

Nanotechnology

Lessons in Materials Science Engineering
for Grades 6-12

Lesson Summary

Special Thanks to:

Dr. Carolyn Vallas, Juliet Trail and the staff of the
University of Virginia Center for Diversity in Education
Dr. Leonid Zhigilei, Eaman Abdul Karim, Chengping Wu and the staff of the
The University of Virginia Computational Materials Group
and the National Science Foundation

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Summary of Nano-Lessons

Nanotechnology – An Introduction

PowerPoint on what is Nanotechnology with example of current work. This PPT is followed by a brain-storming session of possible future projects. Learn about what “*Nanotechnology*” is, and what it is doing for us in today’s world. More specifically it is meant to be an introduction to Materials Science and how computational materials labs are exploring the Nano-world with actual research that is going on at UVA currently.

Atomic (Metal) Structure _HCP vs. FCC Packing

The main idea of this lab is to learn more about the basic crystal structures that metal atoms form and how why their structure is important. Using simplified models to create metallic crystalline structure, students use Styrofoam balls to create models representing HCP and FCC packing (SOL References: PS.3, PS.5 and CH.2 among others)

Materials Structure Dislocations

The purpose of these hands on exercise is to demonstrate different atomic levels and the defects that occur within each level of structure. . Often there are voids, empty spaces known as vacancies, where an atom should be or even has been previously. There are also small mismatches, *dislocations*, in the rows of atoms, and these are found in all metals. Students will use BB’s in a Petri dish represent the movement as dislocation. (SOL References: PS.3, PS.5, PS.10, CH.3)

Atomic Interactions in Materials – Java Simulation

This project uses a JAVA applet developed at UVA to explore particle movement in an atomic system. It gives student the ability to change certain parameters like temperature and pressure thus providing simulated particle behavior of the molecules. Discussions are encouraged to share observations and determine why the molecules are responding in a certain manner. (SOL References: PS.6, PS.7, PS.10, CH.3, CH.5)

Research Paper / Experience on Nanotechnology for students.

Currently in development

SOL to Lesson Comparisons

Between these four lesson modules more than 78 SOL areas can be explored to some degree of which 36 have hands-on experiences for students. They are designed to be modified for your specific grade level and specific topics. – H.R. Applegate

Lesson Module #1: Nanotechnology – An Introduction

Science 6 Standards: 6.1.a, 6.1.c, 6.4.a, 6.4.b, 6.4.c, 6.4.d

Physics Standards: PH.1.g, PH.3.d, PH.4.a, PH.5.a, PH.5.d, PH.6.a, PH.6.c, PH.7.a, PH.10.a, PH.12.e, PH.12.h

Chemistry Standards: CH.2.f, CH.2.i, CH.3.a, CH.3.d, CH.6.b

Physical Sciences Standards: PS.1.e, PS.1.n, PS.2.a, PS.2.b, PS.3.a, PS.3.b, PS.4.a, PS.6.a, PS.10.a, PS.10.b, PS.10.c

Lesson Module #2: Atomic Metal Structure

Science 6 Standards: 6.1.c, 6.4.e, 6.4.i, 6.2.a, 6.4.a, 6.4.b, 6.4.c, 6.4.d, 6.4.e

Physics Standards: PH.1.g, PH.5.a, PH.5.d, PH.6.a, PH.6.c, PH.6.c, PH.7.a, PH.10.a, PH.12.c, PH.12.e

Chemistry Standards: CH.2.a, CH.2.h, CH.2.i, CH.3.a, CH.3.d, CH.3.e,

Physical Sciences Standards: PS.1.e, PS.1.k, PS.1.m, PS.1.n, PS.2.a, PS.2.b, PS.2.c, PS.2.d, PS.2.e, PS.2.f, PS.3.a, PS.3.b, PS.4.b, PS.5.a, PS.6.a, PS.6.c, PS.10.a, PS.10.b, PS.10.c

Lesson Module #3: Atomic Level – Metal Defects

Science 6 Standards: 6.1.d, 6.1.e, 6.1.f, 6.1.g, 6.1.h, 6.1.i, 6.2.a, 6.4.a, 6.4.b, 6.4.c, 6.4.d, 6.4.e

Physics Standards: PH.1.a, PH.3.d, PH.4.a, PH.5.a, PH.5.d, PH.6.a, PH.6.c, PH.7.a, PH.10.a, PH.12.e, PH.12.h

Chemistry Standards: CH.2.h, CH.3.a, CH.3.e, CH.3.f, CH.5.a, CH.5.f

Physical Sciences Standards: PS.1.e, PS.1.k, PS.1.m, PS.1.n, PS.2.a, PS.2.b, PS.2.d, PS.2.e, PS.2.f, PS.3.b, PS.4.a, PS.4.b, PS.5.a, PS.6.a, PS.7.b, PS.7.c, PS.10.a, PS.10.b, PS.10.c

Lesson Module #4: Molecular Dynamics

Science 6 Standards: 6.1.a, 6.1.b, 6.1.d, 6.1.e, 6.1.f, 6.1.h, 6.1.i, 6.1.j, 6.2.a, 6.2.e, 6.4.a, 6.4.b, 6.4.c, 6.4.d, 6.4.a, 6.4.b, 6.4.c

Physics Standards: PH.1.a, PH.3.d, PH.4.a, PH.5.a, PH.5.d, PH.6.a, PH.6.c, PH.7.a, PH.10.a, PH.12.e, PH.12.h

Chemistry Standards: CH.1.d, CH.1.e, CH.2.h, CH.3.a, CH.3.e, CH.5.a, CH.5.c, CH.5.f

Physical Sciences Standards: PS.1.b, PS.1.f, PS.1.i, PS.1.j, PS.1.k, PS.1.m, PS.1.n, PS.2.a, PS.2.b, PS.2.d, PS.2.e, PS.2.f, PS.4.c, PS.5.a, PS.6.a, PS.7.a, PS.7.b, PS.10.a, PS.10.b, PS.10.c

Nanotechnology - An Introduction

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PowerPoint & Discussion Exercise

The purpose of this lesson is to learn about what “*Nanotechnology*” is, and what it is doing for us in today’s world. More specifically it is meant to be an introduction to Materials Science and how computational materials labs are exploring the Nano-world with actual research that is happening today. It is designed to introduce some key terms and to create discussions with and among students.

Background:

Nanotechnology has become a serious buzz-word in the science and engineering industries, and for good reasons. We are starting to see it now commercially. Ipod Nano’s, Nano-clothing, Nano-gears, Nano-processors, etc., etc.. Some key concepts and questions to be explored are... What does Nano refer to? How is Nanotechnology being used? Is it really a new concept? And, how can Nanotechnology help us today and in the future?

Process:

1. Begin a discussion asking if anyone has heard the term NANO used in a word, sentence or to describe something.
2. Have the students discuss what they think it means. You may even have them write out 1 thing they have heard of and what they think it is and what Nano means to them. (No wrong answers, this is a Brainstorming session.)
3. Find a Dictionary term and try to break it down to be understandable, then share with class
4. Proceed with the PowerPoint.
5. Take time to stop and discuss at every opportunity.
6. Ask some open ended questions and have them respond in written format.

Questions: Record Answers in your Notebooks

1. How big is a Nanometer?
2. What does Nanotechnology refer to?
3. How long has Nanotechnology been around?
4. About how many nanometers is 1 strand of human hair?
5. What types of fields is nanotechnology being used in today?
6. Can you think of a field that would benefit from nanotechnology?

7. Can you think of a product that would benefit from nanotechnology

Teacher Notes:

- You are welcome to use this PowerPoint, however you may want to develop your own based on a particular or specific Nano-topic.
- During the PowerPoint take advantage of comments and questions – Don't rush through, the point is to encourage discussions and explore possibilities.
- <http://screencast.com/t/MGMxZTcyN2E> is the website for the interactive nanoscale views.

Materials and Supplies:

Engineer's notebook

PowerPoint: "Introduction to Nanotechnology"

Web Browser

Computer Lab (if available)

Atomic Metal Structure

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Hands-on Exercise

The main idea of this lab is to learn more about the basic crystal structures that metal atoms form and how why their structure is important.

Background:

To maximize the bonding, atoms in metals pack together as closely as possible. Several packing arrangements exist such as face centered cubic (FCC) and hexagonal closest packing (HCP). Look for the basic geometric configurations in the structures. The properties of metals are very dependent on their crystal structure. The metal structure can be altered by processing treatments to make them more useful in various applications.

Process:

1. Sketch the design of each of the three layers in your Engineer's Notebook and label as "Layer A" and "Layer B". For "Layer A", form a triangle with 10 of spheres (like racking a pool table). For "Layer B", form a smaller triangle with just 6 spheres.
2. Each of the Styrofoam balls will represent an atom and the toothpick will represent bonds. Construct "Layer A" first. Use the toothpicks attach them together. This will form the first layer of the packing model.
3. Attach 6 of the balls together with toothpicks to form a triangle with 3 balls at the base. This will form the second layer of the packing model. Make sure to draw a diagram of the arrangement of the atoms in the second layer in Engineer's Notebook.
4. Form a third triangle of Styrofoam balls like the one in procedure 2 with the remaining 10 balls.
5. Place the second layer on top of the first one with "atoms" of the second layer nesting in the hollows between the "atoms" of the first layer. This creates the closest possible packing of atoms.
6. The third layer can be placed on top of the second layer. The third layer can also be placed on top of the second layer so that its "atoms" are not directly over those in the first layer. This gives the ABABAB arrangement which corresponds to hexagonal closest packing (HCP).
7. Now try placing the third layer so that its "atoms" are directly over those in layer one. This gives the ABCABC arrangement which corresponds to face centered cubic (FCC). Try both arrangements with your layers



Questions: Record Answers in your Notebooks

1. Which packing arrangement, FCC or HCP, is more dense?
2. What is the difference in FCC and HCP arrangements?
3. About how small would an atom have to be to fit in an interstitial hole in an FCC or HCP crystal structure?

Teacher Notes:

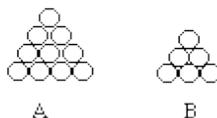
- It would be beneficial for the teacher to have a completed model constructed with the layers painted different colors to help the students visualize the two types of packing arrangements.
- To paint the Styrofoam balls use water based paint diluted slightly and add a small amount of detergent.
- Below are the arrangements for the triangles the students are to construct.

Materials and Supplies:

Either 9 (small structure) or 26 (larger structure, visually more effective) Styrofoam balls, about 2" diameter

Water based paints (3 Colors minimum)

Box of toothpicks (the round kind with the pointed tips work best)



Answers to Questions:

1. Actually, FCC and HCP packing arrangements have the same atomic density. They each have approximately 26% empty space.
2. FCC has an ABC arrangement while HCP is ABA.
3. Depending on the type of hole, an interstitial atom should be approximately one third the size of the atom which makes up the crystal structure in order to "fit" well.

Atomic Level - Metal Defects

Developed by : H.R. Applegate, Technical Education Instructor, Gloucester High School, Gloucester, VA 23061
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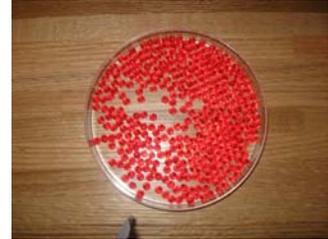
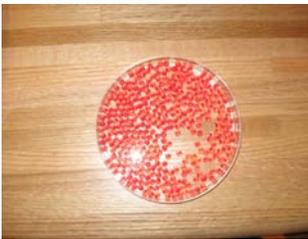
Hands-on Exercise

The purpose of this exercise is to learn more about the basic particle model for metals.

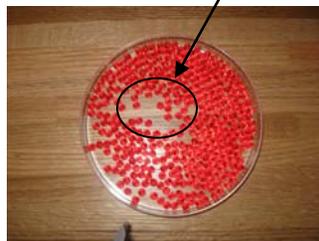
Background: The structure of metal consists of small metallic crystals. These crystals are not perfect. Often there are voids, empty spaces known as vacancies, where an atom should be or even has been previously. There are also small mismatches, *dislocations*, in the rows of atoms, and these are found in all metals. These defects in the crystal structure of metals control many of their properties including hardness and ductility.

Process: Your team will be given a covered Petri dish containing BB's. Keep the dish flat on the table so no BB's spill out!

1. The Bb's represent the molecules or atoms in a metal.



2. To simulate heating metal, simply move the saucer back and forth - the atoms move. This simulates the movement of atoms in a metal when it is heated.
3. Move the dish back and forth somewhat rapidly. (Don't spill the BB's). This simulates heating the metal. (Heating the metal gives the atoms more *kinetic energy*.)
4. Lay the dish on the desk flat and sketch the pattern in your Engineer's Notebook. This is your starting pattern (or pattern #1)
5. Jiggle the dish slightly back and forth and try to get the atoms arranged as neatly as possible. Slowing the motion of the dish and gradually and then stopping, simulates the formation of the metal crystal. Sketch the pattern in your Engineer's Notebook. This is your next pattern (or pattern #2)
6. Make a total of 4 patterns and sketch in your Engineer's Notebook showing how the BB's are arranged.
7. Notice in the dish and subsequently in your sketches, the arrangement of BB's around an empty space. When this happens in the metal it is called a *vacancy*. In a real crystal when atoms are out of line it is called a *dislocation*.



Questions: Answer the Questions below in your Notebook below your four sketched patterns. ;
To help increase understanding, try to write complete idea answers.

1. Describe the bonding between the atoms in a metal.
2. What type of energy do "moving" atoms possess?
3. Do the atoms in a crystal move?
4. Describe the arrangement of the BB's. Are there any empty spaces, i.e., places where a BB is missing?
5. Are the Bb's arranged perfectly? Would you expect atoms to be perfectly arranged?
6. Do more or less defects exist in the metal when it is heated?

Answers to Questions

1. The valence electrons of a metal atom are loosely held and considered to be shared by all the atoms in the crystal. This is called the electron sea model.
2. Kinetic energy.
3. Yes, they vibrate about an equilibrium position.
4. Student answer.
5. It is unlikely that the atoms are perfectly arranged. Some disorder is expected.
6. More defects exist at higher temperatures.

Materials and Supplies:

1- Plastic Petri Dish per group

Approximately 50 Bb's /dish (about 90% full)

Teacher Notes:

A Power point of the actual research is available, however it was designed for higher level (Chemistry & Physics Students)

Molecular Dynamics Worksheet

Developed by : H.R. Applegate, Technical Education Instructor, Gloucester High School, Gloucester, VA 23061
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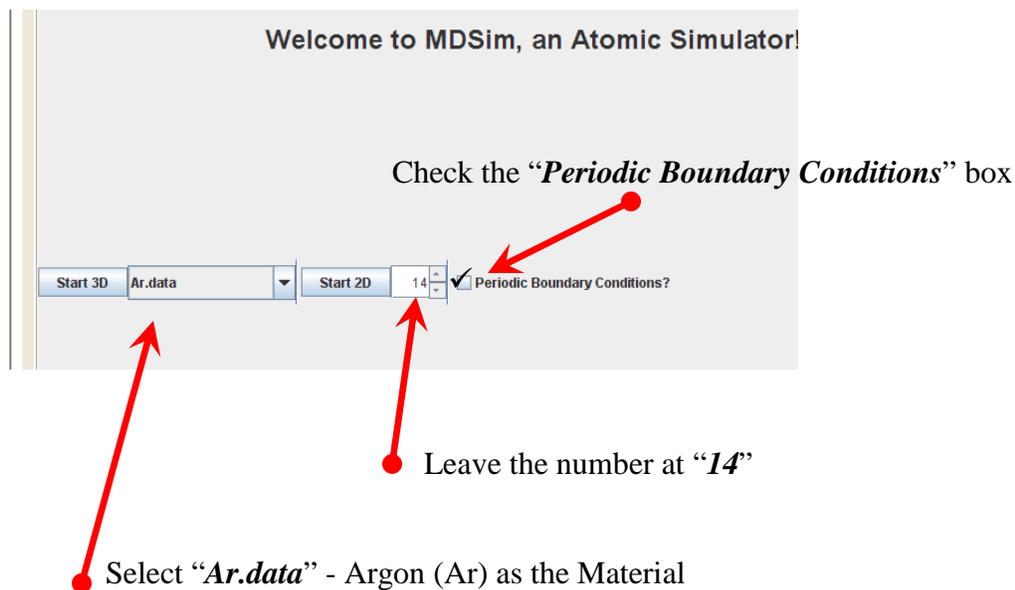
Understanding Molecular Behavior

In this exercise you will use a JAVA Applet developed by my friends at the UVA Materials Sciences Lab to explore how molecules interact with each other in materials (Molecular Dynamics). You will use the computer model to answer the following questions and record your observations. Next divide into groups of 2 and answer the “Group Questions”

To begin go to the following Link:

<http://www.faculty.virginia.edu/CompMat/JavaMD-v1/>

Once you have the JAVA simulation loaded make the following selections:



Check the “*Periodic Boundary Conditions*” box

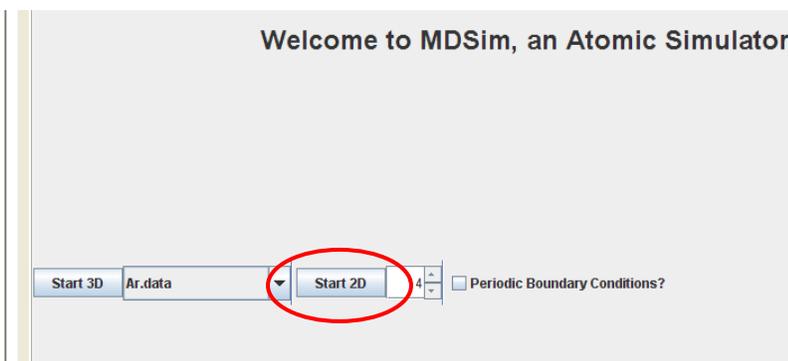
Select “*Ar.data*” - Argon (Ar) as the Material

Leave the number at “*14*”

The screenshot shows the MDSim interface with the following elements: a 'Start 3D' button, a dropdown menu set to 'Ar.data', a 'Start 2D' button, a numeric input field set to '14', and a checked checkbox labeled 'Periodic Boundary Conditions?'. Red arrows point from the text annotations to these specific elements.

Now let’s get familiar with the screen and what it’s telling us.

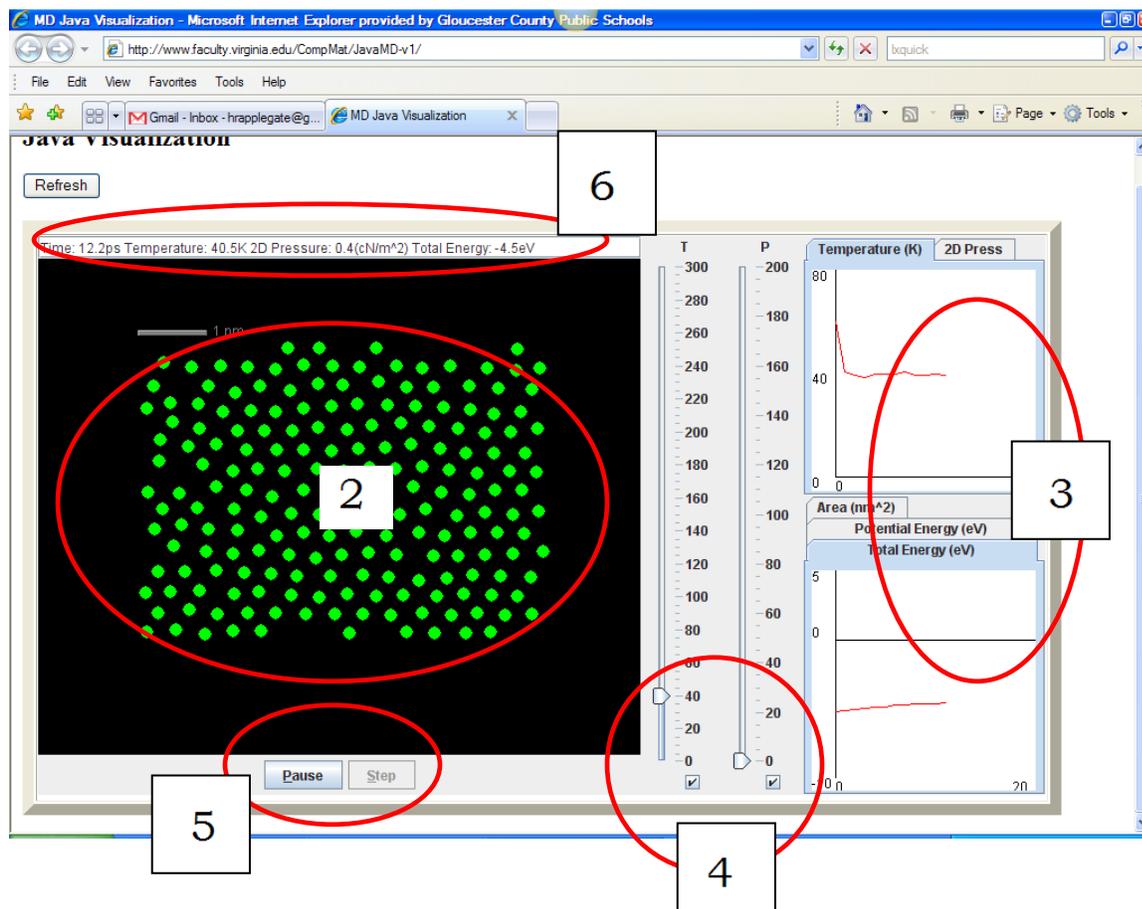
1. Press START 2D Simulation



>Welcome to MDSim, an Atomic Simulator!

The screenshot shows the MDSim interface with the 'Start 2D' button circled in red. The other elements are the same as in the previous screenshot, but the 'Periodic Boundary Conditions?' checkbox is now unchecked.

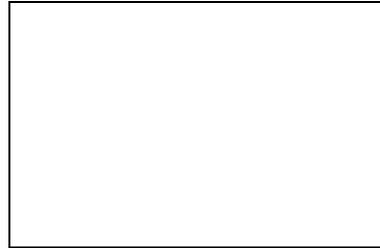
2. Notice the large black screen with green dots that appear to be moving. These green dots represent the molecules in this particular material.
3. To the far right are graphs depicting changes in Temperature / Pressure (upper graph) and Energy (lower graph)
4. You can adjust the temperature as well as the pressure (2D simulation only) with the vertical slide gauges.
5. You can Pause (or Step) the simulation at the bottom of the black screen.
6. And lastly notice that above the black screen are readings for Time, Temperature, Pressure and Energy.



7. Now pause the Simulation for a minute...
8. Notice that the graphs have started to populate and the information in the bar at the top of the screen is populating.
9. Continue the simulation and adjust the temperature and pressure and observe the behavior of the molecules.
10. Pause and refresh if you want.

CAUTION: Before you re-start the simulation, be aware that you need to immediately pause it before your first readings of the exercise.
 Refresh the simulation to the original settings.
 START the 2D Simulation (don't Forget to PAUSE immediately)
 SKETCH in the box provided the layout of the particles as they appear.

Sketch in Here



Your Initial reading should be similar to the first line in the table below.

- Run the simulation and re-pause at 10ps
- Run the simulation and re-pause at 50ps
- Run the simulation and re-pause at 100ps
- Run the simulation and re-pause at 150ps
- Stop at 200ps and record

Record Data Below:

Time	Temp.(K)	P (cN/m^2)	Energy (eV)	Observations and notes (formations, size, movement, vacancies, etc.)
0.0	40.0	0	-6.1	

1. What is the approximate temperature of 40K in farenheight?
2. What did you observe about the movement of particles?
3. Is the Pressure changing? Why?
4. What is happening to the Energy?
5. Sketch The Particles now.
6. What changed? Why do you think it changed this way?



SOL to Lesson Comparisons

Between these four lesson modules more than 78 SOL areas can be explored to some degree of which 36 have hands-on experiences for students. They are designed to be modified for your specific grade level and specific topics. – H.R. Applegate

Lesson Module #1: Nanotechnology – An Introduction

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Physics Standards: PH.1.g, PH.3.d, PH.4.a, PH.5.a, PH.5.d, PH.6.a, PH.6.c, PH.7.a, PH.10.a, PH.12.e, PH.12.h

Chemistry Standards: CH.2.f, CH.2.i, CH.3.a, CH.3.d, CH.6.b

Physical Sciences Standards: PS.1.e, PS.1.n, PS.2.a, PS.2.b, PS.3.a, PS.3.b, PS.4.a, PS.6.a, PS.10.a, PS.10.b, PS.10.c

Lesson Module #2: Atomic Metal Structure

Science 6 Standards: 6.1.c, 6.4.e, 6.4.i, 6.2.a, 6.4.a, 6.4.b, 6.4.c, 6.4.d, 6.4.e

Physics Standards: PH.1.g, PH.5.a, PH.5.d, PH.6.a, PH.6.c, PH.6.c, PH.7.a, PH.10.a, PH.12.c, PH.12.e

Chemistry Standards: CH.2.a, CH.2.h, CH.2.i, CH.3.a, CH.3.d, CH.3.e,

Physical Sciences Standards: PS.1.e, PS.1.k, PS.1.m, PS.1.n, PS.2.a, PS.2.b, PS.2.c, PS.2.d, PS.2.e, PS.2.f, PS.3.a, PS.3.b, PS.4.b, PS.5.a, PS.6.a, PS.6.c, PS.10.a, PS.10.b, PS.10.c

Lesson Module #3: Atomic Level – Metal Defects

Science 6 Standards: 6.1.d, 6.1.e, 6.1.f, 6.1.g, 6.1.h, 6.1.i, 6.2.a, 6.4.a, 6.4.b, 6.4.c, 6.4.d, 6.4.e

Physics Standards: PH.1.a, PH.3.d, PH.4.a, PH.5.a, PH.5.d, PH.6.a, PH.6.c, PH.7.a, PH.10.a, PH.12.e, PH.12.h

Chemistry Standards: CH.2.h, CH.3.a, CH.3.e, CH.3.f, CH.5.a, CH.5.f

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Lesson Module #4: Molecular Dynamics

Science 6 Standards: 6.1.a, 6.1.b, 6.1.d, 6.1.e, 6.1.f, 6.1.h, 6.1.i, 6.1.j, 6.2.a, 6.2.e, 6.4.a, 6.4.b, 6.4.c, 6.4.d, 6.4.a, 6.4.b, 6.4.c

Physics Standards: PH.1.a, PH.3.d, PH.4.a, PH.5.a, PH.5.d, PH.6.a, PH.6.c, PH.7.a, PH.10.a, PH.12.e, PH.12.h

Chemistry Standards: CH.1.d, CH.1.e, CH.2.h, CH.3.a, CH.3.e, CH.5.a, CH.5.c, CH.5.f

Physical Sciences Standards: PS.1.b, PS.1.f, PS.1.i, PS.1.j, PS.1.k, PS.1.m, PS.1.n, PS.2.a, PS.2.b, PS.2.d, PS.2.e, PS.2.f, PS.4.c, PS.5.a, PS.6.a, PS.7.a, PS.7.b, PS.10.a, PS.10.b, PS.10.c

Cost Analysis for Nano-Lessons

By H.R. Applegate, Gloucester High School, Gloucester, VA

QTY	Item	qty	per Unit	Cost	Qty needed for Prototype & Presentations	
Atomic Metal Structure Class Kit						
one time purchase - can be re-used						
8	2" Styrafoam Balls (12pk)	12	\$4.99	\$39.92	3	\$14.97
enough for 8 groups of 2						
1	Toothpicks (1 Box)		\$2.49	\$2.49	1	\$2.49
1	Red Paint (Waterbased)		\$3.49	\$3.49	1	\$3.49
1	Blue Paint (Waterbased)		\$3.49	\$3.49	1	\$3.49
1	Yellow Paint (Waterbased)		\$3.49	\$3.49	1	\$3.49
Atomic Metal Structure Class Kit Only				<u>\$52.88</u>		
Atomic Level Defects Kit						
25	Petri Dishes	1	\$0.98	\$24.50	1	\$0.98
1	BBs's - (1000pk)	<u>1</u>	\$5.00	\$5.00	1	\$5.00
Atomic Level Defects Kit Only				<u>\$29.50</u>		
Miscellaneous Instructional Tools for Nanotechnology						
1	Pipe Cleaners	1	\$1.29	\$1.29	1	\$1.29
1	Case	1	\$5.39	\$5.39	1	\$5.39
1	2.5" Styrafoam Balls	1	\$4.99	\$4.99	5	\$24.95
1	Pipe Cleaners	1	\$1.29	\$1.29	1	\$1.29
1	additional paint	1	\$3.49	\$3.49	0	\$0.00
1	3/4" Styrafoam Balls	12	\$5.98	\$5.98	0	\$0.00
1	1/4" Dia. Dowell Rods	1	\$2.29	\$2.29	0	\$0.00
1	Glue for StroFoam	1	\$2.49	\$2.49	<u>1</u>	\$2.49
Teacher Demo Materials Total					\$69.32	

NOTES: There are more durable "atomic structure models" available that are re-usable (about \$40-50) for these demonstrations, I was trying to keep costs to a minimum. The above lists include everything...I have done a series for as little as \$39.40 using the minimums

For More information email Randy Applegate @ randy.applegate@gc.k12.va.us