Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
2016 Volume IV: Physical Science and Physical Chemistry

Introduction

This seminar covered a range of topics in the physical sciences, with an emphasis on physical chemistry. Quantifying the world around us allows us to fully understand it. The subject of physical chemistry is largely concerned with the description of matter and transformation of matter.

Thermodynamics is the study of energy, heat, and work, and their interconversion on a macroscopic scale. It continues to play a central role in physical chemistry. The three laws of thermodynamics provide rigorous limits to the maximum efficiency of converting heat into work that can be obtained. The relationship of the Gibbs free energy to enthalpy and entropy is also extremely important. Chemical equilibrium and phase changes are fully understood in terms of the Gibbs free energy.

While thermodynamics treats matter on the bulk macroscopic scale, spectroscopy allows the microscopic molecular properties to be measured and understood. Spectroscopy is the interaction of light with matter. Sometimes absorption is measured, and sometimes emission is measured.

This seminar included demonstrations each week, and connections to our everyday life as much as possible. Some demonstrations were done by me, but each Fellow also shared a demonstration when they presented an overview of their curriculum unit.

The primary sources for background reading material were *An Introduction to Physical Science* , 12th Edition, by James T. Shipman, Jerry D. Wilson, and Aaron W. Todd, and *Chemistry* , 8th edition, by Steven S. Zumdahl and Susan A. Zumdahl.

We began by discussing the human side of science which included the scientific method, scientific ethics, and pathological science. [1] We then considered the gas laws which are the relationship among pressure, volume, and temperature of a container of gas, and in this way provide a clear path to thermodynamics. Internal energy, enthalpy, entropy, and Gibbs free energy are important thermodynamic properties, and set the stage for understanding physical change, i.e., phase transitions. In addition to phase diagrams describing solids, liquids, and gases, we discussed how the Gibbs free energy underpins the content of these phase diagrams. Metastable liquids such as water at temperatures above its boiling point [2] or below its freezing point [3] are an interesting phenomenon because they will undergo a very rapid phase transition if the container is bumped or shaken. This section of the seminar was wrapped up by discussing mixtures, chemical reactions, batteries, fuel cells, [4] and nuclear chemistry. [5]

We then moved away from physical chemistry and began discussing physical science more broadly speaking. We spent quite a bit of time on waves, interference, [6] light and color, and polarization. This led to the

application of spectroscopic methods to art conservation, preservation, and analysis, [7] which culminated in a very interesting and engaging tour of the Yale University Institute for the Preservation of Cultural Heritage (http://ipch.yale.edu/). Lastly, we saw how spectroscopic methods are used in astronomy to characterize the temperature and composition of stars, and in the search for extrasolar planets, or exoplanets, which are planets that orbit stars in other solar systems. [8]

The curriculum units developed will be of interest to teachers ranging from second grade to senior year in high school. They provide extensive lists of reading material and other resources, and more importantly, a variety of hands-on activities. One of the recurring themes is that science is best learned in an experiential setting.

The units by Carol Boynton, Ariella Iancu, Stephen Kissel, and Larissa Spreng are overviews of matter and phase changes, and the thermodynamic considerations behind them. Terry Bella's focuses exclusively on the physical properties of water, while Michael Petrescu's focuses on the gas laws, heat engines, and thermodynamic efficiency (using the example of a Stirling heat engine). Christopher Finan's unit approaches the properties of matter in the setting of forensic science.

Jonathan Cap's unit describes the history of batteries and their role in robotics. The units by Amanda Weires and Andrea Zullo each cover light and sound, but from very different perspectives. Amanda's unit is about light and sound in the context of a theatre setting (plus a discussion of exoplanets), and Andrea's is an anatomical description of the human perceptions of sight and sound.

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Additional Readings

1. "Pathological Science" by Irving Langmuir, *Physics Today* , volume 42, page 36, 1989.
2. https://www.youtube.com/watch?v=2FcwRYfUBLM
3. https://www.youtube.com/watch?v=pTdiTe3x0Bo
4. "Fuel Cells," Los Alamos National Lab publication LA-UR-99-3231, www.pdhonline.com/courses/e196/fuelcells.pdf
5. "Inertial Confinement Fusion", https://en.wikipedia.org/wiki/Inertial_confinement_fusion
6. "The Michelson-Morley Experiment" by, R. S. Shankland, *Scientific American* , volume 211, Issue 11, page 107, November 1964.
7. http://www.webexhibits.org/pigments/intro/look.html
8. "NASA Says Data Reveals an Earth-Like Planet, Kepler 452b," New York Times, July 23, 2015; http://www.nytimes.com/2015/07/24/science/space/kepler-data-reveals-what-might-be-best-goldilocks-planet-yet.html)