The workshop “Diffusion – A Microscopic Process With Remarkable Macroscopic Consequences” was part of the German National Academic Foundation’s Summer University in Alpbach 2003. For two weeks, 13 students from all over Germany and the professors Heitjans and Kärger from Hannover and Leipzig, respectively, discussed the nature, properties, and consequences of diffusion in science, economics, social sciences, and transportation. All students gave at least one presentation mostly related to their studies followed by a vivid discussion. The aim of this report is to name the different talks and to outline the common idea.

The main characteristic of all the systems considered during the progress of our seminar is the presence of a high number of particles. The movements of these particles are in some sense random, which is mostly due to the interaction of the particles. Nevertheless, when looking at the system from a macroscopic point of view a certain complexity and regularity can be observed. This is due to the fact that the particles – even though behaving randomly – obey statistical laws. Bearing this in mind, one cannot be surprised that a main tool for dealing with many of these phenomena is the well-known Brownian motion. Even though the particles can be as different entities as atoms, car drivers, or coins, the laws observed are strikingly similar. This fact allows transferring many results obtained in experimental physics to economical and social phenomena. Of course, one always has to be careful when interpreting the results.

Christine Selhuber’s talk about the basics of diffusion provided all of us with a common background in the physical basics of diffusion in gases, fluids and solids. The macroscopic description of diffusion by Fick’s laws and the microscopic one by Brownian motion were introduced and served as the basis of all the following physics related talks. At the end, she gave examples how to examine diffusion in biology and biophysics and emphasized its importance. Lots of her talk’s key words were related to the following talks, percolation and the role of diffusion as regulator in biological systems should be stated here. The latter also was part of Lena Melter’s talk about diffusion-limited processes in biotechnology. She mainly described internal and external mass transfer on a macroscopic basis and showed how its efficiency is improved by nature and in industry.

Coming back to the fundamentals of diffusion, Andreas Alvermann took up the central idea of Brownian Motion and spoke about Einstein’s work on diffusion; especially the Einstein-Smoluchowski relation impressively shows the connection between macroscopic behavior (Stoke’s friction) and the microscopic driving behavior (Brownian motion). In some way even more fundamental was his related talk about transport coefficients and the fluctuation dissipation theorem.

The at first sight simplest case of diffusion, the one-dimensional diffusion, turned out to be quite complex in its macroscopic behavior, as Rubén Cantero-Álvarez pointed out. The normal three-dimensional diffusion is limited by external walls and other diffusing particles. Surprisingly, the macroscopic behavior depends on the time scale. On long time scales, all particles move uniformly, though the underlying reason is a random microscopic process. Due to the discrete nature of the lattice of solids, diffusion in solids is much more complex than in fluids or gases. Wolfram Möbius presented some models and mechanisms of solid-state diffusion. Special attention was paid to the phenomenon of correlation amongst different jumps of one single particle and – in the context of ionic conduction – correlation between different diffusing particles. Thorsten Keller and Jochen Mikosch both reported on special
cases of solid-state diffusion. The former concentrated on (fast) ionic conduction under the perspective of techniques, nanosystems and applications. Latter spoke about grain boundary diffusion where the connections between microscopic structures, its influence on microscopic behavior and its macroscopic consequences were emphasized.

To complete our physical picture of diffusion, we heard three talks about experimental techniques to examine diffusion. Alexander Klein gave an introduction into NMR relaxation and its applications to diffusion experiments, while Rubén Cantero-Álvarez emphasized the theoretical background and gave us an understanding of PFG-NMR. Florian Merkt finished this part of the seminar with his talk on neutron scattering.

In the second part of the seminar, we turned our attention to other phenomena that are not related to diffusion in its physical meaning. As already mentioned above, it is characteristic for these phenomena to contain a high number of particles. Their possibilities - speaking in the language of physics: their degrees of freedom - are microscopic. That means that they only interact with few neighboring particles. An additional point that has to be considered is that the movements of the particles are not governed by strongly deterministic laws (such as gravity or electromagnetic forces). The particles can interact with their environment, thus creating more complexity. Nevertheless, they follow statistical laws and, therefore, concepts of the physical models mentioned above can be applied.

During a presentation on the dynamics of traffic systems given by Frank Aurzada, we discussed how decisions of "particles" of the system (in this case drivers or pedestrians) influence the state of the system in total (e.g., how traffic jams are caused). The analysis of this example is of great importance in everyday life.

Another striking - though academic - example is the diffusion of coins after the introduction of the Euro in 2000. The fact that different coins were issued in all participating countries allows a comparably easy observation of the merging process. Though the example may appear simple, Stephan Ricken’s presentation started an interesting discussion on the limitations of a description by diffusion. Furthermore, Frederik Herzberg talked about the modeling of decision processes in social systems, where concepts of diffusion processes can be applied.

Finally, the example of financial mathematics was discussed by Stephan Ricken and Gerrit Reininghaus. The latter had already given an introduction to the mathematical foundation of the Brownian motion; here, he presented the mathematical background of Stephan Ricken’s to practice related talk about random walk at the stock exchange. In this example as well, the decisions of small order, such as buying and selling shares, influence a global variable, i.e. the stock value. Usually, the small scale-decisions can be considered random and thus they are an excellent example for the use of the Brownian motion model.

We would like to thank the German National Academic Foundation for making this workshop possible. We owe special thanks to the professors Heitjans and Kärger for support in the preparation of the talks and for taking the time to discuss diffusion for two weeks. And last but not least, thanks to all our fellow students for this great time.

Frank Aurzada and Wolfram Möbius

More information about the Summer Universities and this workshop can be found at www.studienstiftung.de and http://ingo.exphysik.uni-leipzig.de/, the latter in particular with the material presented during the diffusion workshop.