UNIVERSITY OF VIRGINIA

nanoSTAR Institute

<u>NanoDays DEMO GUIDE</u>

NanoDays is nanotechnology-related outreach activity occurring at universities and museums nationwide. This activity is a product of the Nanoscale Informal Science Education Network (NISENet), a 5 year, $20 million project sponsored by the NSF. NISENet's goal is to help educate the lay public on the potential risks and rewards of nanotechnology.

Our NanoDays demo kits are relatively simple, but engaging, activities ideally suited for kids in the 10-12 yr-old range. The goal is for <u>each</u> demo to convey a simple nugget of information pertaining to *how physically familiar behavior is modified when things get very small*.

The following guide was prepared here at UVa and is a living document. All demonstrators are encouraged to contribute suggestions to improve the demos, and new ideas are particularly encouraged.

Demos can be run in 2 very different environments: For an Open House, demos can take any length of time, short or long, that the demonstrator requires, subject to being able to maintain interest in the demo while conveying some useful information. For a school visit, the demos are subject to strict time constraints, needing to occupy a 5-6 minute time slot. Properly paced demos must plan on using this amount of time completely – it's just as bad to be too short as too long!

Basic Elements of a Good Demonstration, and a Good Demonstrat<u>or</u> (especially for younger audiences)

Successful demos communicate some basic physical concept or principle in a fun and engaging fashion. An *interesting* demonstrator finds ways to "build up" the demo – e.g., by comparing or contrasting behaviors of different elements of the demo, by engaging student's curiosity, by challenging them to predict what will happen, or explain what just happened, and by using a bit of theatrics. A good demonstrator projects confidence, and a little sense of awe and wonder at the science. She doesn't rush through her demo, and tries to engage a bit with her audience, and even entertain them.

Some demos are highly <u>sequential</u>, e.g., see Forces and Surfaces at the Nanoscale. Here is how a sequential demo runs:

1. In just a few short sentences, tell them what physical concept you want to demonstrate. KISS: Keep It Short and Simple.

2. Start the actual demonstration.

3. Build up: At each stage, try to find a way to ask students what they expect to happen, then allow them to find out by trying. Probe why things behave as they do. Basically, try to first ask "what…?", then after, ask "why?...". Whenever possible, relate the behavior they observe to something familiar.

4. End the demo cleanly with a quick reminder of what physical concept they just learned.

Other demos are more exploratory, e.g., see Oobleck or Ferrofluids. These are nominally easy since they are usually fun or cool, but the challenge is to manage time and to teach some useful concept. Even with these, one should look for opportunities to do a build up or make comparisons with different kinds of behavior.

Words to target: (especially for school demos)
Nano: one billionth
Hydrophobic: doesn't like water
Hydrophilic: likes water

HOW BIG IS NANO?

The Point: give a sense of how small nano is in relation to familiar objects.

Basic demo: (a) Size visualization with rulers, hair; (b) size reduction using spaghetti

Approach:
Ask them how big a meter is. Then show them a meterstick.

Ask them how big a centimeter is. Show them on the meterstick – 1/100 of a meter.

Ask them how big a millimeter is. Show them on a ruler – 1/1000 of a meter. What objects have a dimension about 1 mm?

Ask them how big (across) a human hair is (1/10 mm = 100 um) – show them vs a millimeter. (have a kid pull out a hair and give it to you!) A small optical microscope can really help with this. Tell them they would have to slice the hair lengthwise 100,000 times to get to 1 nm.

Tell them that a nanometer is one billionth of a meter – or, take a mm and divide into one million parts.

Now ask them, how many times would they have to break a noodle in half to get to one nanometer? Encourage them to guess. The answer – only 26 divisions! Then have them try it: students each get a stick of spaghetti, break it in half, keep one half, break it in half again, etc., till they cannot go any further. Make sure to have a container for all the broken spaghetti!

Utilize other visualizations, e.g., the Nanoscale 3 examples, height measurement in nm (can we give them a card with their height in nm?) and explain a bit.

For older students: ask them how big an atom is – 0.1 nm. Tell them a molecule like water is only a little bigger, while a buckyball (a C60 molecule – give them a folding model) is about 1 nm. Are these "molecules" nanotechnology? Yes and No. While their size is nano, nano really means assembling a small group of atoms or molecules into a larger construct that does something very different or provides new behaviors not available in a single atom/molecule, or in the bulk.

Picture or model: the Nanoscale 3 Examples or Nanoruler

Components: dry spaghetti noodles, meterstick, smaller metric ruler, hair.

Cycle: dump broken noodles in a container.

Comments: this is quick and easy, but too quick for a round-robin demo circuit unless combined with something else.

FORCES AND SURFACES AT THE NANOSCALE

The Point: surfaces are super-important to the behavior of small objects.

Basic demo:
(I) SURFACE (capillary) FORCES: a student fills a regular teacup with (colored?) water, and then slowly pours it out. Before they pour, ask them what they think will happen. Have another student fill it halfway, then pour it out. Then, have them try a mini teacup. Ask what they think will happen (tell them the minicup holds 1000x less water), and then have them try to pour it out. Discuss how surface tension defeats gravity when there is lots of surface, but only a little mass…

Additional demo: use the glass capillaries (warn them not to touch!) and some colored water. Ask them whether they think it's harder for the water to go up the small end or the large end. Place a capillary with the wide end in the water and ask them to observe what the water does (very little). Then dry (or use new capillary) and insert the small end. Discuss how surface tension overcomes gravity. Can you discuss fluid flow in a nanoscale pipe, like a carbon nanotubes.

Additional demo: rub an inflated balloon on a piece of felt stick it to their head. Ask them if this would work with a water balloon? Why not?

For older students: discuss how gravitational forces are actually much smaller than both primary and secondary atomic bonds.

(II) REACTIVITY: take out two alka seltzer tablets. (note – you must use fresh, unopened tablets for this to work). Place one in a medicine cup whole Crush the other with a mortar and pestle and put the powder in a medicine cup. You can do it 2 ways: (a) ask which they think will fizz the most (and have them explain why), then put each into separate water cups simultaneously. (b) if you want to drag it out a bit, and get more involvement, give a student a stopwatch timer, and have them time the whole tablet and write down the result. Then have them time the crushed tablet and compare. Use a model to discuss surface area, forces, and reactivity

Picture or model Use marbles in modeling clay to make 2 models: (1) 8x8 square array single crystal (64 atoms, 30 on the surface) and (2) 16 "nanoparticles" of 4 atoms each (64 atoms, 64 on the surface). Discuss how it is the only surface atoms that "stick" (forces) and react, and this is why small things feel bigger forces and are more reactive.

Components: basin, big cup, minicups, beaker(s), mat and sponges, food coloring, capillary tubes, q-tips, balloons, alka seltzer tablets, mortar and pestle, med cups, transparent water cups, dump basin, refill pitcher.

Cycle: dry minicups and capillaries between demos.

Nanoscale Objects

The Point: Super-small things behave differently than big things just due to their size.

Basic demo: two parts: thin films and ferrofluids.

Thin Film: show that transparent fluid can look like a rainbow when it forms a thin film (change in optical properties)

Show them the jar of nail polish, and ask them what color the polish is (clear!). Place water in the basin to 2 inches deep. Give each kid a strip of black construction paper, and have them write their names on them in pairs. Immerse one in the water, then put a drop of nail polish remover on the water. Allow a few seconds to spread, then lift out the strip through the polish. A thin, diffracting layer of polish should be readily visible on the paper. Cut in half and give to each kid. Explain that the polish spread out to form a film so thin that it "reflects" light differently, allowing them to see the rainbow spectrum of colors in white light.

Ferrofluid: compare behavior of dry and wet magnets under zero and applied magnetic fields. Let them play with ferrofluid.

First show them the magnets and comment that some of these are super strong (they should not be allowed to play with the larger magnets since they can get pinched, and the magnets are brittle).

Next show the vial of magnetite-containing sand, in zero field. Show that the sand does respond to a field by forming little spikes and acting "solid-like".

Now show them the vial of ferrofluid in zero field. Show how the ferroblobs move like a liquid and don't seem to care too much about sticking together. Then show them the behavior with both the weak ring magnets, and then the NdBFe magnets. Make sure they see how the ferroblobs are much more "interested" in sticking together. Let them play with the vials (but try not to let anyone drag the plastic vial across the magnets). You can also use a covered Petri dish with ferrofluid for an even better demonstration, but beware the mess!

Explain that having a magnetic fluid can be useful in computers, audio speakers, and motors. But to have a magnetic fluid, the magnetic particles need to be nanosized so that they remain floating (colloidal suspension). Further, we have to coat each nanoparticle to prevent them from sticking to one another and becoming larger and then sinking. Ferrofluid is made of magnetite particles that are nanosized. The particles are actually superparamagnetic, but this is very difficult to explain to younger kids.

For older students: can talk about how nanosized magnetic particles are actually superparamagnetic – each particle is a single magnet, but their magnetic moments are constantly flopping so they seem non-magnetic. But when a field is around, they align strongly and behave very magnetic.

Picture or model? Show cartoon of ferrofluid structure – nanoparticles with ligands, oil solvent. Can have a wireless laptop showing: http://www.youtube.com/watch?v=me5Zzm2TXh4

Components: Basin, nail polish, strips of black construction paper, silver or gold pens, NdBFe magnets on large paper clip holders , dry magnetite sand, ferrofluid vial and dish.

Cycle:

Comments: Thin films is new, so we'll see how it goes. FFs are very popular – the more hands-on, the better, but avoid open containers of ferrofluid -- messy.

MOLECULES

The Point: provide another way to understand the concept of nano, and to show that our noses are pretty good nanodetectors.

Basic demo:
(I) arrange mouthwash vials by degree of dilution (using eyes and nose), can repeat with vinegar.

First show them the array of vials, in no particular order. Tell them they all contain mouthwash, but in different amounts. Show a student vials 1 and 2, and ask them to decide which has more. Show a different student vials 3 and 4, and and ask them to decide which has more. Finally, ask a third student to order the remaining vials.

Now tell them the weakest solution contains 1 million times less mouthwash.

See if another student can order the last three vials by smell. Tell them their noses are very sensitive nanodetectors, but not as sensitive as one of the best nanodetectors: a dog's nose!

This can also be done with vinegar, which avoids all visual cues, but can overwhelm the nose.

Finally, we have another version of this where various scents can be placed into balloons prior to inflation, and kids can guess what they smell.

For older students: could discuss how the nose and olfactory sensors work….

(II) use balloons with scent added to run a similar test
(III) for something completely different, let students play with the liquid crystal sheet

Picture or model?

Components: Mouthwash and/or vinegar, beakers, pre-filled vials, dropper tube, refill jugs jugs to hold waste.

Cycle: pour off beakers between each demo, refill w/mouthwash or water, dry dropper tube.

Comments: the more interactivity, the better.

HYDROPHOBICITY

The Point: surface nanostructures or coatings at the nanoscale keep water away.

Basic demo: compare wetting on cabbage and romaine, then show the behavior of suprehydrophobic “magic sand”. Also show the nanopants!

First hand a student a small piece of romaine lettuce and a small piece of cabbage. Have them feel the texture of each leaf (and then pass around).

Ask the students which leaf water will stick to, and which leaf the water will form drops on. Have one explain their answer.

Place drops of water from a kitchen dropper on fresh romaine, and note what it does. Repeat with collard. Now explain using a picture why collard is SUPERhydrophobic.

Warning: may need to dry cabbage, or use fresh piece, in each demo or else wetting will result.

Take a spoonful of regular sand, show them, then dump in a beaker of water. Then pick up some of the wet sand with the spoon, and show the students.

Now dump a spoonful of magic sand in the beaker. Pick up some of the submerged sand and lift out – it’s perfectly dry! Let them play a bit…

At the Open House, younger participants can make their own magic sand square with rubber cement.

<u>For older students</u>: discuss the uses of superhydrophobicity – bio systems like the lotus leaf and desert beetle, self-cleaning windows, antennas and rooftops, microfluidics for chemistry and DNA analysis.

<u>Picture or model</u>? Sketch of the lotus leaf structure, sketch of hydrophobic molecular coatings. Use to discuss how “being afraid of water” can be achieved by surface structure (nano and micro bumps) and surface chemistry (molecules that are “allergic” to water), or a combination of both.

<u>Components</u>: Cabbage and romaine leaves in a cooler for freshness, nanopants, water dropper and water supply, clear beakers or cups, large jar of regular sand, jars of magic sand, plastic spoons, coffee filters, basin, box to hold drying filters. posterboard squares and rubber cement.

Other leaves that are hydrophobic: collard greens, kale and many tree leaves (on one side only, which is handy for comparison) such as tulip poplar.

<u>Cycle</u>: pour off magic sand in water thru a coffee filter into a basin, allow to dry in cardboard box, pour off water with regular sand (?), dry off or dispose of used leaves.

<u>Comments:</u> can take more than 5 minutes. VERY popular.

HYRDOGELS

The Point: water and other, nastier chemicals can be soaked up by molecules that bond water molecules at the nanoscale.

Basic demo: play 3 cup monty with water, where the water ends up "invisibly" trapped in a gel.

Put three white Styrofoam cups in a line on a table in front of the students, far enough back that they can't easily peer in the bottoms. The middle cup has a teaspoon of sodium polyacrylate (NaP) already in it, unknown to the students. Pour a little water into one of the end cups. Move cups around and ask a student to tell you where the water is. Demonstrate she is correct by pouring the water into the cup with the NaP. Then repeat. This time, when another student guesses, pretend to pour the water out onto the table, and then place the cup upside down. After the second guess, repeat, then again…. Where did the water go?

Show the students the gel, and show them what dry NaP looks like (and how much you added). Ask them what they think this material might be used for (diapers!). Who wears diapers? Babies, of course – and astronauts (who need to pee in their space suits).

Tell them the special molecule can hold up to 500 times its weight in water. That's equivalent to a fifth grader drinking 16 TONS of water = 4000 gallon jugs. Explain the resulting material is a hydrogel. You can demo this directly by seeing how much water a teaspoon of NaP in a large cup will absorb (build up!).

You can also compare how much a water a small sponge will hold vs. a half-teaspoon of hydrogel. Place a sponge in a tray and slowly pour water onto it from a beaker or graduated cylinder till saturated. Then, put the ½-tsp diaper gel into a cup and repeat. Which holds more?

Now show them a piece of aerogel and explain this is a material that was a hydrogel, but all the water was replaced with air. The aerogel is a remarkable NANOmaterial that is SUPERlight but SUPERstrong, and is the world's best insulator. *NOTE: we should develop a contained demo with a candle and stand that shows an aerogel standing off the flame from a flower or crayon. Compare with something of similar weight, e.g., Al foil??*

For older students: discuss the uses of nanoporous materials for sponging up dangerous chemical wastes, making more reactive catalysts, better batteries and fuel cells, filtration. Focus on the surface area per unit volume (a recent new material called Fast Act puts the surface area of a football field in a shot glass! – we might show a video of this in the multimedia area).

Picture or model?

Components: NaP, cups, water for demo refills, posterboard covers for cups, empty jugs for wastewater, salt, plastic spoons, aerogel.

Cycle: pour off water from previous demo, put gel cup aside for recovery with salt.
Comments: our most popular demo.

Amorphous Metal Trampolines

The Point: Cool and useful properties are obtained when materials are structured on the nanoscale.

Basic demo: compare bounciness of ball bearings on steel vs metallic glass.

Show the students the steel cylinder and the bb. Put on the acrylic sleeve. Allow one student to drop the bb after polling everyone about how many times they expect it to bounce.

Now show them the metglass and put on the sleeve. Tell them this is a very special type of metal. Again have a student drop a bb after polling for number of bounces.

You can retest with "double-height" for fun and to see what happens…

Now challenge them to explain what happened. First, why does the bb on steel stop bouncing? Where does the energy go? To explain, ask them what would happen if they drop a bb in mashed potatoes. Use the magnifying glass to show that the steel puck has dimples. Pushing those dimples into the metal drains the energy from the bb…. You can also use a ping pong ball to demonstrate this. Drop the PP ball on a hard surface, and it will bounce quite high. Then, put sand in a tray and drop the PP ball on that. The ball will barely bounce, and an indent in the sand should be detectable.

But, here is the hard part – the dimples are able to form in the steel because the steel is a **crystal**. Show them the 2D crystal model, and explain the crystals can "slide" along the atom rows.

Now show the model for the metglass. Tell them this is a special structure called **amorphous** – no order to the atoms, which are of different types and sizes mixed together. Tell them that to make this, we have to melt the metal (over 2000F) and then freeze it in the blink of an eye.

Ask what elastic metglass might be useful for. Show them the golf club, and mention armor.

For older students: tell them more about the difference between a crystal and a glass; how different atomic size prevents crystallization from occurring during rapid solidification; how the lack of crystal defects prevents energy dissipation (more springiness) and makes the material a little softer. A metal-glass alloy golf club transfers 99% of impact power to ball, while titanium only transfers 70%. But like regular glass, amorphous metals are more prone to catastrophic failure by cracking.

Picture or model? Ball models of atomic structure using marbles and modeling clay. You can preassemble this or let the students play with it.

Components: Two metal cylinders, acrylic sleeves, ball bearings, models.

Cycle:

Comments: this can go too fast, so slow *pacing and buildup* are important. Popular.

Self-Assembly

The Point: Nature takes simple building blocks and finds ways to make complex structures.

Basic demo: use normal and "functionalized" legos to show how self-assembly of various structures can occur.

Give them a grand vision of self-assembly that they can understand – have them imagine a large oven, into which we pour metal powder, rubber chips, sand and plastic beads. Turn on the oven, and come back in a week. Open the oven to discover a new car… (can use a small box and a toy car). Sound far-fetched? How about self-assembly of a human? Define in a basic way that self-assembly is the formation of complex, useful structures from simple nanoscale building blocks.

One way to demonstrate why we want small stuff to build itself is to use the mitten challenge. Ask a child to build a small object (using 8-10 big lego blocks) and time them. Then ask another child if they can do better. But, after they answer, make them wear oven mitts! The idea is that our hands are way too coarse to move nano-things around, and we need a better way.

Put a lego 2x2 into a small bowl of water (lego is upside down – don't let it fill with water, and waters should be about an inch deep). First, ask them what will happen if you put more legos randomly in the bowl. Then show them. Put about a dozen legos, of 2 colors, in one-by-one. Gently shake the bowl. A crystal should grow, with the legos well-aligned to each other. Ask if there is any reason that the legos should form a checkerboard order. Quickly remove the legos to dry.

Now show them the shaker pan with magnetic 2x2 legos, again of 2 colors and opposite M. Don't tell them they're magnetic yet! Shake the pan and watch the checkerboard form. Ask them why is happened. Then show them the magnets. Tell them this is called *functionalization*. We would like to do this with nanoscale blocks to make complex 3D structures.

Self-assemble some more complex structures (e.g., with like-M 2x2s and opposite-M 2x4s, etc) to get the idea of providing instructions (functionalization) across.

Self-assembly of the open square is a great demo of how nature has to try different configurations many times, and must be able to break up weak configurations. Tell them that in nature, billions of nano building blocks are actually floating around in liquids, constantly moving around and banging into each other – and this is how we're simulating that.

<u>For older students</u>: could tell them that protein molecules that can fold into complex shapes govern most self-assembly processes in nature.

<u>Picture or model</u>? Proteins….

<u>Components</u>: Legos with magnets, shaker board, bowl, water, towel.

<u>Cycle</u>: remove the legos in water and dry; break all the self-assembled structures apart.
<u>Comments:</u> this goes just a little too fast for a 5 min round-robin, and could use something additional.

Scanning Probe Microscopy: *Nano Fingers*

The Point: Sharp points tips dragged across surfaces can “see” nanoscale structures and even atoms, as well as forces, properties, and chemistry at the nanoscale.

Basic demo: students use their fingers as scanning probes to “see” 2D surface patterns.

First, ask them this: do you think you can feel individual atoms by dragging your fingernail across the table? But that is how the scanning probe microscope works! Describe the basic idea– a supersharp tip is (really slowly and carefully!) dragged across a surface in a pattern, while the height of the tip is measured at each point to “see” atoms. Use a macro cantliver+tip, and a corrugated surface to demonstrate.

We have several demos you can use:

a) The official NanoDays magnetic probe – kids drag the tip lengthwise on the backside and don’t feel anything but friction. But drag is cross-wise, and suddenly the probe jumps up and down, even though there is nothing to see. It is responding to hidden forces, just like a scanning probe, but in this case the forces are magnetic.

b) Squeezie toys: have them close their eyes (or use blindfolds), flip over the squeezie, and use one finger to try and draw what shape is on the surface. Don’t let them look to confirm – have them hand back the squeezie and then you place it face down. They draw what they felt, and everyone compares. Can have them repeat with gloves to get a sense of resolution and sensitivity issues.

(c) Finger boards: Show the students one of the simpler boards so they understand what they’ll be “scanning”. Instruct them to use ONE FINGER ONLY, and to move their finger square-by-square using touch. Whenever they locate a feature, they should mark it on their paper grid. Let them do it, all at the same time, on afm boards covered by pieces of fabric. From their sheets, can they tell what kind of shape they just scanned? Can have them repeat with gloves to get a sense of resolution and sensitivity issues.

(d) Pin board –this only gives the general idea that height can measure the shape of complex objects. Hide a shape inside and ask them to guess what it is. Can use 2 identical-shape objects of different sizes to convey a sense of resolution.

<u>For older students</u>: can discuss various types of scanning probe techniques, noise issues, limitations. You might tell them that the tip is scanned in tiny (sub-nm) increments using a special material that <u>directly</u> converts small voltage changes into small expansions or contractions (piezoelectric). You might tell them that we measure the height of the tip by measuring the position of a reflected laser beam, or by measuring an electric current between the tip and sample (quantum tunneling).

<u>Picture or model</u>? AFM virtual simulator, image poster showing atoms on surfaces

<u>Components</u>: Cantilever, corrugated surface, squeezies, various AFM boards, fabric covers, pin toy, MFM, foam board rests, paper grids, pencils or stamps.

<u>Cycle</u>: reset boards, new paper sheets

Liquid or Solid

The Point: Very small particles suspended in a liquid can "jam" together when moved to fast, giving solid-like behavior.

Basic demo: play find-the-marble, explore different ways to impose high strain rate (fast motion)

Wear an apron. Lay down a tarp around your entire area. THIS IS MESSY.

Prepare one cup per student with Oobleck, 2-3 inches deep. Put a marble in each, and a metal spoon. Tell them that when you say go, the first to get their marble out is the winner. Make sure that everyone keeps going till they get their marble out. Ask them what they felt. Show them that slower can be better here.

Show them a bowl with dry cornstarch and another with dry flour. Pass a fork through both to show that it really isn't hard. Then show them bowls (large!) filled with oobleck and one with a flour mixture. Let them use fingers to play with each. Give them a wipe when done.

Ask them why they think the oobleck behaves like a solid when they move too fast. Discuss the behavior of oobleck in terms of small, suspended particles running unable to get out of each other's way at high speeds, but able to flow like liquid at low speeds. You can also tell them it is possible to run across a large vat of oobleck, but if you slow down, you sink.

<u>For older students</u>: can discuss rheological fluids, as well as electro- and magneto-rheological fluids, and applications.

<u>Picture or model</u>? To demonstrate basic idea of jamming at high strain rate

<u>Components</u>: corn starch, flour, cups, water/pitcher, spoons, plate, bowls, paper towels, wipes, trash bag, aprons.

<u>Cycle</u>: oobleck will need to be refreshed after an hour with a little extra water. Reorganize all cups, clean up messes.