INTERMOLECULAR FORCES:

WHY CAN SOME THINGS STICK WHILE OTHERS FALL?

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Content Area: Chemistry/Biology/Physics
Grade Levels: 7-12

LESSON RATIONALE

Instructional Objectives

- Students will understand that the dominant force changes with size (ie. gravitational force is dominant at the macroscale, while intermolecular forces are dominant at the nanoscale).
- Students will understand that intermolecular forces exist between molecules. There are four major types: dispersion forces, dipole-induced dipole, dipole-dipole, and hydrogen bonding.
    - Intermolecular forces explain the physical properties of substances. The stronger the force, the more difficult it is to pull molecules away from each other. For example:
        - Solubility-Substances of like intermolecular forces mix.
        - Surface tension-The higher the surface tension, the stronger the intermolecular forces.
        - Capillary Action-The better the capillary action, the stronger the intermolecular forces.
        - Volatility-The more volatile, the weaker the intermolecular forces.
        - Vapor pressure-The higher the vapor pressure, the weaker the intermolecular forces.
        - The melting point/boiling point is higher in substances that have stronger intermolecular forces. Other physical properties include viscosity.
    - Intermolecular forces are involved in phase changes. The forces must be disrupted (break) between molecules for a substance to turn from a solid to a liquid to a gas. The intermolecular forces must interact (form) between molecules for a substance to change from a gas to a liquid to a solid.
    - Intermolecular forces are very important at the nanoscale level. Real-world applications of intermolecular forces at the nanoscale include zinc oxide sunscreens and gecko tape which students will understand.

Big Idea

- Forces: All interactions can be described by multiple types of forces, but the relative impact of these forces change with scale. On the nanoscale, a range of electrical forces with varying strengths tend to dominate the interactions between objects.

Standards

- Indiana Learning Standards:

7th Grade

7.1.7 – Explain how engineers, architects, and others who engage in design and technology use scientific knowledge to solve practical problems.

7.1.9 – Explain how societies influence what types of technology are developed and used in fields such as agriculture, manufacturing, sanitation, medicine, warfare, transportation, information processing, and communication.

7.7.3 – Describe how physical and biological systems tend to change until they reach equilibrium and remain that way unless their surroundings change.

8th Grade

8.1.6 – Identify the constraints that must be taken into account as a new designing is developed, such as gravity and the properties of the materials to be used.

8.1.8 – Explain that humans help shape the future by generating knowledge, developing new technologies, and communicating ideas to others.

8.2.7 – Participate in group discussions on scientific topics by restating or summarizing accurately what others have said, asking for clarification or elaboration, and expressing alternative positions.

8.3.8 – Explain that all matter is made up of atoms which are far too small to see directly though an optical microscope. Understand that the atoms of any element are similar but are different from atoms of other elements. Further understand that atoms may stick together in well-defined molecules or may be packed together in large arrays. Also understand that different arrangements of atoms into groups comprise all substances.

8.3.10 – Explain that increased temperature means that atoms have a greater average kinetic energy of motion and that most gases expand when heated.

8.3.16 – Explain that every object exerts gravitational fore on every other object and that the force depends on how much mass the objects have and how far apart they are.

8.3.18 – Investigate and explain that electric currents and magnets can exert force on each other.

8.7.1 – Explain that a system usually has some properties that are different from those of its parts but appear because of the interaction of those parts.

8.7.3 – Use technology to assist in graphing and with simulations that compute and display results of changing factors in models.

Chemistry 1

C.1.26 – Describe physical changes and properties of matter through sketches and descriptions of the involved materials.

C.1.28 – Explain that chemical bonds between atoms in molecules, such as H_2, CH_4, NH_3, C_2H4, N_2, Cl_2, and many large biological molecules are covalent.

C.1.35 – Infer and explain physical properties of substances, such as melting points, boiling points, and solubility, based on the strength of molecular attractions.

C.1.36 – Describe the nature of ionic, covalent, and hydrogen bonds and give examples of how they contribute to the formation of various types of compounds.

Physics 1

P.1.10 – Demonstrate an understanding of the inverse square nature of gravitational and electrostatic forces.

Integrated Chemistry – Physics

CP.1.1 – Understand and explain that atoms have a positive nucleus (consisting of relatively massive positive protons and neutral neutrons) surrounded by negative electrons of much smaller mass, some of which may be lost, gained, or shared when interacting with other atoms.

CP.1.11 – Understand and give examples to show that an enormous variety of biological, chemical, and physical phenomena can be explained by changes in the arrangement and motion of atoms and molecules.

CP.1.27 – Recognize and describe that gravitational force is an attraction between masses and that the strength of the force is proportional to the masses and decreases rapidly as the square of the distance between the masses increases.

CP.1.28 – Realize and explain that electromagnetic forces acting within and between atoms are vastly stronger than the gravitational forces acting between atoms.

CP.1.29 – Understand and explain that at the atomic level, electric forces between oppositely charged electrons and protons hold atoms and molecules together and thus, are involved in all chemical reactions.

CP.1.30 – Understand and explain that in materials, there are usually equal proportions of positive and negative charges, making the materials as a whole electrically neutral. However, also know that a very small excess or deficit of negative charges will produce noticeable electric forces.

- National Science Education Standards

Content Standards 5-8

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standards 9-12

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. The electric force between the nucleus and electrons holds the atom together.
- Gravitation is a universal force that each mass exerts on any other mass. The strength of the gravitational force between two masses is proportional to the masses and inversely proportional to the square of the distance between them.
- The electric force is a universal force that exits between any two charges objects. Opposite charges attract while like charges repel. The strength of the force is proportional to the charges, and, as well gravitation, inversely proportional to the square of the distance between them.
- Between any two charged particles, electric force is vastly greater then the gravitational force. Most observable forces such as those exerted by a coiled spring or friction may be traced to electric forces acting between atoms and molecules.

Content Standard E: Science and Technology

- Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research.

- <u>Benchmarks for Science Literacy-Project 2061</u>

Grades 6-8

3C: The Nature of Technology – Issues in Technology

- Societies influence what aspects of technology are developed and how these are used. People control technology (as well as science) and are responsible for its effects.

4D: The Physical Setting – Structure of Matter

- All matter is made up of atoms, which are far too small to see directly through a microscope. The atoms of any element are alike but are different from atoms of other elements. Atoms may stick together in well-defined molecules or may be packed together in large arrays. Different arrangements of atoms into groups compose all substances.
- Atoms and molecules are perpetually in motion. Increased temperature mans greater average energy of motion, so most substances expand when heated. In solids, the atoms are closely locked in position and can only vibrate. In liquids, the atoms or molecules have higher energy, are more loosely connected, and can slide past one another; some molecules may get enough energy to escape into a gas. In gases, the atoms or molecules have still more energy and are free of one another except during occasional collisions.

4G: The Physical Setting – Forces of Nature

- Every object exerts gravitational force on every other object. The force depends on how much mass the objects have and on how far apart they are. The force is hard to detect unless at least one of the objects has a lot of mass.

12D: Habits of Mind – Communication Skills

- Locate information in reference books, back issues of newspapers and magazines, compact discs, and computer databases.

Grades 9-12

1C: The Nature of Science – The Scientific Enterprise

- Progress in science and invention depends heavily on what else is happening in society, and history often depends on scientific and technological developments.

4D: The Physical Setting – Structure of Matter

- The rate of reactions among atoms and molecules depends on how often they encounter one another, which is affected by the concentration, pressure, and temperature of the reacting materials. Some atoms and molecules are highly effective in encouraging the interaction of others.

4G: The Physical Setting – Forces of Nature

- Gravitational force is an attraction between masses. The strength of the fore is proportional to the masses and weakens rapidly with increasing distance between them.
- Electromagnetic forces acting within and between atoms are vastly stronger than the gravitational forces acting between the atoms. At the atomic level, electric forces between oppositely charged electrons and protons hold atoms and molecules together and thus are involved in chemical reactions. On a larger scale, these forces hold solid and liquid materials together and act between objects when they are in contact – as in sticking or sliding friction.

8B: The Designed World – Materials and Manufacturing

- Increased knowledge of the molecular structure of materials helps in the design and synthesis of new materials for special purposes.

11D: Common Themes – Scale

- Because different properties are not affected to the same degree by changes in scale, large changes in scale typically change the way that things work in physical, biological, or social systems.

12D: Habits of Mind – Communication Skills

- Participate in group discussions on scientific topics by restating or summarizing accurately what others have said, asking for clarification or elaboration, and expressing alternative positions.

LESSON PREPARATION

*****Students should work in groups of 2-3*****

Materials for Discovery should be put as stations around the room. You will only need to have a limited number of supplies at each location. Volumes at each station are estimated. The liquids should be kept in containers/ jars with lids.

Materials

Discovery: Part A

Item	Number/Amount
Textbooks	2-3/ station
Computers w/Internet access	1/ station

Discovery: Part B-1

Item	**Number/Amount**
Water in small sealed container (50 mL)	1/ station
Ethanol in small sealed container (50 mL)	1/ station
Cyclohexane in small sealed container (50 mL)	1/ station
Disposable pipet (one per chemical)	3/ station
Small test tubes	3/ group

Discovery: Part B-2

Item	**Number/Amount**
Water in small sealed container (30 mL)	1/ station
Ethanol in small sealed container (30 mL)	1/ station
Cyclohexane in small sealed container (30 mL)	1/ station
Disposable pipet (one per chemical)	3/ station
Wax paper (small square piece)	1/ group
Pennies	3/ station
Metric ruler	1/ station

Discovery: Part B-3

Item	**Number/Amount**
Water in small sealed container (10 mL)	1/ station
Ethanol in small sealed container (10 mL)	1/ station
Cyclohexane in small sealed container (10 mL)	1/ station
Capillary tubes (1.5-1.8 x 100 mm); (label for each chemical)	3/ station
Metric ruler	1/ station

Discovery: Part B-4

Item	**Number/Amount**
Water in small sealed container (15 mL)	1/ station
Ethanol in small sealed container (15 mL)	1/ station
Cyclohexane in small sealed container (15 mL)	1/ station
Disposable pipet (one per chemical)	3/ station

Glass plate (microscope slide)	1/ group
Stopwatch	1/ station

Discovery: Part C

Item	**Number/Amount**
Computers w/Internet access	1/ station

Discovery: Part D

Dixie cups, 3 oz.	1/ group
Zinc oxide powder (Flinn Z0013: 500 grams for $12.60)	~10 g/ group
Darvan C-N free sample at: http://www.rtvanderbilt.com/wwwprd/ceramics_4.htm	2 mL/ group
Popsicle sticks or coffee stirrers	1/ group
Disposable pipets (1 for water, 1 for Darvan C-N)	2/ station
Distilled water	6 mL/ group

Discovery: Part E

Granulated sugar	5 tsp/ station
Powdered sugar	5 tsp/ station
Container to catch sugars	2/ station
Black contact paper on cardboard (1 for each sugar)	2 pieces/ station
Plastic spoons (1 for each sugar)	2/ station

Discussion

Item	Number/Amount
250-mL Erlenmeyer flask	3
2-hole rubber stopper	3
Latex tubing (3-4 inches)	3
Pinch clamp	3
Glass tubing bent into manometer	3
Food coloring/ pipet	1
Water	20 mL
Rubbing alcohol (2-propanol)	20 mL
Acetone	20 mL
Taped “beaker” on classroom floor	1
Nametags for oxygen/hydrogen atoms	1/student
Overhead transparencies (optional)	1/group

Lab

Item	Number/Amount
Textbooks or Computers w/Internet access	1/ group
Water (unknown A)	25 mL/ group
Hexane (unknown B)	25 mL/ group
Acetone (unknown C)	25 mL/ group
Butanol (unknown D)	25 mL/ group
Glycerol (unknown E)	25 mL/ group
Cyclohexane (test reagent)	10 mL/ group
Ethanol (test reagent)	10 mL/ group
Water (test reagent)	10 mL/ group
Disposable pipet (1 per chemical)	8/ group
Small test tubes (in test tube rack)	6/ group
Glass slide or glass plate	1/ group
Graph paper	1 sheet/ group
Stopwatch	1/ group
Metric ruler	1/ group

Capillary tubes	8/ group
Wax paper (small square piece)	1/ group

Possible Misconceptions or Student Difficulties

- Intermolecular forces are actually bonds between molecules. Students especially think this with hydrogen bonds because of the name.
- When water evaporates, the water molecules break apart into hydrogen and oxygen.

Safety Issues

- Goggles need to be worn for the Discovery (Parts B, C, & D) and the Lab.
- Students should wash their hands after working with the chemicals in the discovery and lab.
- Zinc oxide mixture can be disposed of in the garbage.

Doing the Lesson

Opening: Eliciting Students' Ideas

1. Have the questions below written on the board for students to work on individually as they enter the classroom and for the first 3-5 minutes of class. Then have students get into groups (lab groups) to discuss possible answers to the questions for 5 minutes.
    - How can a gecko walk upside-down on a ceiling?
    - Why can a gecko walk upside-down on ceilings, while humans cannot?
    - How can you turn powdered zinc oxide into a solution that could be used in a sunscreen?
2. Discovery (attached)

    Students work with a partner to complete a series of activities that study the concepts. They are asked to make observations, collect data, and propose explanations. By listening to the students discuss the activities in their groups, asking the students questions, and reading the students explanations, the teacher elicits the students' ideas.

Investigation: Concept Development/Making Sense

1. Discovery (attached)

   The students begin to develop the concept of intermolecular forces by creating their own models for each type of force, observing physical properties of different liquids, and observing what happens when a phase change occurs (wet-lab experiment and computer simulation). The students discuss their ideas with their lab partner and sometimes with other groups. The teacher acts as a facilitator, encouraging the students to think about their observations and provide clear explanations for their ideas.

2. Large Group Discussion

   After the students complete the discovery, the entire class discusses their ideas of the concepts. The large group discussion focuses on three major questions that come from the discovery. The teacher helps guide the students to the scientific explanation for the phenomena they observed. The teacher provides new examples or ideas for the students to apply/test their new understandings.

   (1) What is chemically special about each type of intermolecular force?

   - Students share their understandings of each type of intermolecular force. The group discusses and critiques the different models that are presented.

     (Overhead transparencies could be made of the student cartoon models.)
   - The teacher provides examples of molecules for the students to predict the type of intermolecular force that would form between them. (Why would that type of intermolecular force form? What is the evidence?)
   - After classifying the examples, the students predict and discuss the relative strength of the forces between the different molecule examples. (The teacher asks the students to clarify their predictions with explanations. Then, the teacher asks how we could test their predictions—leads to the next question).

   (2) How do intermolecular forces relate to the physical properties of substances?

   - Discuss student ideas for each property examined in the discovery. Relate the explanations for their results to the concept of intermolecular forces.
   - Have the students predict results for similar experiments with the new molecules discussed in Question 1.
   - Vapor Pressure Demonstration: Manometer using water, rubbing alcohol, and acetone. Have the students make a prediction on the vapor pressure created by each liquid. (Ask them why or how they know that will happen.) Conduct the demonstration. Have the students record and explain the results.
   - Discuss what happened in the flasks to create the vapor pressure. This leads to the next question about phase changes.

(3) What happens to intermolecular forces during a phase change?

- Discuss the computer simulation results. Relate them to the vapor pressure demonstration from Question 2. How does the strength of intermolecular forces impact the molecules during a phase change?
- Discuss student ideas from the discovery about what happens to the molecules during a phase change (solid to liquid to gas).
- Demonstration/Student Activity: Water in a Jar activity. Have the students pretend to be water molecules and go through a phase change. Then, have the students become molecules with weaker attractive forces. How does the activity change? Discuss misconceptions that arise during the activity.

Follow-Up: Application of Learning

1. Mystery Chemical Lab (attached)

   The students design their own experiment to determine the identity of five different liquids. The students can decide which properties to test, but must conduct at least three tests.

2. Application Assignment (attached)

   The students perform the assignment that provides them an opportunity to apply their knowledge of intermolecular forces to a real-world nanoscience application. They will use data and observations collected during the discovery to assist in answering the questions.

Assessment

1. Discovery—Teacher asks students questions while they are completing the discovery activities. Teacher grades students' written responses based on the completeness and thoughtfulness of their explanations.
2. Large Group Discussion—Teacher asks students questions about their ideas about concepts they explored in the discovery activities.
3. Mini-topic Quiz—Students are assessed on a five-question quiz related to the concepts studied in the discovery, discussion, and worksheet.
4. Mystery Chemical Lab Report—Assess the students predictions and explanations (how do they know), experimental design, and conclusions (are they based on evidence? are they explained using intermolecular forces?).
5. Application Assignment—How well can the students explain gecko's feet and zinc oxide solutions using the concept of intermolecular forces? How well do the students present their findings and information to others?

Resources

1. Phase Change Experiment Simulation

   http://www.chm.davidson.edu/ronutt/che115/Phase/Phase.htm

2. NCLT Professional Development Workshop, Purdue University, 2006

   - What Attractions Exist Between Molecules? (Shanna Daly)
   - Using a Manometer to Measure Vapor Pressure (David Sederberg)
   - All About Forces (Kelly Hutchinson)
   - The Structure of Matter (Kelly Hutchinson)
   - Molecular Attractions: Why do chemicals behave the way they do (Becky Creech, Lesson plan developed during workshop from other lessons).

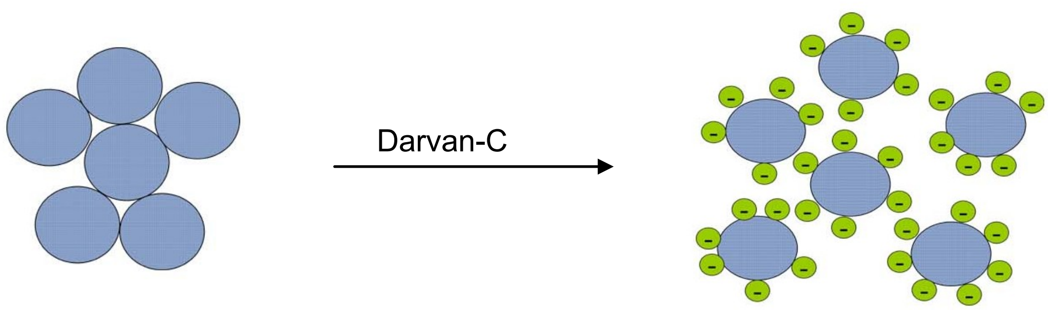
An Explanation for Teachers

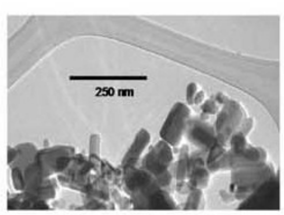
Sugars

- The granulated sugar falls essentially grain by grain off of the black contact paper into the sugar container and all of the sugar falls off (a few grains may remain). This is due to the force of gravity on the sugar particles.
- The powdered sugar falls off in one clump. There will be a trail left by the powdered sugar as well as clumps of powdered sugar remaining on the card. Even if the card is tipped upside down, these clumps will remain on the card. All of this is due to electrostatic forces, specifically Van der Waals forces, and not gravity.
- The size of the object affects the dominant forces acting upon it.
- IMPORTANT: The powdered sugar is not nanosized! The average particle size is 1-10 μm, which is 1,000-10,000 times bigger than a nanometer.

Zinc Oxide

- Zinc oxide forms weakly agglomerated nanoparticles.
- An aqueous dispersion of zinc oxide is very viscous due to Van der Waals interactions which in turn makes the liquid very difficult to stir.
- Addition of Darvan C, a polyelectrolyte, coats each nanoparticle with negative charge. This causes the particles to repel each other significantly lowering the viscosity.
- This repulsion causes the particles no longer want to stick together as much and the solution becomes easy to stir.
- The behavior of the ZnO illustrates how important electrostatic forces are in determining the behavior of the ZnO solution.
- The ZnO particles range from 200-800 nm which is much closer to the nanometer size range compared to the powdered sugar.





SEM of zinc nanoparticles