Mesoscale Science: Lessons from and Opportunities for Nanoscience

Earlier this month, I attended and spoke at a workshop of the Chemical Sciences Roundtable on mesoscale science.[1] We discussed the opportunities available at this next scale up from nano. The program, slides, and synopsis will be made publicly available.

The first question to address is what is mesoscale science? One set of defining characteristics is given by a widely discussed U.S. Department of Energy report on the subject,[2] which posits that the key components of the mesoscale are granularity, defects, energy quantization, collective behavior, fluctuations and variations, interacting degrees of freedom, and structural and dynamical heterogeneity. One can see how these properties diverge from many nanoscale systems where precision, monodispersity, and other such properties are targeted, if not attained.[3,4]

An additional advantage that we in nanoscience have in addressing problems in mesoscale science is that we have already learned to talk across fields.

The hope in moving to more heterogeneous, and typically larger, systems is that some of the constraints of details of the nanoscale science may be relaxed. For example, in larger volumes, dopant statistics are less important than one finds in state-of-the-art electronics, at the ~10 nm and smaller scales. In addition, new phenomena appear at the mesoscale; as Phil Anderson wrote in an opinion piece more than 40 years ago,[5] "At each level of complexity entirely new properties appear, and the understanding of the new behaviors requires research." He argued for the importance of constructionist science in addition to reductionist approaches. That is a strong argument for how nanoscience and nanoscientists can contribute in building up to the mesoscale.

One of the central questions of mesoscale science is what do we *not* need to know in detail? How can heterogeneity and scale be used to simplify these heterogeneous systems? For example, variations in grain sizes lead to structural heterogeneity, but often the resulting surfaces and interfaces are critically important in terms of chemical and physical properties. Thus, the grain properties might be considered as variable and heterogeneous, but we may still require specific details of the interfaces formed. With this detailed knowledge, as in nanoscience, we may learn to control those interfaces. Or, consider a virus, which might typically be ~100 nm across. The capsid can have high symmetry and precision, but its genome, while varied in precise chemical composition, has highly specific coding that cannot be ignored in elucidating biological function. In some cases, heterogeneity has specific meaning, and in other cases, it is simply variability. This sorting of what degrees of precision will be required at multiple simultaneous scales is an important starting point that has not been solved.

As we have found as a field for nanoscale science, new tools will be required for spectroscopic and spatial isolation of the key components of mesoscale systems.[6] Heterogeneity and multiple scales pose substantial challenges in experiment, theory, and simulation; much creativity and great opportunities lie ahead. The coupling of mesoscale science to nanoscience is *via* the key component parts of mesoscale systems.

An additional advantage that we in nanoscience have in addressing problems in mesoscale science is that we have already learned to talk across fields. Indeed, this is one of the key contributions of nanoscience and nanotechnology. We have broken down barriers between fields such as chemistry, engineering, environmental health and safety, materials science, mathematics, medicine, physics, and others; we have taught each other approaches,

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terminology, techniques, and even what problems matter in each field. Thus, I anticipate that nanoscientists will play key roles in advancing mesoscale science; we will look forward to reporting those advances, challenges, and opportunities here.

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REFERENCES AND NOTES

1. Chemical Sciences Roundtable: Mesoscale Chemistry. *A Workshop by the Chemical Sciences Roundtable*, November 6–7, 2014, Washington, DC (Agenda: chemsciround-agenda-9-9.pdf.) http://dels.nas.edu/Past-Events/Chemical-Sciences-Roundtable-Mesoscale-Chemistry/AUTO-8-82-22-G. Accessed November 10, 2014.
2. Crabtree, G.; Sarrao, J.; Alivisatos, P.; Barletta, W.; Bates, F.; Brown, G. French, R.; Greene, L.; Hemminger, J.; Kastner, M. *et al.* From Quanta to the Continuum: Opportunities for Mesoscale Science, 2012. http://science.energy.gov/~/media/bes/pdf/reports/files/OFMS_rpt.pdf.
3. Pelaz, B.; Jaber, S.; Jimenez de Aberasturi, D.; Wulf, V.; Aida, T.; de la Fuente, J. M.; Feldmann, J.; Gaub, H. E.; Josephson, L.; Kagan, C. R.; *et al.* The State of Nanoparticle-Based Nanoscience and Biotechnology: Progress, Promises, and Challenges. *ACS Nano* **2012**, *6*, 8468–8483.
4. Claridge, S. A.; Castleman, A. W.; Khanna, S. N.; Murray, C. B.; Sen, A.; Weiss, P. S. Cluster-Assembled Materials. *ACS Nano* **2009**, *3*, 244–255.
5. Anderson, P. W. More Is Different: Broken Symmetry and the Nature of the Hierarchical Structure of Science. *Science* **1972**, *177*, 393–396.
6. Weiss, P. S. New Tools Lead to New Science. *ACS Nano* **2012**, *6*, 1877–1879.