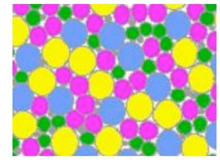
MRSEC Education and Outreach



Amorphous Metal Activity Guide

Quick Reference Activity Guide

Activity Materials
Two acrylic tubes
A stainless steel base and a stainless steel base with an amorphous metal disk glued on with epoxy
Two stainless steel ball bearings
The face-centered cubic (fcc) model built with the solid state model kit
Different sized marbles in a jar (represents an amorphous arrangement of atoms)

Starting Points
Let's do an experiment. Can a steel ball bounce? Lets drop it on a steel base. Lets try again on a base with a disk of amorphous metal on the surface. Is there a difference?

Atoms are arranged in a crystalline solid with a repeating patternwhile the atoms in an amorphous material have no regular pattern (they are all jumbled). The properties of a material are highly dependent on the arrangement of atoms in that material. Let's compare the rebounding properties of a crystalline and an amorphous metal.

Which material would you like to use for the head of your golf club? What are the important properties of a golf club? Let's compare the two surfaces to figure out which one would make a better golf club.

Demonstration Procedures
Have a volunteer drop one ball bearing down the center of the tube with the stainless steel base and watch how it bounces on the surface. Count the number of times that the ball bearing bounces. Then, take the same ball and repeat the experiment using the base with the amorphous metal. Again, count how many times the ball bearing bounces. How does it compare between the two materials? The ball bearing bounces on the amorphous metal as if it were on a trampoline.

After the ball bearing is released, it has kinetic energy, or the energy of motion that is determined by an objects mass and how fast it is moving. Each time the ball bounces its kinetic energy decreases. Students can list the ways in which the ball is losing energy (air friction, sound, collisions with the acrylic tube, impact of the ball with the surface).

Look closely at the surface of each base. You should notice lots of pits in the stainless steel base. How did the pits get there? (Where di the energy come from to make the pits?) And what about the amorphous metal? There are hardly any pits. This gives us a clue as to why the ball is bouncing more on the amorphous metal surface.

At this point explain the different rebounding properties are related to the structures. A crystalline metal has slip planes, planes of atoms that are lined up and can slip easily past one anothers. Demonstrate a slip plane using the fcc model by lifting a lower corner "atom" of the model. An amorphous metal has varying sizes of atoms that exist in a random arrangement in the solid, which eliminates the possibility of slip planes (dislocations). Because there are no slip planes in an amorphous material, the material can be thought of as atomic gridlock - the atoms do not move. This means that the kinetic energy of the ball is not transferred as easily into deforming the amorphous metal and the ball bounces much longer. One consequence of this atomic gridlock is that some amorphous metals are very hard; amorphous metal is two times harder than stainless steel.

Fact Sheet

The Vitreloy amorphous metal used in the demonstration is composed of

$Zr_{41.2} Be_{22.5} Ti_{13.8} Cu_{12.5} Ni_{10.0}$

This particular amorphous metal was developed by Prof. W.L. Johnson from the Department of Applied Physics at the California Institute of Technology in 1993.

Most amorphous metals are formed by rapidly cooling the material from a molten state, Vitreloy is particularly impressive because it can be cooled from liquid state at rates as low as 1°C per second and still form an amorphous solid. The slow cooling rate of this amorphous metal allows it to be cast into molds.

Vitreloy is 2-3 times more resistant to permanent deformation than conventional metals, has a density between that of titanium and steel, and is corrosion resistant.

Applications

Golf clubs with amorphous metal heads, created by Liquidmetal®, have been on the market in 1998.

Industrial coatings for equipment and machinery that are exposed to environments of high wear, temperature, and corrosion. Amorphous metal has the lowest coefficient of friction of any metallic coating, and significantly extends part lifetime. Example: the wall of a refinery coker.

Armor-piercing ammunition that enhances the performance and safety levels for users. The military is developing armor-piercing ammunition that uses amorphous metal instead of Depleted Uranium (DU) alloy.

Casings for electronics and telecommunications equipment, such as cellular handsets, that are stronger, smaller, and thinner.

Amorphous metal knives are used in medical fields, such as ophthalmic medicine, because they are sharper than steel, less expensive than diamond, and higher quality than diamond. They are more consistently manufactured than steel or diamond and they have longer lasting blades.

Solar wind collector tiles on NASA's Genesis spacecraft, the first mission to collect and return samples of the solar wind. The mission was designed to measure the composition of isotopes in solar matter. For information see: http://www.lpi.usra.edu/meetings/lpsc2000/pdf/1783.pdf (The spacecraft parachute failed to open and Genesis crashed on Earth landing on Sept. 8, 2004, but the tiles survived. See http://www.nasa.gov/home/hqnews/2005/apr/HQ_05102_genesis_collectors.html)

References

Also see http://www.liquidmetaltechnologies.com for further information about general applications.

K. J. Nordell, N. D. Stanton, G. C. Lisensky & A. B. Ellis. *The "Atomic Trampoline" Kit: Demonstrations with Amorphous Metal* (ICE, Madison, WI, 2000).

For movies see: http://www.mrsec.wisc.edu/edetc/amorphous

Authors: Amy Payne, Wendy Crone, George Lisensky, Cindy Widstrand, Janet Kennedy, Mike Condren, Ken Lux, Karen Nordell, Nick Stanton, and Arthur Ellis

Acknowledgements

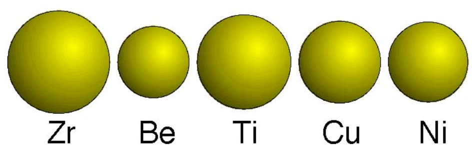
The Nanotechnology Activity Guides are a product of the Materials Research Science and Engineering Center and the Internships in Public Science Education Project of the University of Wisconsin – Madison.

Funding provided by the National Science Foundation.

Background and Supporting Information

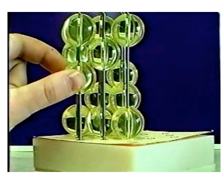
Many scientists and engineers develop and characterize new materials. Amorphous materials are an interesting area of such study. One natural example of an amorphous material is obsidian (volcanic glass). Another is the mineral opal which is a hydrated amorphous silica. Although these materials have very different properties from each other and from the Vitreloy, they share a commonality in their atomic structure – the atoms of these materials do not have a regular arrangement, they are randomly arranged and unorganized.

Vitreloy amorphous metal is comprised of five elements (41.2% zirconium, 22.5% beryllium, 13.8% titanium, 12.5% copper, and 10.0% nickel). The different atomic radii of atoms in Vitreloy promote its highly disordered arrangement. Different sized marbles in a jar can be used to represent this amorphous arrangement of atoms. With all of the different atomic sizes it is difficult for the atoms to pack neatly.



If a material can be frozen (i.e. quenched) into the solid state fast enough, crystallization can be prevented and the random arrangement can be trapped in a tightly-packed solid form.

Crystalline materials are the opposite of amorphous. They have a regular atomic structure where the atoms can be described by a unit cell that repeats to form the structure. The face-centered cubic (fcc) model built with the Solid State Model Kit is an example of one such unit cell. Copper has the face-centered cubic structure. Copper wire is easy to bend because the structure contains planes of atoms that can slip easily past one another. A slip plane can be observed in the face-centered cubic (fcc) model by picking up one of the bottom corners of the model so that half of the model slides up. Amorphous materials do not contain such planes.



The coefficient of restitution represents the degree to which an impact is elastic. Upon collision, one or both of the objects may deform, and this deformation may be elastic or plastic (permanent). A perfectly elastic impact, in which the kinetic energy loss is zero, would have a coefficient of restitution of one. A perfectly inelastic impact, where all of the energy goes into plastic deformation, will have is no rebound and a coefficient of restitution of zero. The coefficient of restitution can be determined for the two cases in this demonstration by measuring the height from which the ball is dropped (h_1) and the height of the first bounce (h_2).

$$\text{Coefficient of Restitution} = e = (h_1/h_2)^{1/2}$$

There are several ways in which the bouncing ball loses kinetic energy: sound, random collisions with the sides of the tubes, and friction with the air. Assuming these factors are the same, on average, for both bases, the difference in the bouncing of the ball must be due mainly to the difference in energy transfer between the ball and each surface. The fact that the ball bounces longer on the amorphous metal surface indicates a much different energy transfer interaction than that of the stainless steel base. You can observe the pits that have been made in the steel base where the ball has bounced on it. These pits are a direct result of the impact to movie planes of atoms and cause permanent deformation. If the ball starts out with an initial amount of kinetic energy then some of the energy lost with each bounce goes into the displacement. Such pits are not seen in the amorphous metal because the random arrangement of atoms in this material precludes sliding planes of atoms. Thus energy is not lost in the movement of dislocations in the amorphous material. One consequence of this atomic gridlock, is that some amorphous metals are very hard. Vitreloy is more than two times harder than stainless steel.

By the end of the 8th grade, students should know that*

- Energy cannot be created or destroyed, but only changed from one form into another.
- Energy appears in different forms. Heat energy is in the disorderly motion of molecules; chemical energy is in the arrangement of atoms; mechanical energy is in moving bodies or in elastically distorted shapes; gravitational energy is in the separation of mutually attracting masses.

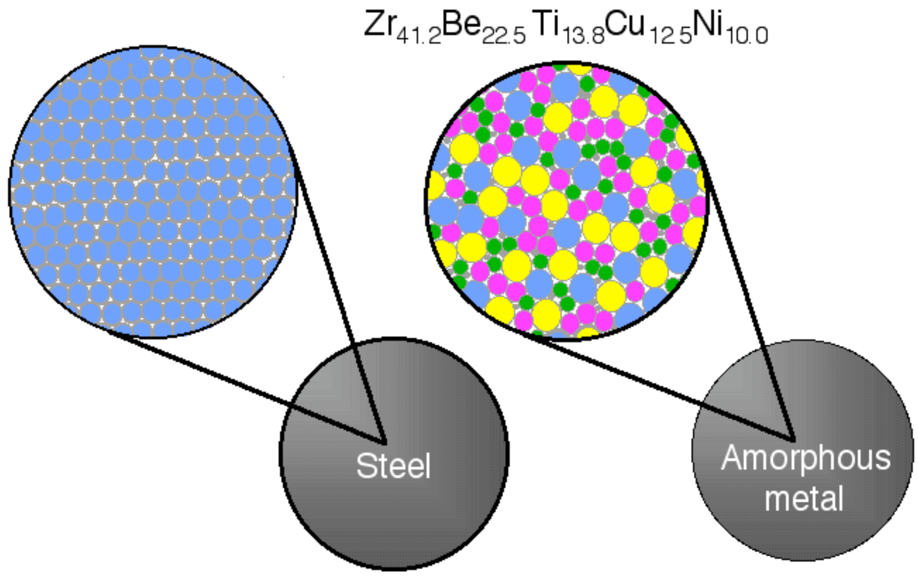
By the end of the 12th grade, students should know that

- Whenever the amount of energy in one place or form diminishes, the amount in other places or forms increases by the same amount.

* (Taken from "Benchmarks for Science Literacy," Project 2061, American Association for the Advancement of Science, 1993.)

The Nanotechnology Activity Guides are a product of the Materials Research Science and Engineering Center and the Internships in Public Science Education Project of the University of Wisconsin – Madison.
Funding provided by the National Science Foundation.

The Importance of Structure



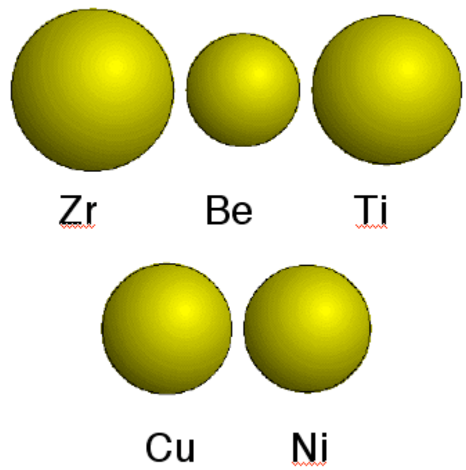
Examine the Evidence:

7.5 magnification

plastic deformation of the stainless steel

Amorphous Metal-Vitreloy™

$Zr_{41.2}Be_{22.5}Ti_{13.8}Cu_{12.5}Ni_{10.0}$



Atomic Trampolines

The Nanotechnology Activity Guides are a product of the Materials Research Science and Engineering Center and the Internships in Public Science Education Project of the University of Wisconsin – Madison.
Funding provided by the National Science Foundation.