Innovation in Chemistry Laboratory Teaching:

Deductive Introduction to Quantum Principles through a Resonance-Focused Chemistry Laboratory

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Introduction

Communicating the principles of quantum mechanics to underclassmen can be a particularly difficult objective. However, laboratory demonstrations of quantum principles can greatly enhance young scientists' capacity to understand such concepts.

Through this UTRA, we designed and developed a new underclassmen laboratory with the aim of providing hands-on learning of quantum mechanics, in order to allow the students to better relate to these concepts, which are usually left very abstract.

Through this laboratory, students are first led to investigate resonance and standing waves at macroscopic level via mechanical vibration of membranes subject to varying boundary conditions. Then, they are exposed to the wave mechanics at mesoscopic level by synthesizing silver nanoparticles and analyzing how their plasmon frequencies change with size and shape of the nanoparticle.

Through this practical macroscopic and mesoscopic level demonstration of wave mechanics, students obtain an intuition that opens the road to further questions in the realm of quantum mechanical aspects of chemistry.

Overview: Macroscopic vs. Mesoscopic Level

Figure 1: The vial on the left (blue) contains silver nanoprisms; the vial on the right (yellow) contains

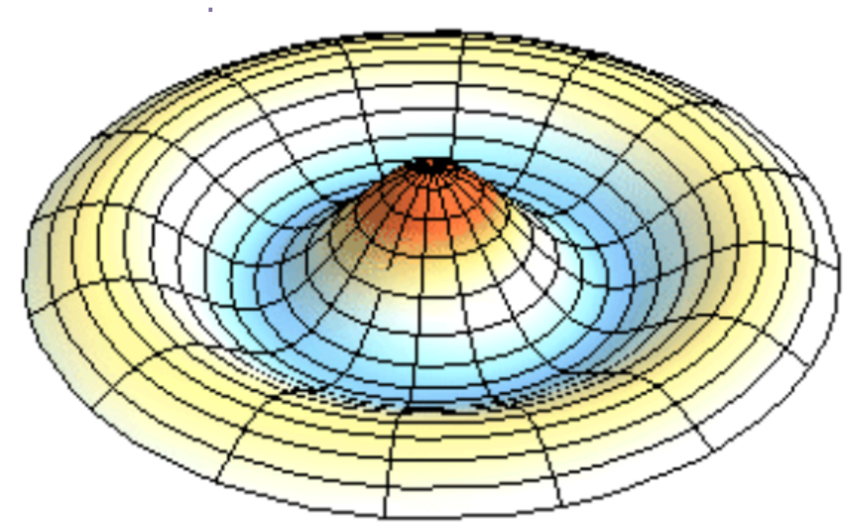


Figure 2: Normal mode of vibration for a standing wave membrane.[1]

What happens at a macroscopic level?

- A bubble solution membrane is made to vibrate through a speaker connected to a signal generator;
- Normal modes of vibration of the membrane can be identified at specific frequencies and visualized on a macroscopic scale.

What happens at a mesoscopic level?

- Synthesis of anisotropic nanoparticles;
- $NaBH_4$ (aq) + 8$AgNO_3$ (aq) + 4H_2O (l) <-> Na[$B(OH)_4$] (aq) + **8Ag (s)** + 8HNO_3 (aq) -
- Hydrogen peroxide is the etching agent. Without it, nanospheres are formed. With it, we form nanoprisms.
- Localized Surface Plasmon Resonance (LSPR) variations lead to color changes that can be visualized through UV-spectroscopy.
- With LSPR, the conducting electron cloud of the NP oscillates as quantized waves and absorbs EM radiation of a particular energy.

Results and Discussion

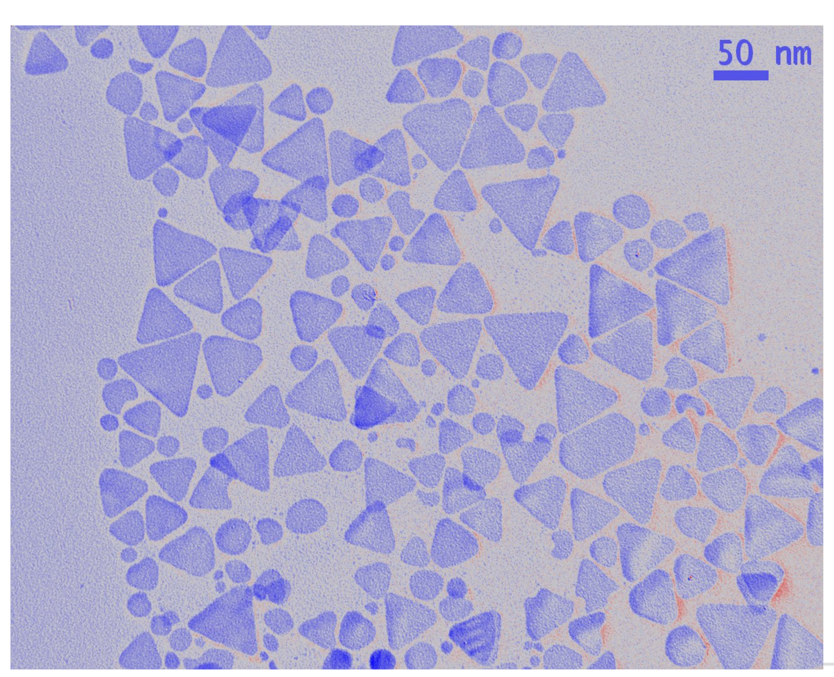
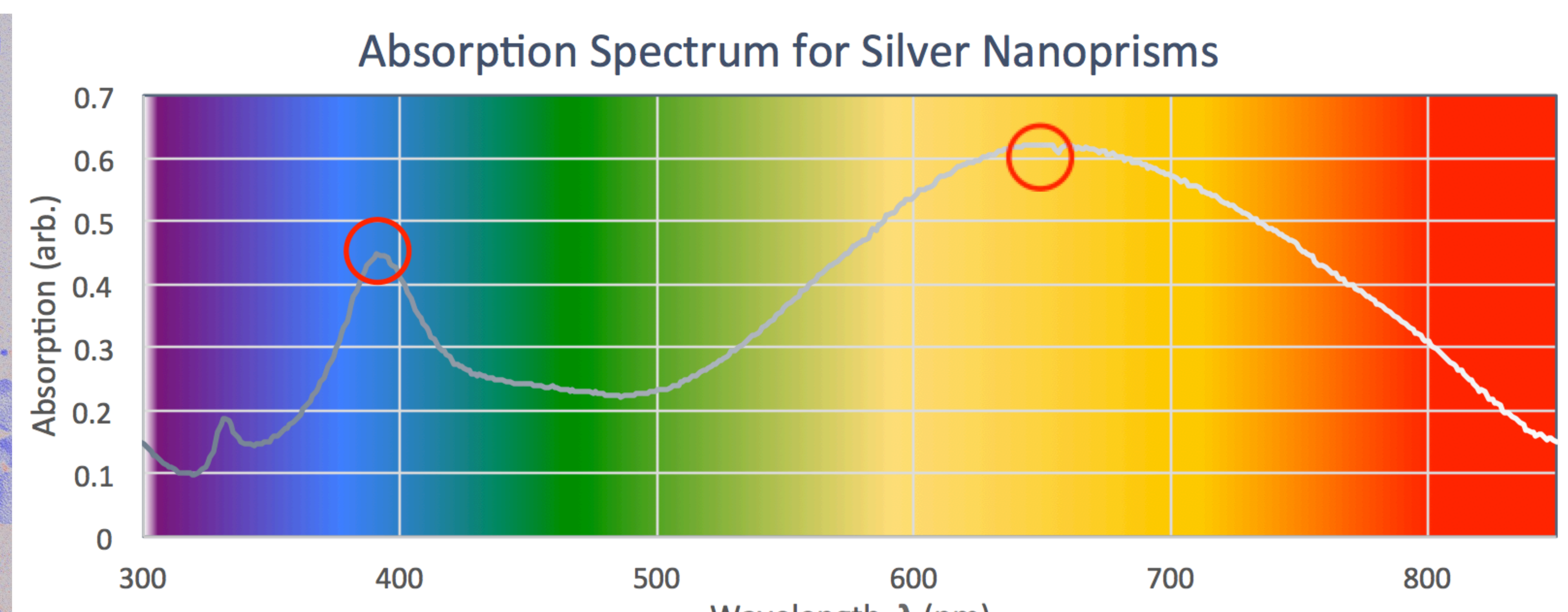


Figure 3a: Transmission Electron Microscopy (TEM) image of silver nanoprisms, size 50nm.



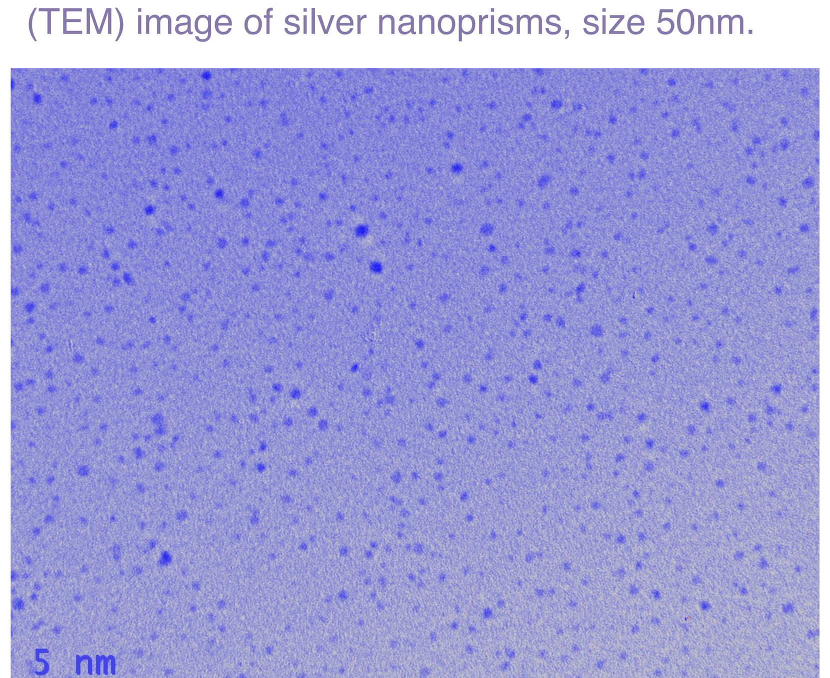
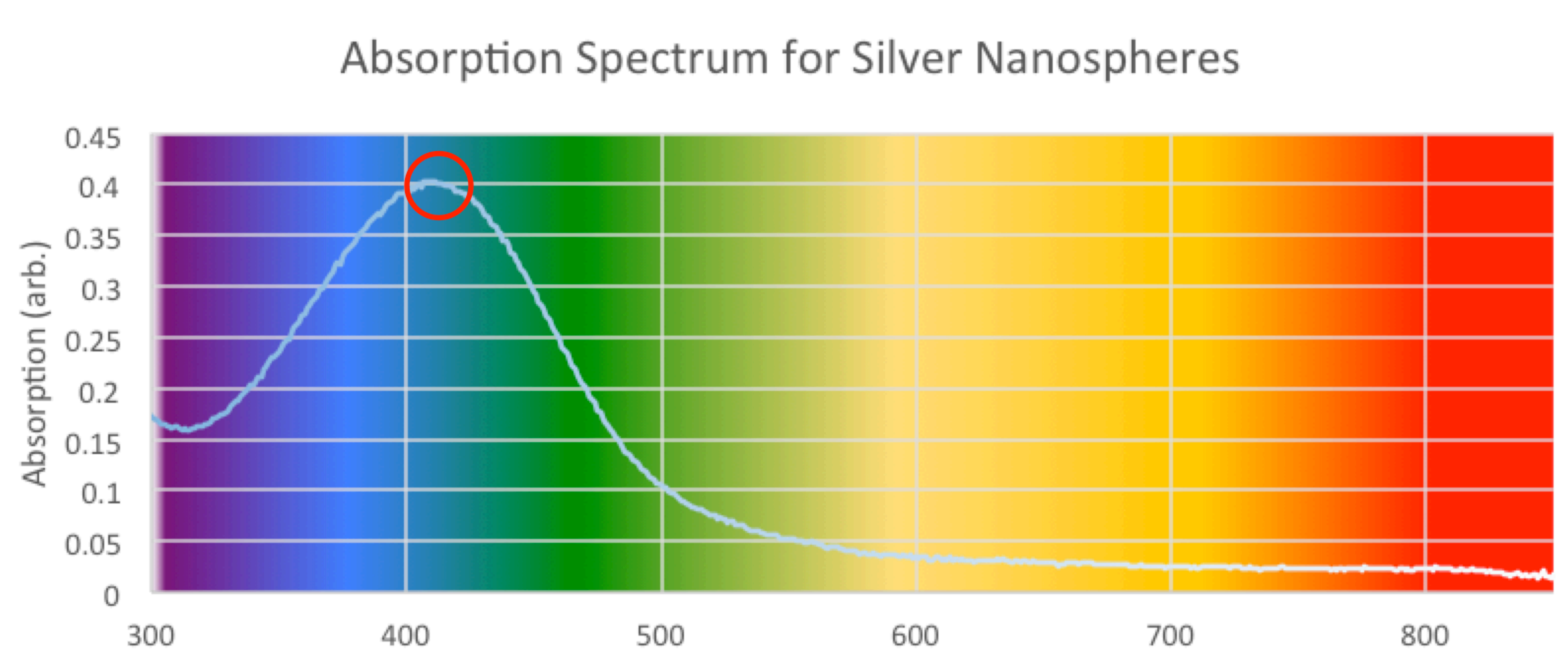


Figure 3b: Transmission Electron Microscopy (TEM) image of silver nanospheres, size 5nm.



•The silver nanoprisms are formed by an equilateral triangle of side *x*, and develop in depth through a distance *y*. Consequently, they display two possible *boundary conditions*. This results in two peak wavelengths as shown in the first Absorption Spectrum on the left.

•The silver nanospheres only display one boundary condition (the sphere's radius is constant). Hence, the second Absorption Spectrum shows only one peak (plasmon resonance maxima ≈400 nm).

•The size of the nanoparticles differs by one order of magnitude. This difference in size is also reflected in the positioning of the peaks in the two absorption spectra.

Background Knowledge

Why synthesize *silver* nanoparticles? – Dimensional confinement of the electron density in a metal nanoparticle gives it properties that differ from those of non-metal nanoparticles: quantum-size effect.

What is LSPR? - An important physical property derived from this size effect is Localized Surface Plasmon Resonance (LSPR) – the collective interaction of geometrically constrained delocalized electrons with light.

How does this relate to the *particle-in-a-box* model? - The excited delocalized electrons can be thought of as a "particle in a box", where the nanoparticle itself acts as the *box*.

Why do the absorption spectra show different peaks if solutions contain *silver* nanoparticles? Nanoparticles of different sizes and shapes display different plasmon resonances and as a consequence absorb light of different wavelengths, thereby giving rise to different colors of NP dispersions.

How do we control the nanosprims size? – Volume of sodium borohydride added is crucial.

Why is this relevant?

- Early exposure to physical chemistry allows interested students to familiarize with the subject early on.
- Recently there has been great interest and extended progress in the field of nanochemistry. An undergraduate experiment where nanoparticles are synthesized is both relevant to modern chemistry and very appealing to students.
- Focusing on the mathematics of quantum mechanics leads to losing sight of the physical results. By presenting chemical concepts through a quantum mechanical description in the first year, faculty teaching the course are forced not to rely principally on mathematics and thus can focus on how the quantum world behaves

Accomplishments with the UTRA

•Newly developed Quantum Chemistry laboratory;

•Inquiry-based lab procedure and experimental report;

•Current development of a biological laboratory involving the use mimicking over-the-counter drugs' absorption.

Acknowledgements

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Source of image 2: http://askthephysicist.com/images/mode03.gif