Liquid Body Armor

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General Description

Type of program:
Cart Demo

Visitors will learn how nanotechnology is being used to create new types of protective fabrics. The classic experiment "Oobleck" is used to demonstrate how scientists are using similar techniques to recreate this phenomenon in flexible fabrics.

Program Objectives

Big idea:
Nanotechnology can be used to create new protective fabrics with unique properties.

Learning goals:
As a result of participating in this program, visitors will be able to:

1. Explore and learn about the molecular behavior which gives Oobleck its unique properties.
2. Learn how nanotechnologists and material researchers are applying these properties to protective fabrics.

NISE Network content map main ideas:

[ ] 1. Nanometer-sized things are very small, and often behave differently than larger things do.

[X] 2. Scientists and engineers have formed the interdisciplinary field of nanotechnology by investigating properties and manipulating matter at the nanoscale.

[X] 3. Nanoscience, nanotechnology, and nanoengineering lead to new knowledge and innovations that weren't possible before.

[ ] 4. Nanotechnologies have costs, risks, and benefits that affect our lives in ways we cannot always predict.

National Science Education Standards:

2. Physical Science
   - [X] K-4: Properties of objects and materials
   - [ ] K-4: Position and motion of objects
   - [ ] K-4: Light, heat, electricity, and magnetism
   - [X] 5-8: Properties and changes of properties in matter
   - [X] 5-8: Motions and forces
   - [X] 5-8: Transfer of energy
   - [X] 9-12: Structure of atoms
   - [X] 9-12: Structure and properties of matter
   - [ ] 9-12: Chemical reactions
   - [X] 9-12: Motions and force
   - [ ] 9-12: Conservation of energy and increase in disorder
   - [X] 9-12: Interactions of energy and matter

5. Science and Technology
   - [ ] K-4: Abilities to distinguish between natural objects and objects made by humans
   - [X] K-4: Abilities of technological design
   - [X] K-4: Understanding about science and technology
   - [X] 5-8: Abilities of technological design
   - [X] 5-8: Understanding about science and technology
   - [X] 9-12: Abilities of technological design
   - [X] 9-12: Understanding about science and technology

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Time Required

Set-up	Program	Clean Up
15 minutes	30 minutes =	15 minutes

Background Information

Definition of terms

Nano is the scientific term meaning one-billionth (1/1,000,000,000). It comes from a Greek word meaning "dwarf."

A nanometer is one one-billionth of a meter. One inch equals 25.4 million nanometers. A sheet of paper is about 100,000 nanometers thick. A human hair measures roughly 50,000 to 100,000 nanometers across. Your fingernails grow one nanometer every second.

(Other units can also be divided by one billion. A single blink of an eye is about one-billionth of a year. An eyeblink is to a year what a nanometer is to a yardstick.)

Nanoscale refers to measurements of 1-100 nanometers. A virus is about 70 nm long. A cell membrane is about 9 nm thick. Ten hydrogen atoms are about 1 nm.

At the nanoscale, many common materials exhibit unusual properties, such as remarkably lower resistance to electricity, or faster chemical reactions.

Nanotechnology is the manipulation of material at the nanoscale to take advantage of these properties. This often means working with individual molecules.

Nanoscience, nanoengineering and other such terms refer to those activities applied to the nanoscale. "Nano," by itself, is often used as short-hand to refer to any or all of these activities.

Program-specific background

Oobleck:
Oobleck is a polymer (a long-chain of molecules) made of corn starch, food coloring, and water. The reason Oobleck can act like both a liquid and a solid is because it is a non-Newtonian fluid. Newtonian fluids only change in viscosity (resistance to motion in a fluid) when the temperature changes. Non-Newtonian fluids have the same properties that Newtonian fluids have as well as being able to change depending on the force

applied, for example how hard it is stirred. Viscosity of Oobleck depends on how a force is applied to it.
The long starch molecules of Oobleck flow freely until pressure is applied which causes them to tangle and resist force. If it hit suddenly and hard, it feels like a solid where as if a stick or finger is moved slowly in it, it behaves like a liquid.

Liquid Body Armor:

Liquid body armor was originally developed by the University of Delaware chemical engineering professor Norman J. Wagner, Ph.D. and U.S. Army Research Laboratory staff member Eric D. Wetzel, Ph.D. in 2002. It is now being actively developed by *BAE* Systems, a British multinational defense, security and aerospace company and is expected to be introduced to into the marketplace in the next two years.

Liquid body armor is created by saturating traditional Kevlar material with a sheer thickening fluid (STF) comprised of nano-sized **silica** particles suspended in **polyethylene glycol**. In a liquid state, the nano-silica particles stay evenly separated in the **colloid** due to a weak molecular repulsion. However, if the saturated Kevlar is forcefully hit or punctured, the energy of the sudden impact overrides the molecular repulsion and forces the particles into small groups called *hydroclusters*. The hardening process occurs in milliseconds, but quickly reverts itself and allows the material to return to its original flexibility.

Because of its additional strength, less layers of STF-treated Kevlar are needed than in the standard Kevlar jackets commonly used in the military. In recent tests by BAE Systems, they found that 10 layers of the STF-treated Kevlar outperforms up to 31 layers of traditional Kevlar. In addition, STF-treated fibers don't stretch as much on impact as traditional fabrics, including Kevlar. As such, bullets don't penetrate the fabric as deeply and it would take a slow thrust to penetrate the fabric with a knife.

Though still in the experimental phase, STF-treated fabric could soon replace military flak jackets as well be used for prison guards and EMTs.

Additional Dilatant (Sheer-Thickening) Fabrics

Two other dilatant or sheer-thickening fabrics are currently on the market as well. Two companies, d3o, and Active Protection System, use a sheer-thickening material in personal protective equipment such as ski apparel, football pads, point shoes and motorcycle jackets.

Like liquid body-armor, these materials retain their flexibility until force is applied and the material hardens on impact. This allows the creation of light-weight flexible clothing that allows for an equal amount of protection as the bulky and constrictive modern protective sporting equipment of today. Both companies have multiple products that have made their way into the commercial marketplace.

References:

Ashley, Steven. “Enhanced Armor: New Shields to fend off evolving battlefield threats.” http://www.scientificamerican.com/article.cfm?id=enhanced-armor.

BAE Systems. “Liquid Armour.”
http://www.baesystems.com/AboutUs/LiquidArmour/index.htm.

d3o. http://www.d3o.com/d3o-technology/

“d3o Create Intelligent Material for Use in Protective Clothing.”
http://www.azom.com/article.aspx?ArticleID=2555

Eaton, Kit. “U.K. Scientists Demo Bulletproof Liquid Armor.”
http://www.fastcompany.com/1668668/bullet-proof-liquid-armor-kevlar-bae-non-newtonian

“Liquid Armor.” http://www.youtube.com/watch?v=rYIWfn2Jz2g

“Liquid Armour: Fluid Defenses.” The Economist.
http://www.economist.com/node/16731563.

“Liquid Armor.”
http://www.nanooze.org/main/Nanooze/More_Nano/Entries/2010/5/10_Liquid_Armor.html

Wilson, Tracy V. “How Liquid Body Armor Works.”
http://science.howstuffworks.com/liquid-body-armor1.htm

Wikipedia:
Dilatant: http://en.wikipedia.org/wiki/Shear_thickening_fluid

Materials

Experiment 1:
2 Boxes of Cornstarch
3 Containers
Food Coloring
Spaghetti
Water

Experiment 2:
1 Box of Cornstarch
3 Quart-sized Bags

Real eggs
Mallet
Step stool (optional)
Experiment 3:
Magnet
Metal BB's or washers
Pie Tin

Experiment 4a (o*ptional):*
D30 Hat or clothing (not required, can be purchased on Amazon.com)
Eggs (Real)
Plastic Bags

Experiment 4b (optional):
D30 Hat or clothing (not required, can be purchased on Amazon.com)
Eggs (Real)
Plastic Bags
Rubber Mallet

Set Up

Time: 15 minutes

Experiment 1:

1. Prep a bowl of Oobleck.
2. Fill a similar container with an equal amount of water.
3. Fill a third container with cooked spaghetti
4. Rubber mallet (optional)

Oobleck Preparation:

2 cup cornstarch
1 cup water
Food Coloring

Mix until you reach the desired consistency. The Oobleck solution should harden when pressure is applied, but otherwise flow like a liquid.

Experiment 2:

1. Add a cup of water to a quart-size plastic bag. Seal the bag with clear tape.
2. Add a cup of cornstarch to a quart-size plastic bag. Seal the bag with clear tape.
3. Add a cup of Oobleck (colored) to a quart-size plastic bag. Seal the bag with clear tape.
4. Place three eggs near the bags.

5. Have a distance of 24 inches measured out.

Experiment 3:

1. Place a pie tin with metal BB’s on the counter.
2. Add a magnet to the side of the container.

Experiment 4a (optional):

1. Double-bag an egg and put it by the regular hat.
2. Double-bag a second egg and place it by the d3o hat.
3. Have a distance of 12 inches measured out.

Experiment 4b (optional):

1. Double-bag an egg and put it by the regular hat.
2. Double-bag a second egg and place it by the d3o hat.
3. Place a mallet near both hats.

Program Delivery

Time: 30 minutes

Safety

Make sure the educator or visitors wear safety goggles when smashing the eggs to protect their eyes from any projectiles.

Talking points and procedure

Introduction:

Hi Everyone! (Introduce Yourself). Today we are going to learn about special new fabrics that do some really cool things. How many of you are familiar with a material called Oobleck? (Show example and field answers). Oobleck is a mixture of cornstarch and water that acts pretty funny. We can play with Oobleck in a minute, but let’s do an experiment first.

<u>Experiment 1:</u>

As you can see, we have two bowls, one with water and one with Oobleck. What do you think will happen when we hit the mixtures at the same time? (Field questions). Okay, let’s give it a shot.

Hit (can be a flick, or light slap, or even hit with mallet) the Oobleck and water at the same time with equal amounts of force. The Oobleck will harden while the water will splash (splash will depend on choice of hit). If the space is appropriate, you can allow a visitor to perform this demonstration, but be prepared for a bigger mess.

As you can see, if you apply pressure to Oobleck, like thumping it or squeezing it into a ball, it hardens like a solid. However, when no pressure is applied, its flows like a liquid.

So I bet you are wondering what makes Oobleck so unique. Oobleck is actually made of long chains of cornstarch molecules that are suspended in water. The molecules flow freely until pressure is applied which causes them to tangle and resist force.

Optional Demonstration: Grab your bowl of noodles for the next demonstration. Have a visitor swirl the spaghetti and then press the flat of their hand on the spaghetti quickly.

Optional: In this bowl, I have some long strings of cooked spaghetti which are like the long chains of starch molecules in Oobleck, but much, much, much bigger. When you slowly twirl your finger in the spaghetti, you can move through it quite easily, can't you? However, when you press down against it, it feels like a solid because the noodles or "molecules" get pressed together under your hand. Oobleck acts in a similar way.

What kinds of things do you think we can do with something that hardens like a solid on impact, but flows easily like a liquid if no pressure is applied?

Field answers from visitors.

Those all sound like great ideas. Oobleck has been around for a long time, but it is only in the last decade that scientists began experimenting with what they could do with this strange non-Newtonian property. Let's do another experiment to figure out how this unique substance can be used.

<u>Experiment 2:</u>

I have three bags, one with water, one with cornstarch and one with Oobleck. I am going to put an egg in each bag and then drop it from a distance. What do you think is going to happen when our egg in the water hits the ground? How about the egg that is in the Oobleck bag? Okay, let's drop them and see what happens.

Drop the egg bags one at a time from a distance of 12 inches. You can drop them directly on your counter from a standing position or drop them onto the floor.

Hmm, Oobleck protected the egg from the great fall, didn't it? That's because on impact with the floor, Oobleck hardened for a second, spreading out and lessening the impact of the fall on the egg. However, with our water and cornstarch, the egg took the impact directly and cracked.

At this point you can field predictions from the visitors on what height they think the egg will crack. Continue dropping the egg in the Oobleck until it reaches the height that it cracks from.

<u>Experiment 3:</u>

In 2002, two scientists began working on a project to make fabric that acts just like Oobleck. What they created is a special fabric now referred to as liquid body armor. Liquid body armor is created by mixing traditional Kevlar, a protective fabric commonly used by police officers and soldiers, with a special mixture of nano-sized **silica** particles suspended in polyethylene glycol. Silica is a component of sand and quartz while polyethylene glycol is a non-toxic substance often used in adult medicines.

When this special fabric is hit or punctured with great force, all those tiny particles that are normally spread out get squeezed together and create a solid structure for a couple milliseconds. Think about it like this group of BB's here.   (Small metal washers can also be used.)

Put a magnet underneath the pie tin, let the bb's clump together and then pull the magnet away quickly. Repeat as needed.

They stay separated until I place a magnet underneath the pie tin. Watch how they clump together and then fall apart again when I release the magnet. The BB's react the same as the silica particles; clumping together under pressure and then spreading back out quickly.

This makes liquid armor particularly effective because the force of the impact is spread out and weapons aren't able to penetrate the vest. Even better, this sheer-thickening fluid fabric works so well, you only need ten layers of the fabric to the average untreated 31-layers of fabric which is found in your standard flak jacket. As such, the vests will be less bulky and give our soldiers and police officers more flexibility in movement.

<u>Experiment 4a:</u>

Similar sheer thickening fabrics have also been created by other companies who specialize in personal protective equipment such as ski wear, motorcycle jackets and football pads. Like the liquid armor, these companies are make clothing and protective gear that is normally flexible and soft, but when impact is applied, the material hardens for a couple of seconds which absorbs and disperses the force of the energy. This potentially allows athletes much more freedom in terms of movement while still giving them the necessary protection.

Here I have a hat from a company called d3o which is making this sheer thickening fluid fabric. Now, their process is a carefully guarded secret, but I figure we can put it to the test. On the other side, I have a regular hat with no additional protection. The d3o hat is a little bulkier, but still flexible and not as cumbersome as a helmet. To test how the STF material works, I am going to put an egg in a bag inside both hats (in the middle) and then drop them parallel to the counter from a height of 12 inches. Let's try this for both to see if there is a difference.

Test both hats by dropping them the same distance, 12 inches from the counter or floor, making sure the same amount of force is applied for both hats. Also make sure that the hats are parallel to the counter.

As you can see our egg under the d3o hat survived. This material is being used for all kinds of products and could go a long way in making things stylish as well as safe. The US and Canadian ski teams all have uniforms and hats made of d3o material to make sure they are protected. d3o can now be found in everything from iPhone cases to pointed ballet shoes.

At this point you can field predictions from the visitors on what height they think the egg will crack. Continue dropping the egg in the d3o hat until it reaches the height that it cracks from.

Experiment 4b (optional):

For another test, I am placing a double-bagged egg inside each hat and then will hit it with a mallet. Let's try it on both to see if there is a difference.

*Test both hats with a mallet, making sure the same amount of force is applied for both hats. This can be done by lifting the mallet the same number of inches above each hat. For example, for both hats, make sure to lift the mallet 4 inches above the hat. *Note, try to use the same amount of force as well.*

After a couple of tries on the d3o hat, use excessive force when hitting it with the rubber mallet to show that the egg will break when enough force is used.

Societal and Ethical Implications:

Explain to the visitors the positives and negatives of relying on the d3o hat for safety purposes.

So we've seen the positives and the negatives of the d3o hat. We see that it holds up when pressure is added but will eventually crack when enough pressure is added. Would this be a good purchase for you, given that I bought this hat (hold up regular hat) at Target for less than $5 and I had to buy this hat (hold up d30 hat) online for about $50 plus shipping and handling? Is there a danger in relying on the d3o hat to fully protect us in the case of an accident?

Conclusion:

Who would have thought that something as simple as cornstarch and water could inspire something so cool. By the time you are an adult, there is no telling what kind of properties fabrics may have.

Tips and troubleshooting

- When placing the egg in the hat/beanie, make sure that it is placed in the center of the beanie. When dropping the hat/beanie, hold it parallel to the table.
- Try and use the same amount of force when hitting both hats with the mallet.

Common visitor questions

- How does it work? – this can be explained by elaborating on the liquid armor material again.

Going further…

Here are some resources you can share with your visitors:

Recommended Books on Oobleck and Nanotechnology:

Dr. Seuss. 1949. Bartholomew and the Oobleck. Random House Books for Young Readers.
Maddox, Dianne Maddox. 2005. Science on the Edge: Nanotechnology. Blackbirch Press.

Johnson, Rebecca L. 2006. Nanotechnology. Lerner Publications Company.

Williams, Jennifer. 2009. Oobleck, Slime & Dancing Spaghetti: Twenty Terrific at Home Science Experiments Inspired by Favorite Children's Books. Bright Sky Press.

Recommended Videos about STF Fabrics:

"d3o on the Discovery Channel AU."
http://www.youtube.com/watch?v=8EBWGbhsuws

"Liquid Armor." http://www.youtube.com/watch?v=rYIWfn2Jz2g

Clean Up

Time: 15 minutes

1. Empty all Oobleck directly into the trashcan, NOT the sink. Oobleck can clog a sink if too much is put down the drain.
2. Throw away used bags.
3. Put non-disposable items in a kit and clean off demonstration space.

Universal Design

This program has been designed to be inclusive of visitors, including visitors of different ages, backgrounds, and different physical and cognitive abilities.

The following features of the program's design make it accessible:

[X] 1. Repeat and reinforce main ideas and concepts

- Explicitly state overarching main idea and supporting concepts visually and aurally.
- Actively engage visitors with the content visually, aurally, and tactilely.
- Deliver one core concept at a time.
- Repeat core concepts frequently during the program.
- Punctuate the delivery of key ideas by presenting them visually, aurally and tactilely.

[X] 2. Provide multiple entry points and multiple ways of engagement

- Enable learners to enter at different places and take away different messages.
- Actively engage audience members in the program.
- Ask questions that encourage visitors to relate the content to their everyday life.
- Connect the content to a range of prior experience and everyday life examples.
- Use multiple analogies to represent the same idea.
- Engage more than one sense when delivering jokes and special effects.

[X] 3. Provide physical and sensory access to all aspects of the program

- Speak slowly and provide extra time for people to process important ideas.
- Provide auditory descriptions of models and images.
- Provide tactile models that are easy to handle and manipulate.

To give an inclusive presentation of this program:

- Ask the audience questions, and check in with them along the way to make sure they're engaged and with you.
- Engage as many senses as possible when presenting the Oobleck. While you audibly explain the oobleck and its properties, allow them to touch and explore the oobleck.

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