Scripts for High School Visits to the Herman Group at Columbia University

Evan Spotte-Smith, Jiayang Hu, and Irving P. Herman

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These presentations were developed for visits from high schools to the Herman group at Columbia University, to help engage students and their teachers and to help the students think about technical matters.

The visiting student group was divided into two sections, as needed due to group size. Each group presentation was divided into two 20-30 minute sections, where the overarching questions addressed in one section were: (1) What is the nanoscale? What are nanoparticles? What happens to light when it goes through materials?, and in the other: (2) What are the current and future building-block materials used in electronics and lasers? How do you "see" structures of these materials? The two presentations were presented at the same time to halves of the groups. After each one, the groups changed rooms and the presentation was repeated. The scripts were developed so either could be presented first or they can be combined.

In the first section we used cells filled with colloids of CdSe nanoparticles of different sizes, along with black lights, and red and green laser pointers, and showed a set of images. In the second section, we used structure models and the lab optical microscope and Raman microprobe system, and displayed a series of images.

Student engagement was good during both sections, and even improved when we began to ask students questions during the presentations. We developed several questions for the first section, and used them as needed: What number term does nano sound like? (nine, nine zeros); if you use chemical reactions to grow the particles from molecules, how do you make the different sizes of these particles? (let them react longer and/or at higher temperature and they will be bigger); how would you go about making a one layer of particles, as in the pictures shown to them? (a colloid/solution of the particles -- drop on a surface and let the solvent evaporate); and then, does it make sense to also do this also on another liquid? (yes, if they don't mix, and this is something we do in this lab).

Questions we developed for the second section: (after talking about Si and GaAs) included: What are the different types of carbon? (coal, diamond (looks like Si, but with C), graphite (pencils))--and this leads to a discussion about graphene); what are the ways you can see small objects, aside with your eyes? (optical microscopy); (after talking about using light in microscopy and Raman scattering) what are limits to the use of light (its wavelength---a millionth of a meter); what else can be used? (use electrons, and then show SEMs and TEMs, including from our work).

Section 1

Hello, everyone. My name is (Evan Spotte-Smith), and I work here, in the Herman group lab. Today, you're going to be hearing two different talks. In this room, we'll be talking about the nanoscale, nanoparticles, and how material properties change when size changes. In the other room, you'll be hearing about some specific materials used in electronics and optics, and about how we "see" things that are too small for our eyes to detect, specifically with spectroscopy and microscopy.

So, first, can anyone tell me what "nano" means? **Accept answers from students**. "Nano" means one-billionth, one divided by 1,000,000,000. When we talk about the "nanoscale", we mean things that are between one and one hundred nanometers. And one nanometer is about one-billionth the size of you. It's about one thousandth the thickness of one of your hairs. That's pretty small, right? And when materials get that small, they start to behave differently.

Can anyone give me an example of something that's different when it's big from when it's small? **Accept answers from students**. When you reduce the size of an object, especially as you get in the nanoscale, properties start changing significantly. This includes mechanical properties, electrical properties, thermal properties, and so on. The property that we'll be focusing on today is the optical properties of materials, how the materials interact with light.

What is light? **Accept answers from students.** Right. Light consists of streams of particles that carry energy, called photons. It is also a wave, and like all waves, it also has a wavelength, and in the case of light, that wavelength determines the color that we see. ***How do we get color? What makes one thing red, and another thing blue?*** **Accept answers from students**. Color comes from how light interacts with the material. ***And what are some different ways that light can interact with something?*** **Accept answers from students.** Okay, so we have four different ways that light can interact with a material. The material can absorb the light. It can reflect it. It can transmit it, meaning that the light goes right through. Or, it can emit it, meaning that, rather than the light going into the material, the material is sending light out. And sometimes, a material will absorb light at one wavelength and emit light at another wavelength.

So, now that we understand light, and understand color, let's look at some examples. So, first, I want to show you something that we work with in this lab. <u>Pick up a cuvette of silver nanocubes.</u> These are nanoparticles. ***Does anyone want to guess what kind of nanoparticles?*** I'll give you a hint. They're rather expensive. **Accept guesses from students.** These are actually silver nanocubes. They don't look silver at all, do they? That's because, on the nanoscale, the optical properties change. At this scale, the color of the nanoparticles changes because of the electrons confined in them. The smaller the particles, the more tightly the electrons are confined. We'll see another cool effect of that confinement in a little bit. But first, I want to show you an application of these different colors. ***Any questions so far?*** **Accept questions from students**.

<u>*Pick up poster with stained glass and nanoparticle information*</u>***. Does anyone know how stained glass is made?*** **Accept answers from students**. So, you take the molten glass, and you add other substances to it, usually metals and metal oxides. And those metal and oxide particles make the glass different colors. Some of those particles are actually nanoparticles. People were using nanoparticles for over a thousand years, and they didn't even know it! <u>*Explain how the different sizes and shapes of nanoparticles give different colors, as explained on the graphic.*</u> ***So, how is the light interacting with this stained glass?*** **Accept answers from students.** Right. Some light gets transmitted, and some gets absorbed. Now, I'm going to show you how the light emitted can change. Here <u>*gesture to cuvettes with CdSe nanoparticles*</u> we have cadmium selenide nanoparticles. Now, all of these nanoparticles are made of the exact same material, but you can already see that they're different colors. Part of that has to do with the how concentrated the solution is, but a lot of it also has to do with the sizes of the particles. And, when we turn the lights off <u>*turn lights off, turn the blacklight on*</u>, you can see that the light that they emit changes, too. This here is a blacklight. It shines ultraviolet light on the nanoparticles, which is then emitted out as different colors. Now, I said that these nanoparticles are all different sizes. ***Which ones do you think are the biggest?*** **Accept answers from students.** So, the red particles are actually the largest. And the reason why is because red light has lower energy photons than blue light. I said before that the smaller the particle, the higher the energy. So, the smaller the cadmium selenide nanoparticle, the closer it gets to emitting blue light.

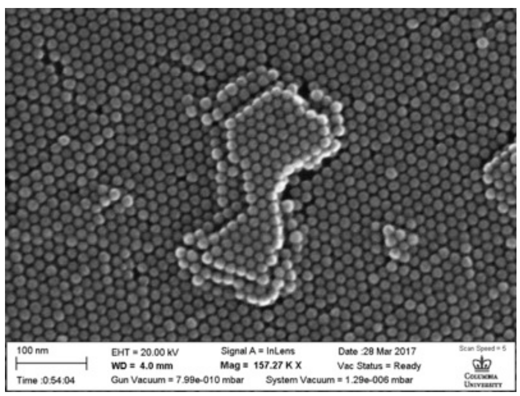
<u>*Turn lights on*</u>. I have one last demonstration. <u>*Take out laser pointer, shine it on ground*</u>**.** This is a laser pointer. It has two colors, red and green. This <u>*gesture to cuvette with CdSe nanoparticles*</u> has another solution of cadmium selenide. ***When I shine the red light on it, what happens?*** <u>*Shine light.*</u> **Accept answers from students**. Right, the light is transmitted. It goes right through. ***But, what happens when I shine the green light?*** <u>*Shine green light.*</u> **Accept answers.** It's absorbed, and then it's emitted as yellow light. ***Any questions on any of this?*** **Accept questions.**

So, in this lab, we work with nanoparticles. Specifically <u>*show board with SEM and TEM images*</u> we work with single layers of nanoparticles. Now, I said before that we had nanoparticles of all different sizes. We make all of those nanoparticles here in the lab. ***How do you think we can make the nanoparticles bigger or smaller?*** **Accept answers from students**. Well, there are a couple of things we can do. We can change the concentration of the reagents. We can change the temperatures at which the reactions take place. Or, we can change the amount of time that we hold the solution at each temperature. All of those will have effects. And, as you see here, we try to form the nanoparticles into a single layer. **How could we do that? Accept answers from students**. What we do is give the nanoparticles a choice. They start out randomly dispersed in solution. But they want to be at their lowest possible energy. So, when we drop them onto a solid or onto another liquid, they can stay where they are, or they can go to the interface, and usually, they prefer to go to the interface, because they can achieve a more stable, low-energy state there.

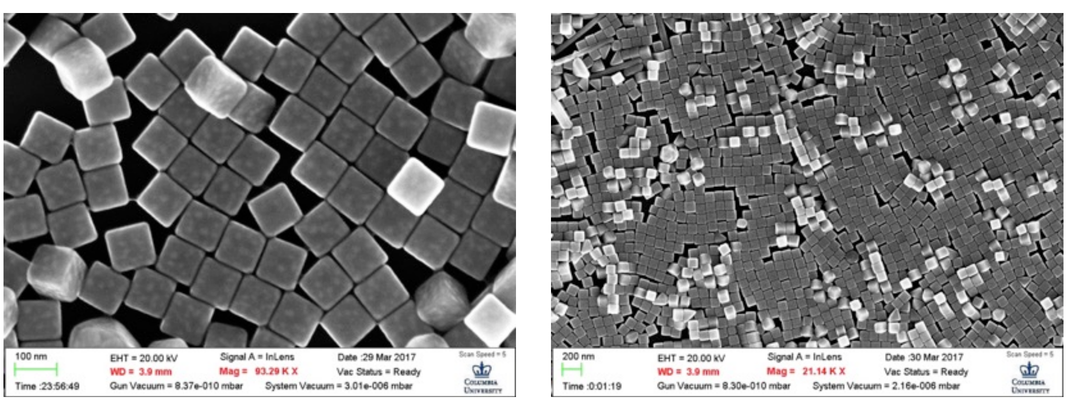
Alright, so we have just a little bit of time left for last-minute questions. ***Anyone?*** **Accept questions from students.**

Okay. So, we're out of time. Thank you all so much for listening. I hope that it was informative, if not enjoyable. Have a good day!

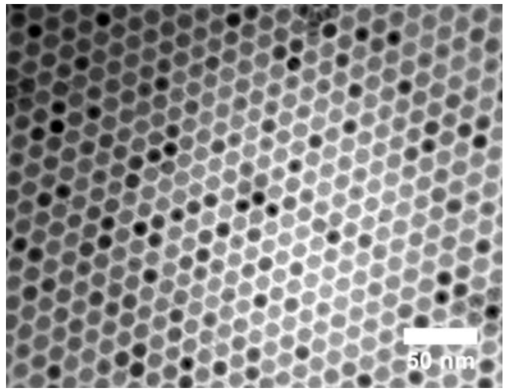
Pictures shown during the presentation:



Scanning electron micrograph (SEM) of ordered iron oxide nanoparticles, showing a single layer in one region and more than one layer in the middle region (Herman group).



Scanning electron micrographs (SEMs) of 100 nm silver nanocubes layer, with some region more than a monolayer, at two different magnifications (Herman group).



Transmission electron micrograph (TEM) image of a monolayer of 10 nm iron oxide nanoparticles, showing hexagonal order (Herman group).

Examples of stained glass windows, from the Metropolitan Museum of Art website, from www.metmuseum.org

Section 2

Good Afternoon!

I'm (Jiayang Hu, a PhD student in the Herman Group. And, this is Xiang, who is also a PhD student). Today I'm going to introduce you the current and future materials in electronics and lasers, what their structures look like, and how we can "see" or identify these structures.

The first material I'd like to introduce is silicon. *Show a silicon wafer***.** Our computers and cellphones are based on it. Look at its structure. *Show the model.* It has the same lattice structure of diamond. Every point here is a silicon atom. The most significant component on a chip – transistor is made of silicon. This material has deeply shaped our world.

This is a laser pointer. *Show it.* The building-block material is a material similar to gallium arsenide. This is a kind of semiconductor material. Let's see its structure. *Show the model.* Every red point in this lattice structure is gallium, and the black ones are arsenic. Or vice versa. But it has the same lattice structure as silicon; both are diamond structure. These kinds of light emitting materials have another important and daily use application. ***Who knows what that is?*** **Accept answers from students**. Right, LEDs or display LEDs.

Now let's talk about the material super stars in the future. ***Who knows any types of carbon?*** **Accept answers from students**. (coal, diamond (looks like Si, but with C) and graphite) There are more types. The first one is fullerene, or the Bucky ball. This structure has 60 points, 12 pentagons and 10 hexagons. All lattice points here are carbon atoms. This is an important material in solar optoelectronic industry.

The other one is the famous graphene, a possible nano-material of future electronics. It is one of the thinnest materials in the world, but it is still firm. Let's look at its structure. *Show the model.* It has the structure of honeycomb, but has the thickness of only one atom. So, it's basically a carbon monolayer sheet. We can get it from another daily use material – graphite. It's a kind of daily use material. ***Who knows where we can find it?*** **Accept answers from students.** (pencil) We know that graphene is a single of carbon atoms. If we stack a lot of these sheets together, that's graphite. When you write, you literally exfoliate some graphite out of the pencil and leave it on paper. So, you can see what you write. If we can carefully control the exfoliation process from graphite – not using a pencil, but in another friendlier form (*show them graphite flakes*), we can get graphene.

These are very small objects. ***How can we see the small world aside with your eyes?*** **Accept answers from students**. Yes, we can use optical microscopes.

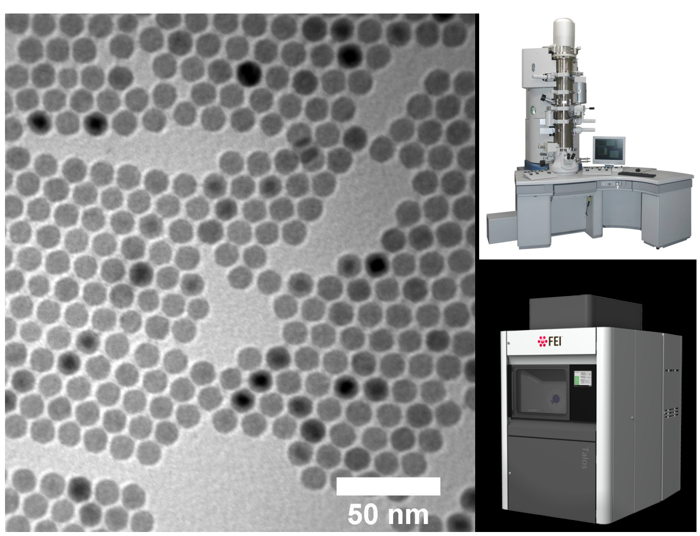
Now, I have a graphene sample on a silicon wafer under the microscope objective lens. The purple background is silicon. All these flakes are graphene multi- or single-layers. These black flakes may contain hundreds of layers. These yellow ones may contain tens of layers. And here is a flake with a light contrast. According to our experience, it could be graphene. But the graphene flake is so thin, very small, we cannot look at its thickness directly with optical microscopes.

Here, we use a kind of laser-based technique called Raman spectroscopy. This is another graphene sample. When the laser hits the silicon wafer and reflects, some of the photons gain or lose energy because of the vibration of the material lattice. So, the energy of the photon (particle of light) has a shift from the laser. Xiang, could you please help me measure the spectrum? We will be able to see a spectrum on the scale of wavenumber, which shows the energy shift. If we see a peak around 520 cm^{-1} (wavenumbers) that's silicon. If we see a peak around 1575 cm^{-1}, that's the signal from graphene. Now, we see two peaks. So, we know that's graphene on silicon. (*Explain peaks due to cosmic rays, if any show up*.)

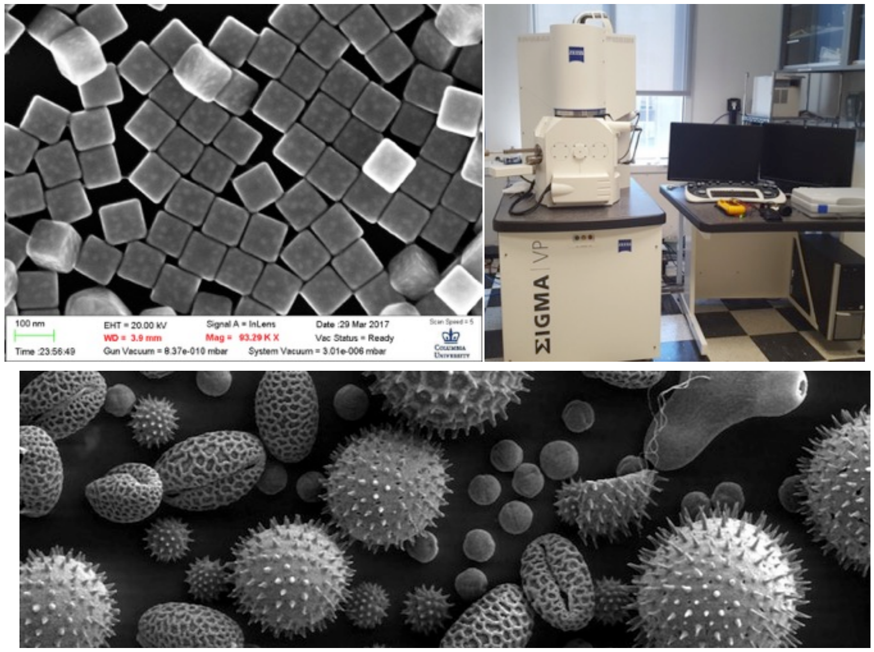
There are limits of the use of light. ***Who knows what those are?*** **Accept answers from students.** Optical microscopy has a limit in seeing very small targets because of the limit of visible light wavelength. The wavelength; the smaller the wavelength is, the better the resolution is. So, we can use other ways to "see" the tiny world. ***What are they?*** **Accept answers from students.** (use electrons!) This picture was taken with a Transmission Electron Microscope. These are our nanoparticles, you've seen (or will see) in the other room. We can also use Scanning Electron Microscopes to see them.

Any other questions? **Accept questions from students.** Thank you.

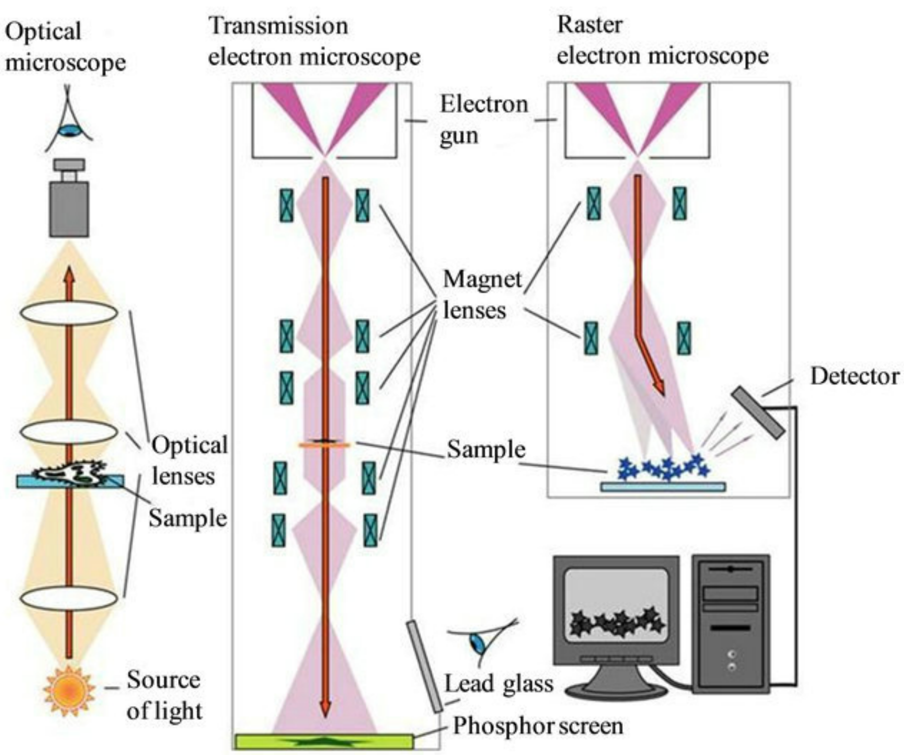
Pictures shown during the presentation:



Transmission electron microscopes (right, FEI Talos F200X S/TEM and Hitachi HF-3300 FE-TEM) and (TEM) image of iron oxide nanoparticle layer (left, Herman group).



Scanning electron microscope (top, right, Zeiss Sigma VP SEM) and SEM images of silver nanocubes (upper left, Herman group) and pollen (lower, https://en.wikipedia.org/wiki/Scanning_electron_microscope).



Instruments (use if there are questions) (E.A. Gudilin, “Electron Microscopy,” 2008).