order to increase the efficiency of energy conversion processes, by relating the frictional losses measured at the surface to the physical properties of the underlying material. Friction is an everyday phenomenon, since it occurs always when two materials slide against each other, e.g. during walking between our shoes and the floor or in motors. A closer look at the contact area between the materials reveals very rough surfaces at the nano scale. It consequently consists of many nanoscale contacts. Moreover, components of technical innovations become smaller and smaller. That is why, the project A01 investigates friction at the nano down to the atomic scale by using an Atomic Force Microscope (AFM). Here, we present a workshop on friction addressing school students which reveals that the simple laws used to describe friction at the macroscopic scale cannot be applied at the nanometer scale. It shows the great value of research at small scales. Therefore, the main educational goals of the workshop are to pass an appreciation and understanding of research on to school students and to arouse their interest in energy science.

The friction workshop developed within the scope of a Bachelor project is one of a few workshops the CRC offers to school students [2]. Further public outreach activities [3] aim to encourage everybody to contribute to a sustainable energy future by an active participation in discussions about the future energy supply and by using energy consciously.

2. Workshop concept

The one-day workshop targets high school students, because the used measuring methods of the AFM require advanced cognitive capabilities. The first unit of the workshop deals with friction at the macroscopic scale and the second with friction on the nanometer scale. An additional unit about using friction losses to generate electric energy [4] is optional. As an introduction into the topic, simple questions are raised: Do you know friction from your everyday life? Why is it important for energy conversion processes? Since the students do not know us and the Göttingen University Campus, the questions act as ice breakers and activate the students, but they also evaluate their pre-knowledge about friction which gives us the opportunity to adapt the first unit to it.

In the first unit, school students apply the simple law which describes the proportional correlation between the friction force and the normal force. Based on their everyday life knowledge about friction they acquire the law experimentally using the inductive approach. Thus, students construct their knowledge according to the constructivist learning theory. If the students know the law already, the deductive approach is used instead. In this case, the only intention of the first unit is to ensure that every participant has the basic knowledge about friction needed to understand the main message of the workshop.

First, students are divided in groups of two to four students and each group is asked to develop an appropriate experiment to measure friction and its dependencies based on their everyday life experiences with friction. If they e.g. want to stop their bicycles faster than usually, they increase the friction force by applying a stronger normal force on the brake blocks. According to that, they usually have the idea to test in their experiments how the friction force depends on the normal force. They might also investigate, if friction depends on the size or roughness of the surface area or the material itself. The experiment students usually develop will be described in the following section 3.1. One group which plotted their measured friction forces F_R against the different applied normal forces F_N and which thereby figured the law $F_R = \mu \cdot F_N$ out (μ: friction coefficient), presents its results to the other groups.

In the second unit, the school students gain insights into the research topic and methods of the CRC project A01. We show them an animation film, in which the surfaces of the bearings of a wind turbine are slowly magnified until one can see that the contact area is in fact composed of many nanoscale contacts. This gives a first idea why the project A01 investigates friction at the nanoscale. Students might wonder: How can friction be measured at a scale we cannot see with our eyes or with the light microscope in school? Researchers use an AFM. In the workshop, students learn how the AFM friction measurements work by performing a model experiment described in section 3.2. Afterwards, they mount the sample & the cantilever which are only a few millimeters in size and measure the sample topography & friction under supervision (s. Fig. 1 and section 3.3). Then, they use the AFM friction data to plot the friction forces vs. the normal forces again. Comparing this plot with the plot from the macroscopic measurements of the first unit creates a cognitive conflict, because the fit line does not meet the zero-point. This means that the observations on the macroscopic scale cannot simply be transferred to the nano scale. Instead, the experimental results at the nano scale reveal the following equation: $F_R = \mu \cdot F_N + F_A$. F_A is caused by adhesion forces. Adhesion forces can be neglected at the macroscopic scale, but they cannot at the nano scale.

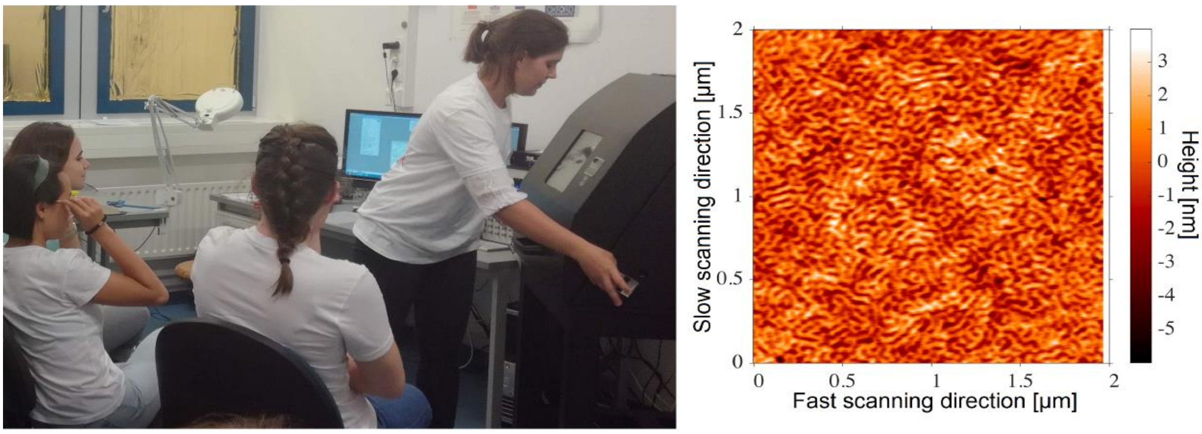

Fig. 1. School students at the AFM (left) and AFM image of polymer composite PS-b-PMMA (right).

3. Hands-On Experiments

In the workshop, friction is measured at the macroscopic scale and at the nano scale using an AFM. To help students understand how the AFM measurements work, they perform them with an AFM model first.

Students work with the exact same AFM instrument & the measuring mode the CRC researchers in the project A01 use. Additionally, they have the chance to ask the PhD student of this project questions to his project and the work as a researcher.

The main learning objective of the experiments is that the school students work like an experimental scientist measuring and comparing friction at different scales to understand how size affects friction.

3.1 Measuring friction at the macroscopic scale

Two materials lay on top of each other (e.g. a box made of an arbitrary material on a table surface) and a force gauge is fixed to the upper material. By moving the force gauge parallel to the contact area, the upper material is slid against the other material. Thereby, the friction force F_R is measured with the force gauge. This process is repeated with different weights laying on top of the upper material. Finally, the friction force is plotted against the normal force.

3.2 Measuring friction with an AFM model

Height measurements: The topography of a material surface (sample) containing e.g. a few bumps is measured with an AFM model. The model consists of the basic AFM components (s. Fig. 2): A cantilever connected with a tip reflects laser light onto a screen. To measure the material surface in the contact mode, the cantilever tip needs to touch the surface. Then, the material is moved parallel to the length of the cantilever. Depending on the local sample height, the cantilever is bent and the laser point on the screen moves up and down (vertical movement).

Friction measurements: To measure friction, the cantilever pressed onto the sample with a constant force F_N is moved perpendicular to the cantilever length. The Friction between the cantilever tip and the underlying sample leads to a torsion of the cantilever visible on the screen by the horizontal movement of the laser point.

3.3 Measuring friction at the nano scale using an AFM

An AFM height profile / topography of a sample is measured in the same manner as in the model experiment (s. section 3.2). To obtain the heights of an area, the cantilever tip, scans the area line by line.

The friction measurement in the AFM is analogous to the macroscopic experiment in section 3.1: The cantilever tip slides against the sample surface. The friction force is measured by the torsion of the cantilever as it is done in the model experiment (s. section 3.2). After every scanned line, the normal force is increased. After the AFM experiment, the measured friction force is plotted against the applied normal force.

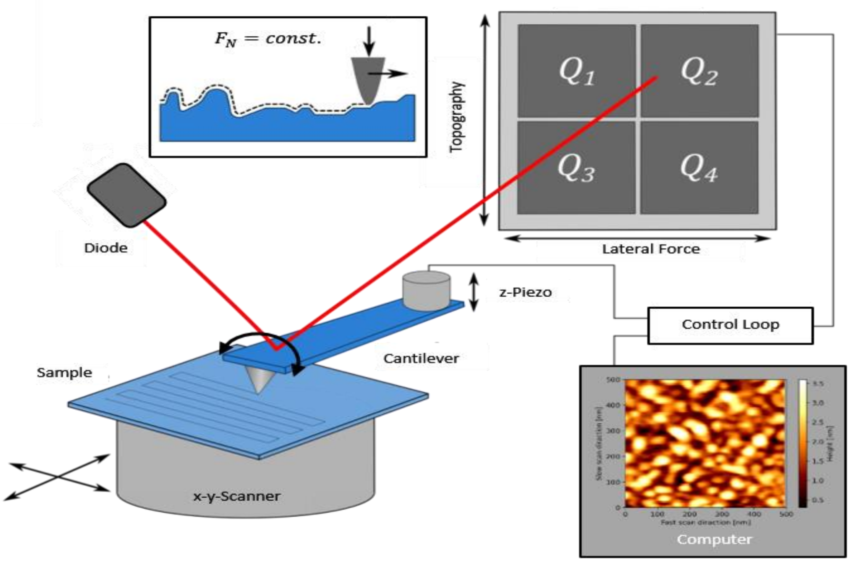

Fig. 2. Schematic picture illustrating the basic operation principle of an AFM [5].

4. Summary

We presented a workshop in which students work like researcher in the CRC project A01. They use the same equipment and reproduce the experimental approach by which researchers understood that size affects friction and material behavior / properties in general. These findings are especially important for technical innovations whose components become smaller and smaller.

5. References

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