nanosense

NanoSense Curriculum Series | February 2008

Fine Filters: Filtering Solutions for Clean Water

NanoSense Curriculum Series

About the NanoSense Project

The goal of the NanoSense project is to help high school students understand science concepts that account for nanoscale phenomena. Working closely with partner teachers and scientists, the NanoSense team has created, classroom tested, and disseminated several units to help students understand underlying principles, applications, and implications of nanoscale science.

License Information

Attribution Information

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Electronic Versions of Materials

Electronic versions of all PowerPoint slides and other materials in this unit are available for download from the NanoSense Web Site at http://nanosense.org

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Fine Filters: Table of Contents

Unit Overview

Teacher Materials

Contents

For Anyone Planning to Teach Nanoscience…
Read This First!

Nanoscience Defined

Nanoscience is the name given to the wide range of interdisciplinary science that is exploring the special phenomena that occur when objects are of a size between 1 and 100 nanometers (10^{-9} m) in at least one dimension. This work is on the cutting edge of scientific research and is expanding the limits of our collective scientific knowledge.

Nanoscience is "Science-in-the-Making"

Introducing students to nanoscience is an exciting opportunity to help them experience science in the making and deepen their understanding of the nature of science. Teaching nanoscience provides opportunities for teachers to:

- Model the process scientists use when confronted with new phenomena
- Address the use of models and concepts as scientific tools for describing and predicting chemical behavior
- Involve students in exploring the nature of knowing: how we know what we know, the process of generating scientific explanations, and its inherent limitations
- Engage and value our student knowledge beyond the area of chemistry, creating interdisciplinary connections

One of the keys to helping students experience science in action as an empowering and energizing experience and not an exercise in frustration is to take what may seem like challenges of teaching nanoscience and turn them into constructive opportunities to model the scientific process. We can also create an active student-teacher learning community to model the important process of working collaboratively in an emerging area of science.

This document outlines some of the challenges you may face as a teacher of nanoscience and describes strategies for turning these challenges into opportunities to help students learn about and experience science in action. The final page is a summary chart for quick reference.

Challenges & Opportunities

1. You will not be able to know all the answers to student (and possibly your own) questions ahead of time …

Nanoscience is new to all of us as science teachers. We can (and definitely should) prepare ahead of time using the resources provided in this curriculum as well as any others we can find on our own. However, it would be an impossible task to expect any of us to become experts in a new area in such a short period of time or to anticipate and prepare for all of the questions that students will ask.

… This provides an opportunity to model the process scientists use when confronted with new phenomena.

Since there is no way for us to become all-knowing experts in this new area, our role is analogous to the "lead explorer" in a team working to understand a very new area of science. This means that it is okay (and necessary) to acknowledge that we don't have all the answers. We can then embrace this situation to help all of our students get involved in generating and researching their own questions. This is a very important part of the scientific process that needs to occur before anyone steps foot in a lab. Each time we teach nanoscience, we will know more, feel more comfortable with the process for investigating what we don't know, and find that there is always more to learn.

One strategy that we can use in the classroom is to create a dedicated space for collecting questions. This can be a space on the board, on butcher paper on the wall, a question "box" or even an online space if we are so inclined. When students have questions, or questions arise during class, we can add them to the list. Students can be invited to choose questions to research and share with the group, we can research some questions ourselves, and the class can even try to contact a nanoscientist to help us address some of the questions. This can help students learn that conducting a literature review to find out what is already known is an important part of the scientific process.

2. Traditional chemistry and physics concepts may not be applicable at the nanoscale level …

One way in which both students and teachers try to deal with phenomena we don't understand is to go back to basic principles and use them to try to figure out what is going on. This is a great strategy as long as we are using principles and concepts that are appropriate for the given situation.

However, an exciting but challenging aspect of nanoscience is that matter acts differently when the particles are nanosized. This means that many of the macro-level chemistry and physics concepts that we are used to using (and upon which our instincts are based) may not apply. For example, students often want to apply principles of classical physics to describe the motion of nanosized objects, but at this level, we know that quantum mechanical descriptions are needed. In other situations it may not even be clear if the macroscale-level explanations are or are not applicable. For example, scientists are still exploring whether the models used to describe friction at the macroscale are useful in predicting behavior at the nanoscale (Luan & Robbins, 2005).

Because students don't have an extensive set of conceptual frameworks to draw from to explain nanophenomena, there is a tendency to rely on the set of concepts and models that they do have. Therefore, there is a potential for students to incorrectly apply macroscale-level understandings at the nanoscale level and thus inadvertently develop misconceptions.

… This provides an opportunity to explicitly address the use of models and concepts as scientific tools for describing and predicting chemical behavior.

Very often, concepts and models use a set of assumptions to simplify their descriptions. Before applying any macroscale-level concept at the nanoscale level, we should have the students identify the assumptions it is based on and the situations that it aims to describe. For example, when students learn that quantum dots fluoresce different colors based on their size, they often want to explain this using their knowledge of atomic emission. However, the standard model of atomic emission is based on the assumption that the atoms are in a gaseous form and thus so far apart that we can think about their energy levels independently. Since quantum dots are very small crystalline solids, we have to use different models that think about the energy levels of the atoms together as a group.

By helping students to examine the assumptions a model makes and the conditions under which it can be applied, we not only help students avoid incorrect application of concepts, but also guide them to become aware of the advantages and limitations of conceptual models in science. In addition, as we encounter new concepts at the nanoscale level, we can model the way in which scientists are constantly confronted with new data and need to adjust (or discard) their previous understanding to accommodate the new information. Scientists are lifelong learners and guiding students as they experience this process can help them see that it is an integral and necessary part of doing science.

3. Some questions may go beyond the boundary of our current understanding as a scientific community…

Traditional chemistry curricula primarily deal with phenomena that we have studied for many years and are relatively well understood by the scientific community. Even when a student has a particularly deep or difficult question, if we dig enough we can usually find ways to explain an answer using existing concepts. This is not so with nanoscience! Many questions involving nanoscience do not yet have commonly agreed upon answers because scientists are still in the process of developing conceptual systems and theories to explain these phenomena. For example, we have not yet reached a consensus on the level of health risk associated with applying powders of nanoparticles to human skin or using nanotubes as carriers to deliver drugs to different parts of the human body.

… This provides an opportunity to involve students in exploring the nature of knowing: how we know what we know, the process of generating scientific explanations, and its inherent limitations.

While this may make students uncomfortable, not knowing a scientific answer to why something happens or how something works is a great opportunity to help them see science as a living and evolving field. Highlighting the uncertainties of scientific information can also be a great opportunity to engage students in a discussion of how scientific knowledge is generated. The ensuing discussion can be a chance to talk about science in action and the limitations on scientific research. Some examples that we can use to begin this discussion are: Why do we not fully understand this phenomenon? What (if any) tools limit our ability to investigate it? Is the phenomenon currently under study? Why or why not? Do different scientists have different explanations for the same phenomena? If so, how do they compare?

4. Nanoscience is a multidisciplinary field and draws on areas outside of chemistry, such as biology, physics, and computer science…

Because of its multidisciplinary nature, nanoscience can require us to draw on knowledge in potentially unfamiliar academic fields. One day we may be dealing with nanomembranes and drug delivery systems, and the next day we may be talking about nanocomputing and semiconductors. At least some of the many areas that intersect with nanoscience are bound to be outside our areas of training and expertise.

… This provides an opportunity to engage and value our student knowledge beyond the traditional areas of chemistry.

While we may not have taken a biology or physics class in many years, chances are that at least some of our students have. We can acknowledge students' interest and expertise in these areas and take advantage of their knowledge. For example, ask a student with a strong interest in biology to connect drug delivery mechanisms to their knowledge about cell regulatory processes. In this way, we share the responsibility for learning and emphasize the value of collaborative investigation. Furthermore, this helps engage students whose primary area of interest isn't chemistry and gives them a chance to contribute to the class discussion. It also helps all students begin to integrate their knowledge from the different scientific disciplines and presents wonderful opportunities for them to see the how the different disciplines interact to explain real world phenomena.

Final Words

Nanoscience provides an exciting and challenging opportunity to engage our students in cutting edge science and help them see the dynamic and evolving nature of scientific knowledge. By embracing these challenges and using them to engage students in meaningful discussions about science in the making and how we know what we know, we are helping our students not only in their study of nanoscience, but in developing a more sophisticated understanding of the scientific process.

References

Luan, B., & Robbins, M. (2005, June). The breakdown of continuum models for mechanical contacts. *Nature 435*, 929-932.

Table 1. Challenges of teaching nanoscience and strategies for turning these challenges into learning opportunities.

	The Challenge…	Provides the Opportunity to…
1	You will not be able to know all the answers to student (and possibly your own) questions ahead of time	Model the process scientists use when confronted with new phenomena: Identify and isolate questions to answer Work collectively to search for information using available resources (textbooks, scientific journals, online resources, scientist interviews) Incorporate new information and revise previous understanding as necessary Generate further questions for investigation
2	Traditional chemistry and physics concepts may not be applicable at the nanoscale level	Address the use of models and concepts as scientific tools for describing and predicting chemical behavior: Identify simplifying assumptions of the model and situations for intended use Discuss the advantages and limitations of using conceptual models in science Integrate new concepts with previous understandings
3	Some questions may go beyond the boundary of our current understanding as a scientific community	Involve students in exploring the nature of knowing: How we know what we know The limitations and uncertainties of scientific explanation How science generates new information How we use new information to change our understandings
4	Nanoscience is a multidisciplinary field and draws on areas outside of chemistry, such as biology and physics	Engage and value our student knowledge beyond the area of chemistry: Help students create new connections to their existing knowledge from other disciplines Highlight the relationship of different kinds of individual contributions to our collective knowledge about science Explore how different disciplines interact to explain real world phenomena

Fine Filters: Overview, Learning Goals & Standards

Type of Courses:	Chemistry
Grade Levels:	9-12
Topic Area:	Separation of solutions
Key Words:	Nanoscience, nanotechnology, separation of mixtures, filtration, nanofiltration, solutions, water
Time Frame:	4 class periods (assuming 50-minutes classes), with extensions available

Overview

The shortage of clean drinking water is a pressing global issue. In the twentieth century, demand for water increased six fold, more than double the rate of growth of the human population. At the same time, pollution and over-extraction of water in many regions of the world has reduced the ability of supplies to meet the demand. The United Nations estimates that over a billion people lack access to safe drinking water.

Part of the solution to the water crisis comes from filtration technologies that make water clean enough to drink. For water that contains salt, (97% of earth's water), reverse osmosis is now in use for removing sodium ions. Reverse osmosis is an expensive process, because it requires high pressure—and hence more energy in the form of electricity—to force the affluent (impure water) through the filter membrane.

For water that does not contain salt, a new and more cost-effective technology—nanofiltration—is just beginning to be used. Nanofiltration can remove minerals, sugars, and color from water, and costs much less than reverse osmosis because the process requires much less pressure. There are a multitude of research efforts to develop nanomembranes for water filtration. Researchers anticipate that several forms of this new technology will be available in the next few years. This new generation of membranes is designed to be equally effective as currently used purification treatments, but significantly less expensive so that poor communities can afford clean drinking water.

Enduring Understandings (EU)

What enduring understandings are desired? Students will understand:

1. A shortage of clean drinking water is one of the most pressing global issues.
2. As a result of water's bent shape and polarity, water has unique properties, such as an ability to dissolve most substances. These properties are responsible for many important characteristics of nature.
3. Pollutants can be separated from water using a variety of filtration methods. The smaller the particle that is to be separated from a solution, the smaller the required pore size of the filter and the higher the cost of the process.
4. Innovations using nanotechnology to create a new generation of membranes for water filtration are designed to solve some critical problems in a cost-effective way that allows for widespread use.

Essential Questions (EQ)

What essential questions will guide this unit and focus teaching and learning?

1. Why are water's unique properties so important for life as we know it?
2. How do we make water safe to drink?
3. How can nanotechnology help provide unique solutions to the water shortage?
4. Can we solve our global water shortage problems? Why or why not?

Key Knowledge and Skills (KKS)

What key knowledge and skills will students acquire as a result of this unit? Students will be able to:

1. Describe the global distribution of clean drinking water and explain some of the causes and consequences of water scarcity.
2. Describe different types of filtration in terms of the pore size of the filter, substances it can separate, and cost of use.
3. Use laboratory procedures to compare the relative effectiveness of different filtration methods on particle separation.
4. Describe the basic structure and charge distribution of water.
5. Explain how hydrogen bonding accounts for many of water's unique properties.

Prerequisite Knowledge

This unit assumes that students are familiar with the following concepts or topics:

1. Atoms, molecules, ions.
2. Homogeneous and heterogeneous solutions.
3. Solute-solvent interaction between ionic and molecular solutes and water.

NSES Content Standards Addressed

K-12 Unifying Concepts and Process Standard

As a result of activities in grades, K-12, all students should develop understanding and abilities aligned with the following concepts and processes: (1 of the 5 categories apply)

- Form and function

Grades 9-12 Content Standard A: Scientific Inquiry

Abilities Necessary to Do Scientific Inquiry

- **Design and conduct scientific investigations.** Designing and conducting a scientific investigation requires introduction to the major concepts in the area being investigated, proper equipment, safety precautions, assistance with methodological problems, recommendations for use of technologies, clarification of ideas that guide the inquiry, and scientific knowledge obtained from sources other than the actual investigation. The investigation may also require student clarification of the question, method, controls, and variables; student organization and display of data; student revision of methods and explanations; and a public presentation of the results with a critical response from peers. Regardless of the scientific investigation performed, students must use evidence, apply logic, and construct an argument for their proposed explanations. (12ASI1.2)

- **Formulate scientific explanations and models.** Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical. In the process of answering the questions, the students should engage in discussions and arguments that result in the revision of their explanations. These discussions should be based on scientific knowledge, the use of logic, and evidence from their investigation. (12ASI1.4)
- **Communicate and defend a scientific argument.** Students in school science programs should develop the abilities associated with accurate and effective communication. These include writing and following procedures, expressing concepts, reviewing information, summarizing data, using language appropriately, developing diagrams and charts, explaining statistical analysis, speaking clearly and logically, constructing a reasoned argument, and responding appropriately to critical comments. (12ASI1.6)

Grades 9-12 Content Standard B: Physical Science

Structure and Properties of Matter

Compounds. The physical properties of compounds reflect the nature of the interactions among its molecules. These interactions are determined by the structure of the molecule, including the constituent atoms and the distances and angles between them. (12BPS2.4)

Grades 9-12 Content Standard E: Science and Technology

Abilities of Technological Design

- **Propose designs and choose between alternative solutions.** Students should demonstrate thoughtful planning for a piece of technology or technique. Students should be introduced to the roles of models and simulations in these processes. (12EST1.2)
- **Communicate the problem, process, and solution.** Students should present their results to students, teachers, and other in a variety of ways, such as orally, in writing, and in other forms—including models, diagrams, and demonstrations. (12EST1.5)

Grades 9-12 Content Standard F: Science in Personal and Social Perspectives

Personal and Community Health

- **Selection of foods and eating patterns determine nutritional balance.** Nutritional balance has a direct effect on growth and development and personal well-being. Personal and social factors—such as habits, family income, ethnicheritage, body-size, advertising, and peer pressure—influence nutritional choices. (12FSPSP1.5)

Population Growth

- **Populations can reach limits to growth**. Carrying capacity is the maximum number of individuals that can be supported in a given environment. The limitation is not the availability of space, but the number of people in relation to resources and the capacity of earth systems to support human beings. Changes in technology can cause significant changes, either positive or negative, in carrying capacity. (12FSPSP2.1)

Natural Resources

- **Human populations use resources in the environment in order to maintain and improve their existence**. Natural resources have been and will continue to be used to maintain human populations. (12FSPSP3.1)
- **The earth does not have infinite resources**; increasing human consumption places severe stress on the natural processes that renew some resources, and it depletes those resources that cannot be renewed. (12FSPSP3.2)

Environmental Quality

- **Many factors influence environmental quality.** Factors that students might investigate include population growth, resource use, population distribution, over-consumption, the capacity of technology to solve problems, poverty, the role of economic, political, and religious views, and different ways humans view the earth. (12FSPSP4.3)

Science and Technology in Local, National, and Global Challenges

- **Science and technology are essential social enterprises**, but alone they can only indicate what can happen, not what should happen. The latter involves human decisions about the use of knowledge. (12FSPSP6.1)
- **Understanding basic concepts and principles of science and technology should precede active debate** about the economics, policies, politics, and ethics of various science- and technology-related challenges. However, understanding science alone will not resolve local, national, or global challenges. (12FSPSP6.2)

Unit at a Glance

Overview

The Fine Filters Unit has been designed in a modular fashion to allow you maximum flexibility in adapting it to your student's needs. Lesson 1 provides an introduction to the context and human need for clean drinking water. Combined with Lesson 3 (Nanofiltration), they make up the basic sequence for the unit. Lesson 2 is an extension that reviews some of the science basics of water. In particular, it reviews the structure of water and its unique properties based on the quantum mechanical model of the atom, the shape of the water molecule and the distribution of charge.

Lesson	Basic Sequence	Optional Extensions
Lesson 1: The Water Crisis	√	
Lesson 2: The Science of Water		√
Lesson 3: Nanofiltration	√	

Most lessons contain an interactive presentation and one or more options for activities so you can tailor the depth and duration of the lesson to meet your needs. The following pages contain a suggested sequencing of activities for the unit, but of course there are other combinations possible.

Suggested Sequencing of Activities for Unit

Lesson	Teaching Days	Main Activities and Materials	Learning Goals	Assessment	Homework
Lesson 1: The Water Crisis	2 days: *Day 1*	The Water Crisis: PowerPoint and Discussion Initial Ideas: Student Worksheet	EU: 1 KKS: 1	Initial Ideas Worksheet	Student Data Worksheet
	Day 2 (10 min only for quiz)	Take and review quiz		Water Crisis Quiz	
Lesson 2: The Science of Water (Optional)	3 days: *Day 1*	Science of Water PowerPoint and Discussion	EU: 2 KKS: 3, 4		Read Science of Water Lab Activity and generate hypotheses
	Day 2	Science of Water Lab Activities		Reflection on Guiding Questions	Reflection on Guiding Questions
	Day 3 (35 min)	Reflection on Guiding Questions Take and review quiz		Science of Water Quiz	
Lesson 3: Nanofiltration	3 days: *Day 1*	Nanofiltration: PowerPoint and Discussion Which Method is Best Activity	EU: 3, 4 KKS: 2, 3	Which Method is Best Worksheet	Nanofiltration: Student Reading Read Filtration Lab and generate hypotheses
	Day 2	Comparing Nanofilters to Conventional Filters Lab Activity		Filtration Lab Activity Worksheet	New Nanomembranes: Student Reading
	Day 3	Cleaning Jarny's Water Discuss Nano-Membranes Reading Discussion of Reflection on Guiding Questions		Jarny Student Report Final Reflections Worksheet	

What **enduring understandings (EU)** are desired? Students will understand:

1. A shortage of clean drinking water is one of the most pressing global issues.
2. As a result of water's bent shape and polarity, water has unique properties, such as an ability to dissolve most substances. These properties are responsible for many important characteristics of nature.
3. Pollutants can be separated from water using a variety of filtration methods. The smaller the particle that is to be separated from a solution, the smaller the required pore size of the filter and the higher the cost of the process.
4. Innovations using nanotechnology to create a new generation of membranes for water filtration are designed to solve some critical problems in a cost-effective way that allows for widespread use.

What **essential questions (EQ)** will guide this unit and focus teaching and learning?

1. Why are water's unique properties so important for life as we know it?
2. How do we make water safe to drink?
3. How can nanotechnology help provide unique solutions to the water shortage?
4. Can we solve our global water shortage problems? Why or why not

What **key knowledge and skills (KKS)** will students acquire as a result of this unit? Students will be able to:

1. Describe the global distribution of clean drinking water and explain some of the causes and consequences of water scarcity.
2. Describe different types of filtration in terms of the pore size of the filter, substances it can separate, and cost of use.
3. Use laboratory procedures to compare the relative effectiveness of different filtration methods on particle separation.
4. Describe the basic structure and charge distribution of water.
5. Explain how hydrogen bonding accounts for many of water's unique properties.

Alignment of Unit Activities with Learning Goals

	Lesson 1	Lesson 2	Lesson 3
Presentation	*Introduction/ Water Crisis*	*Science of Water*	*Nanofiltration*
Activity	*Student Reading, Data Worksheet*	*Water Lab Activity*	*Student Reading/ Jarny/ Filtration Lab*
Learning Goals / **Assessment**	*Quiz/ Initial Ideas Worksheet*	*Label Results/ Quiz/ Reflection Worksheet*	*Lab Results/ Jarny, Reflection Worksheets*
Students will understand…			
EU 1. A shortage of clean drinking water is one of the most pressing global issues	•		
EU 2. As a result of water's bent shape and polarity, water has unique properties, such as an ability to dissolve most substances. These properties are responsible for many important characteristics of nature.		•	
EU 3. Pollutants can be separated from water using a variety of filtration methods. The smaller the particle that is to be separated from a solution, the smaller the required pore size of the filter and the higher the cost of the process			•
EU 4. Innovations using nanotechnology to create a new generation of membranes for water filtration are designed to solve some critical problems in a cost-effective way that allows for widespread use.			•
Students will be able to…			
KKS1. Describe the global distribution of clean drinking water and explain some of the causes and consequences of water scarcity.	•		
KKS2. Describe different types of filtration in terms of the pore size of the filter, substances it can separate, and cost of use.			•
KKS4. Use laboratory procedures to compare the relative effectiveness of different filtration methods on particle separation.			•
KKS3. Describe the basic structure and charge distribution of water.		•	
KKS5. Explain how hydrogen bonding accounts for many of water's unique properties.		•	

Alignment of Unit Activities with Curriculum Topics

Chemistry

Unit Topic	Chapter Topic	Subtopic	Fine Filters Lessons	Specific Materials
Structure of Matter	Electron Configuration	Atomic Structure	• Lesson 2 (L2): Science of Water	**Slides** • L2: 3-10
		Bonding	• Lesson 2 (L2): Science of Water	**Slides** • L2: 11-19
Chemical Equilibrium	Solutions	Nature of solutions Precipitates Common Ion Effect	• Lesson 2 (L2): Science of Water • Lesson 3 (L3): Nanofiltration	**Slides** • L2: (all) • L3: (all) **Activity/Handout** • L2 ○ Science of Water Labs ○ Reflecting on Guiding Questions • L3 ○ The Filtration Spectrum ○ Which Method is Best? ○ Cleaning Jarny's Water ○ Comparing Filtration to Nanofiltration Lab Activities

Biology

Unit Topic	Chapter Topic	Subtopic	Fine Filters Lessons	Specific Materials
Nature of Life	The Chemistry of Life	The Nature of Matter; Properties of Water; Carbon Compounds	**Fine Filters** • Lesson 2 (L2): Science of Water	**Slides** • L2: 20-32 **Activity/Handout** • L2 ○ Science of Water Labs ○ Science of Water Quiz

Physics

Unit Topic	Chapter Topic	Subtopic	Fine Filters Lessons	Specific Materials
Light and Optics	Light Rays	Electron clouds Orbitals Charges	**Fine Filters** • Lesson 2 (L2): The Science of Water	**Slides** • L2: 5-16

Environmental Science

Unit Topic	Chapter Topic	Subtopic	Fine Filters Lessons	Specific Materials
Water	Our Water Resources	Solutions to Water Shortages	• Lesson 1 (L1): The Water Crisis	**Slides** • L1: 1-27 **Activity/Handout** • The World-Wide Water Shortage: Student Reading • The Water Crisis: Student Data Worksheet • The Water Crisis Initial Ideas • Student Quiz
	Freshwater Pollution	Wastewater Treatment Plants	• Lesson 2 (L2): The Science of Water • Lesson 3 (L3): Nanofiltration	**Slides** • L2: 1-34 **Activity/Handout** • L2: The Science of Water Quiz • L3: ○ Comparing Filtration and Nanofiltration Lab Activities ○ Reflecting on the Guiding Questions
		Pathogens	• Lesson 3 (L3): Nanofiltration	**Slides** • L3: 1-21 **Activity/Handout** • Reading: New Nanomembranes • Which Method is Best? • Jarny Water Activity • Comparing Filtration and Nanofiltration Lab Activities • Reading: New Nanomembranes

Fine Filters Pretest/Posttest: Teacher Answer Sheet

20 points total

1. Which of the following types of contaminants can nanomembranes filter out of water? For which of these, would you typically use a nanomembrane for removal? Explain why or why not. (1 point each, total of 12 points)

	Can a nanomembrane filter it out?	Is a nanomembrane the best way to filter it out?
Bacteria	**Yes** or No	Yes or **No**
	Why/why not: Bacteria are large enough that micromembranes can also filter them out of water. Micromembranes are less expensive to use and the large bacteria would quickly foul the nanomembrane.	
Lead (Pb^{2+})	**Yes** or No	**Yes** or No
	Why/why not: Divalent ions (such as lead) are too small to be separated out by micro- or ultra-filtration. Nanofiltration can remove them from water and is less expense than reverse osmosis (which would also remove them).	
Salt (Na^{+} and Cl^{-})	Yes or **No**	Yes or **No**
	Why/why not: Monovalent ions are too small to be filtered out by current nanomembranes. Reverse osmosis must be used.	
Sand	**Yes** or No	Yes or **No**
	Why/why not: Sand is large enough that it can be filtered by a simple mesh cloth. This is less expensive to use and the sand would quickly foul the nanomembrane.	

2. Name two benefits that nanomembranes bring to the filtration of water that help to address the world's problem of a scarcity of clean drinking water. (1 point each, 2 points total)

- More effective in removing particles of a given size
- More cost efficient than other technologies to remove small particles
- Nanofiltration can be engineered in many different ways (design flexibility)

Common Incorrect Answer:

- Can remove smaller particles than existing technologies (RO removes smaller particles)

3. Describe three ways in which nanofilters can operate differently than traditional filters to purify water: (2 points each, 6 points total)

- Layering: Nanomembranes can be uniquely designed in layers. This allows different parts of the membrane (the different layers) to be made out of different materials and have different properties to target different contaminants.
- Embedded Agents: Can embed specialized substances that do specific jobs in relation to certain kinds of contaminants – for example a chemical that kills bacteria on contact
- Water Channels: Create hydrophilic tubes in membranes that "pull" water through while keeping everything else out
- Electrostatic Repulsion 1: You can weave into the membrane a type of molecule than can conduct electricity and repel oppositely charged particles, but let water through.
- Electrostatic Repulsion 2: Pores of one to two nanometers in diameter create an electric field over the opening. This electric field is negative and repels negatively charged particles dissolved in water
- Self-Cleaning: Can send signal for them to self-clean (remove fouling residue)
- Less pressure is needed than conventional RO filters

Unit Overview

Student Materials

Contents

Name_________________________________ Date_____________________ Period ______

Fine Filters: Pretest

1. Which of the following types of contaminants can nanomembranes filter out of water? For which of these, would you typically use a nanomembrane for removal? Explain why or why not. (1 point each, total of 12 points)

	Can a nanomembrane filter it out?	**Is a nanomembrane the best way to filter it out?**
Bacteria	Yes or No	Yes or No
	Why/why not:	
Lead (Pb^{2+})	Yes or No	Yes or No
	Why/why not:	
Salt (Na^+ and Cl^-)	Yes or No	Yes or No
	Why/why not:	
Sand	Yes or No	Yes or No
	Why/why not:	

2. Name two benefits that nanomembranes bring to the filtration of water that help to address the world's problem of a scarcity of clean drinking water. (1 point each, 2 points total)

3. Describe three ways in which nanofilters can operate differently than traditional filters to purify water: (2 points each, 6 points total)

Name________________________________ Date_____________________ Period ______

Fine Filters: Posttest

1. Which of the following types of contaminants can nanomembranes filter out of water? For which of these, would you typically use a nanomembrane for removal? Explain why or why not. (1 point each, total of 12 points)

	Can a nanomembrane filter it out?	**Is a nanomembrane the best way to filter it out?**
Bacteria	Yes or No	Yes or No
	Why/why not:	
Lead (Pb^{2+})	Yes or No	Yes or No
	Why/why not:	
Salt (Na^{+} and Cl^{-})	Yes or No	Yes or No
	Why/why not:	
Sand	Yes or No	Yes or No
	Why/why not:	

2. Name two benefits that nanomembranes bring to the filtration of water that help to address the world's problem of a scarcity of clean drinking water. (1 point each, 2 points total)

3. Describe three ways in which nanofilters can operate differently than traditional filters to purify water: (2 points each, 6 points total)

Lesson 1:
The Water Crisis

Teacher Materials

Contents

Introduction to the Water Crisis: Teacher Lesson Plan

Orientation

This lesson is an introduction to the context and human need for clean drinking water. Many students in the United States are unaware that in several parts of the world, clean drinking water is unavailable. This introductory lesson is intended to increase students' awareness of the problem in terms of human health and as a potential source of conflict between nations, especially as the world population grows.

A key goal is to spark students' interest by addressing a topic of personal and global significance. It is within the context of the urgent need for clean water by the people of several nations that they will better understand the significance that nanomembrane filtration technology could potentially have on helping to solve one of the current largest global problems. They will refine this understanding over the course of the unit and have a chance to reflect on their initial thoughts at the end of the unit.

- The Water Crisis PowerPoint slide set introduces facts about the global distribution of fresh water geologically. Areas of the world that do not have access to enough clean drinking water are highlighted. Per capita water usage, wealth, and access to sanitation are shown for several countries, and consequences from drinking contaminated water are highlighted. The final slide in the set introduces the driving questions for the unit.
- The Water Crisis: Student Data Worksheet captures the images of the data graphs and tables embedded in the slide set. The questions associated with the data sets that are designed to get students to think about the information portrayed. We recommend that the students do the data sheet as a homework assignment previous to seeing the slides. Alternately, they can complete it as you present the slides, pausing at each slide that portrays a data representation in order to give students time to think about the information depicted.
- The Initial Ideas: Student Worksheet gives students the chance to draw on their existing knowledge to formulate first thoughts about the unit. This is a great tool for eliciting students' prior knowledge (and possible misconceptions) related to the unit topics.
- The Water Crisis: Student Quiz can help you to assess the student understandings before the lesson is taught, so you can adjust the lesson appropriately, or it can be used as a summative evaluation after the lesson.

Essential Questions (EQ)

What essential questions will guide this unit and focus teaching and learning?

(Numbers correspond to learning goals overview document.)

2. How do we make water safe to drink?
3. How can nanotechnology help provide unique solutions to the water shortage?
4. Can we solve our global water shortage problems? Why or why not?

Enduring Understandings (EU)

Students will understand:

(Numbers correspond to the learning goals overview document.)

1. A shortage of clean drinking water is one of the most pressing global issues.

Key Knowledge and Skills (KKS)

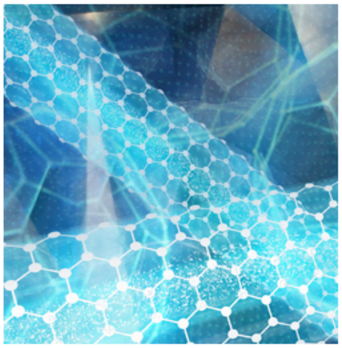
Students will be able to:

(Numbers correspond to the learning goals overview document.)

1. Describe the global distribution of clean drinking water and explain some of the causes and consequences of water scarcity.

Introduction & Initial Ideas Timeline

Day	Activity	Time	Materials
Prior to this lesson	*Homework*: Water Crisis: Student Data Worksheet	*40 min*	Photocopies of Water Crisis: Student Data Worksheet
Day 1 (50 min)	Hand out the Initial Ideas Student Worksheet and have students work alone or in pairs to brainstorm answers to the driving questions. Let students know that at this point they are just brainstorming ideas and they are not expected to be able to fully answer the questions.	10 min	Copies of Fine Filters Initial Ideas: Student Worksheet Fine Filters Initial Ideas: Teacher Instructions
	Show the Water Crisis: PowerPoint Slides, using the question slides and teacher's notes to start the class discussion. Hand out the Water Crisis: Student Data Worksheet if students did not complete it as a homework assignment the night before. Students can interpret the data representations or update their responses as you show the PowerPoint slide set.	30 min	Water Crisis: PowerPoint Slides & Teacher Notes Computer and projector Water Crisis: Student Data Worksheet
	Return to whole class discussion and have students share their ideas with the class to make a "master list" of initial ideas. The goal is not only to have students get their ideas out in the open, but also to have them practice evaluating how confident they are in their answers. This is also a good opportunity for you to identify any misconceptions that students may have to address throughout the unit.	10 min	
Day 2 (10 min)	Optional: Water Crisis: Student Quiz	7-10 min	Photocopies of Water Crisis: Student Quiz Water Crisis: Quiz Answer Key



The Water Crisis

A lack of clean water results in poverty, disease and death

NanoSense
the basic sense behind nanoscience

Question

Have You Ever Gotten Sick from Drinking Impure Water? Do You Know Someone Who Has?

Source: http://www.seykota.com/tribe/FAQ/2003_Aug/Aug_10-16/sick_to_stomach.gif

NanoSense 3

Clean Water is Necessary for Life

- Drinking
- Bathing
- Agriculture
- Sanitation

Sources: http://www.islamic-relief.com/projects/chechnya/index.htm
http://www.frontlineonnet.com/fl2209/images/20050506001403701.jpg

NanoSense 4

World Water Gap

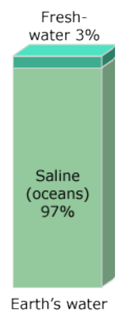
- Despite the apparent abundance of clean water in the US and most of the developed world, more than 20% of the Earth's population lacks clean, safe drinking water.

Sources: http://www.battelle.org/environment/images/water-drop.jpg
http://www.tribuneindia.com/2004/20040718/pb3.jpg

NanoSense 5

How is the World's Water Distributed? I

- Less than 3% of Earth's water is fresh water
- The vast majority (97%) is undrinkable salt water in the oceans

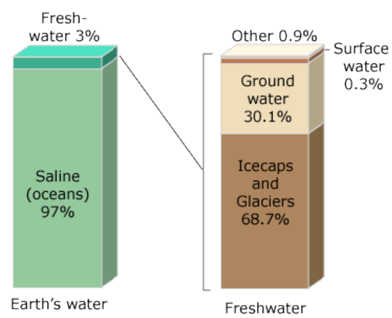


Source: http://ga.water.usgs.gov/edu/watercyclesummary.html#global

NanoSense 6

How is Water Distributed? II

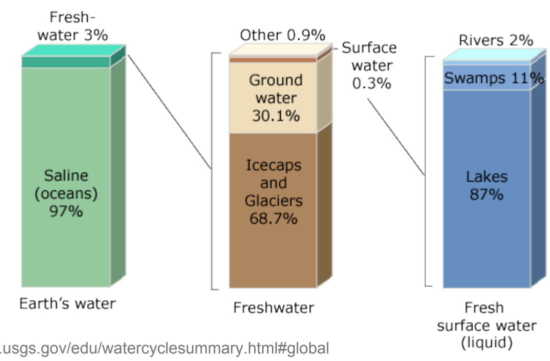
- Of the fresh water, most is in ice caps and glaciers, and some is in ground water
- Less than 1% is in more easily accessible surface water (lakes, swamps, rivers, etc.)



Source: http://ga.water.usgs.gov/edu/watercyclesummary.html#global

How is Water Distributed? III

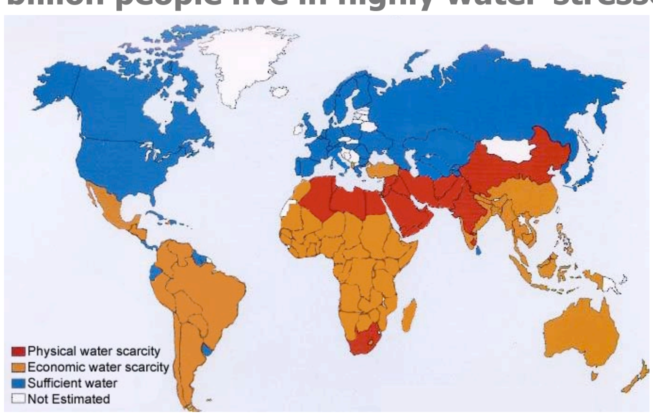
- Most of the surface water is in lakes; a bit is in swamps and rivers
- The point: very little water is easily available for drinking



Source: http://ga.water.usgs.gov/edu/watercyclesummary.html#global

Water is Scarce in Some Regions

- 2.4 billion people live in highly water-stressed areas



Current Water Scarcity: 2006

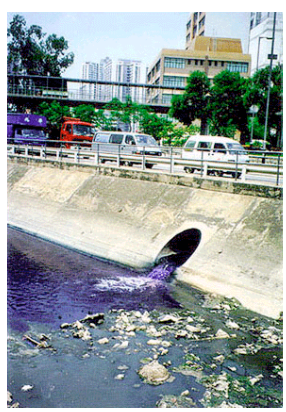
Source: Adapted from http://www.waterlink.net/assets/images/waterscarity2025.jpg

No Single Cause for the Water Crisis

- **Many factors**
  - Climate and geography
  - Lack of water systems and infrastructure
  - Inadequate sanitation
    - 2.6 billion people (40% of the world's population) lack access to sanitation systems that separate sewage from drinking water
    - Inadequate sanitation and no access to clean water have been highly correlated with disease

Pollution is a Big Problem Too

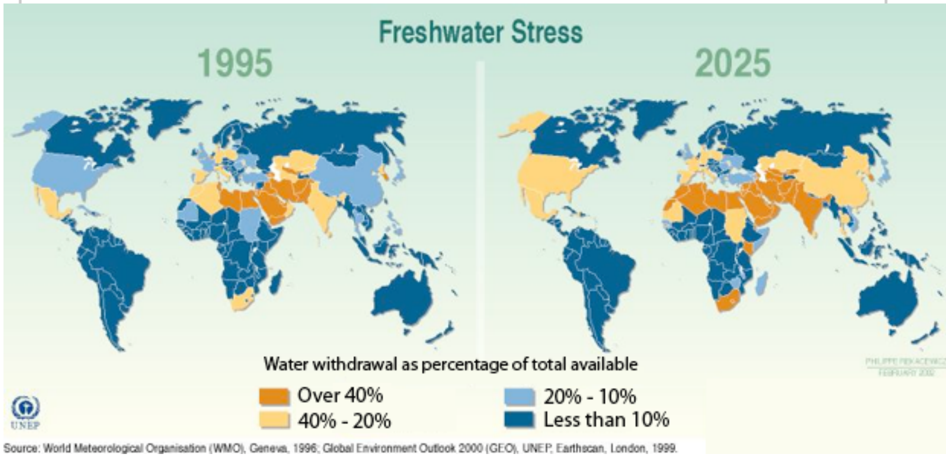
- **Types of pollution in fresh water:**
  - Sewage is the most common
  - Pesticides and fertilizers
  - Industrial waste dumping
  - High levels of arsenic and fluoride



Sources: http://www.marenrecycling.com/polluted_water.JPG
http://mainegov-images.informe.org/agriculture/pesticides/drift/mstblow1.gif

NanoSense 11

Water Scarcity is Projected to Worsen

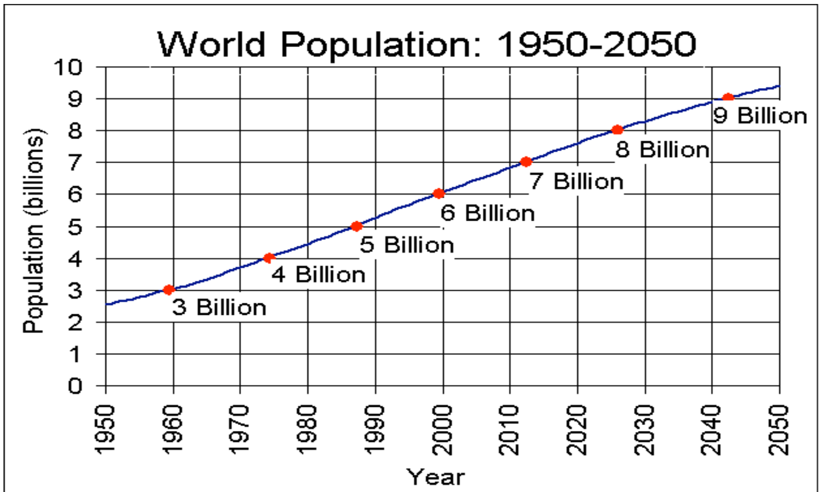


NanoSense 12

Question

Why is the Water Shortage Projected to Worsen?

World Population is Increasing

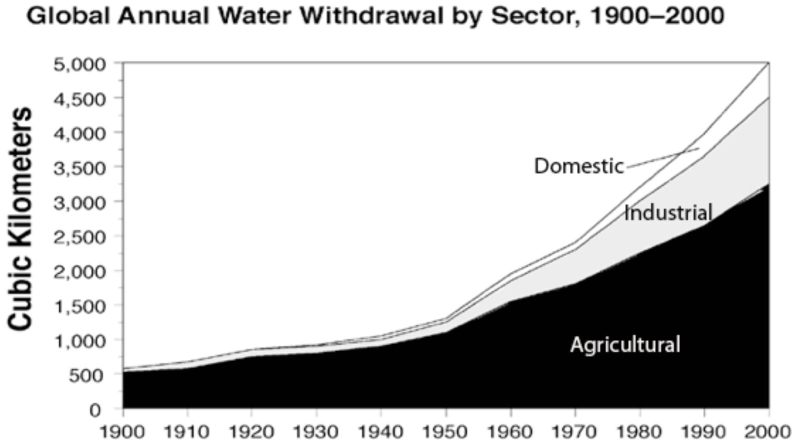


Source: U.S. Census Bureau, International Data Base, August 2006 version.

Question

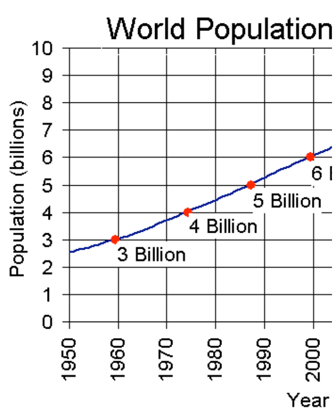
In What Ways Would an Increasing World Population Affect Water Consumption?

Where Clean Water Use is Rising

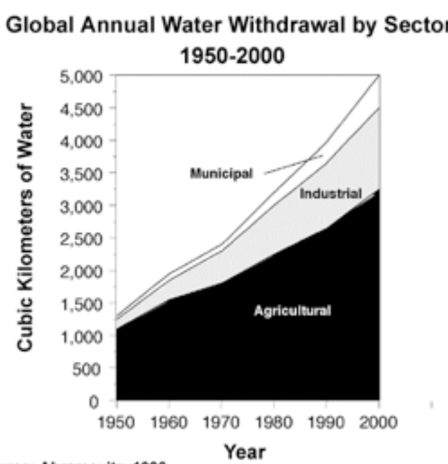


Source: Abramovitz 1996 (1)

Trends in Population and Water Use



Source: U.S. Census Bureau, International Data Base,



Source: Abramovitz, 1996

NanoSense 17

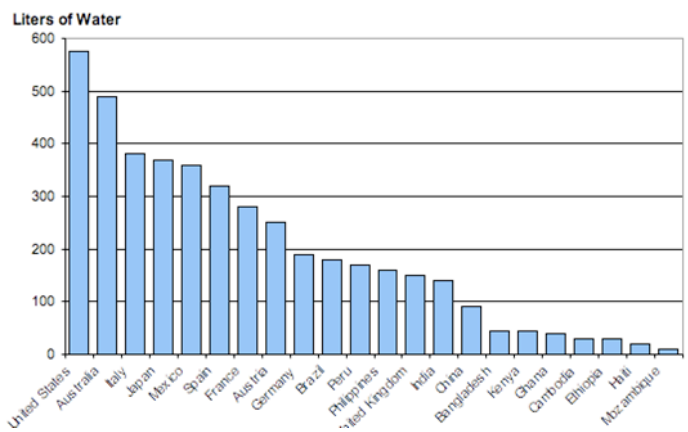
Question

Is There a Relationship Between Poverty and a Lack of Clean Drinkable Water?

NanoSense 18

Countries Differ Widely in Water Usage

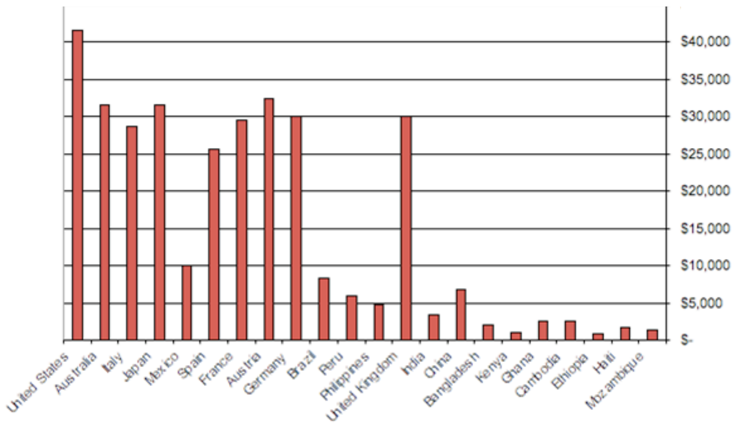
Average Daily Water Use Per Person (1998-2002)
For Selected Countries



Source: http://ww.cia.com

Countries Differ Widely in Wealth

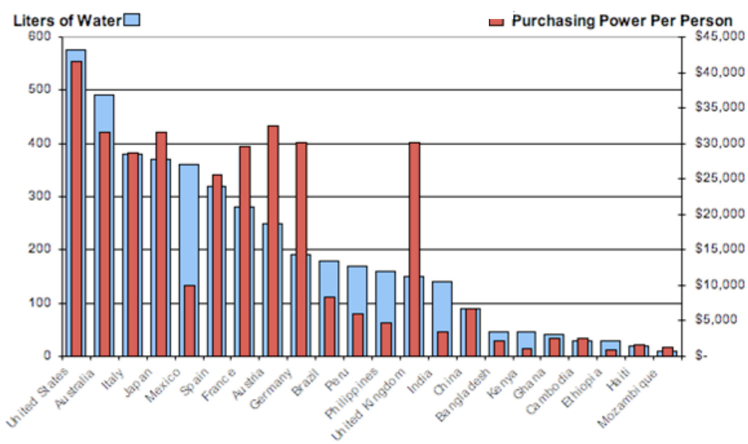
Average Wealth (Purchasing Power Per Person in 2005) For Selected Countries



Source: http://ww.cia.com

Notice Any Correlations?

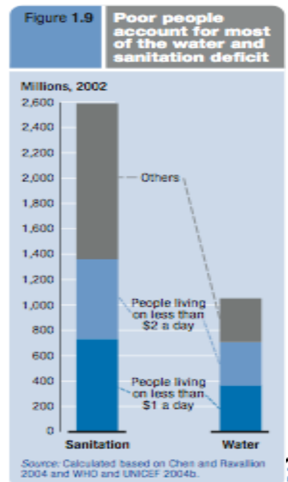
Average Daily Water User Per Person & Wealth For Selected Countries



Source: http://ww.cia.com

Many Without Access Live in Poverty

- **People without clean water**
  - Almost two in three people survive on less than $2 a day, with one in three living on less than $1 a day
- **People without sanitation**
  - Of the 2.6 billion people who do not have adequate sanitation, a little more than half live on less than $2 a day



Impact of Water Scarcity I

- **Health, education, and economic growth are impacted**
- **World Water Forum estimates:**
  - 1.4 billion people lack clean drinking water
  - 2.3 billion people lack adequate sanitation
  - 7 million people die yearly from diseases linked to water

  - Half the world's rivers and lakes are badly polluted
  - Shortages could create millions of refugees seeking homes in a location accessible to water

Source: National Geographic, "The World Water Gap" World Water Forum, The Hague March 17-22, 2000

NanoSense 23

Impact of Water Scarcity II

- **World Health Organization estimates:**
  - 80% of all sickness in the world is attributable to unsafe water and sanitation
  - The leading causes of death in children under 5 are related to unclean water; there are about 5,000 child deaths every day
  - Without action, as many as 135 million people could die from water-related diseases by 2020

Source: http://homepage.mac.com/mastercommunication/runningdry/Personal36.html

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Impact of Water Scarcity III

- **Carrying water takes time!**
  - Women and children can trek miles every day to retrieve water
  - This hard manual labor takes time that they might otherwise spend pursuing education or earning additional income

Photographer: Chantal Boulanger

Sources: http://mamacass.ucsd.edu/~jat/117-1769_IMG.JPG
http://english.people.com.cn/200506/22/images/water1.jpg

NanoSense 25

Children Carrying Water

Sources:
http://www.flourish.org
http://www.lcweb2.loc.gov
http://www.unhcr.ca/earthwater/images/water_on_head.jpg
http://www.lwr.org/news/00/images/ethwelfd.jpg
http://ag.arizona.edu/OALS/ALN/aln57/gifs/reed7b.jpg

NanoSense 26

War for Diminishing Resources?

"The next world war will be over water," says Vice President Ismail Serageldin from the World Bank

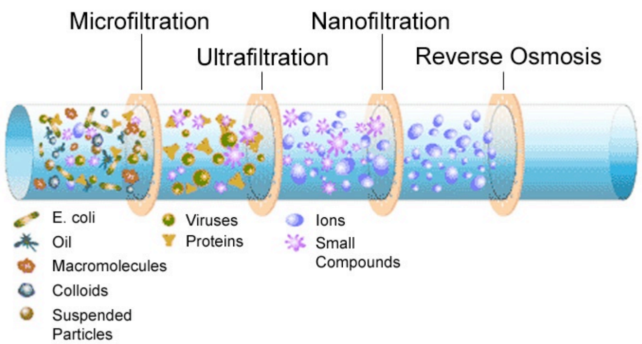
Sources: http://www.missiontohaiti.org/Media/Clean-Water-Color-Mask.jpg

How Can We Address the Water Crisis?

- **Use less water**
  - More efficient irrigation, like drip irrigation
  - Low-flow shower and toilets
  - Use native plants for crops and landscaping
  - Eat less meat
- **Find new sources of clean water**
  - Um… Where? On the moon?
- **Treat the undrinkable water that we have**
  - Use reverse osmosis to desalinize salt (ocean) water
  - Clean polluted water using filters, chemicals, and UV light

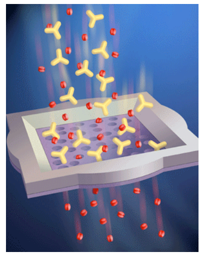
Using Filters to Clean Water

- **Pebbles, sand, & charcoal filter out large particles**
- **Membranes filter out smaller particles**
- **It is efficient to use a series of membranes to filter increasingly smaller particles**



Can Nanotechnology Help?

- **Nanotechnology offers new solutions to filter small particles**
  - Unique properties at the nanoscale mean that membranes can be made to filter by electrical and chemical properties
  - A huge effort to create better, cheaper nanomembrane filters is currently underway!



Membranes clean water by filtering out unwanted substances

Professor Eric Hoek at UCLA is patenting a new nanomembrane filter

Sources: http://www.esemag.com/0902/nano_1.jpg
http://www.simpore.com/pictures/moleculefilter_300.gif

Questions

- **How Do We Make Undrinkable Water Safe to Drink?**
- **How can Nanotechnology Help Provide Solutions to the Water Shortage?**
- **Can We Solve Our Global Water Shortage Problems?**
  - Why or Why Not?

The Water Crisis: Teacher Notes

Overview

This set of slides provides background information on the importance of clean water, why there is a problem with access to clean water, the geographical distribution of fresh water sources globally, a correlation between a country's wealth and water usage, and describes the impact of fresh water shortages on the human population. In this way we establish an important global context for learning about the potential of nanomembranes to help solve this problem of water shortage. These notes are intended to provide you with additional background content for each slide. Some slides will contain questions. These are invitations to engage students in an interactive classroom discussion about the question raised. You will also find a variety of resources for optional use to deepen your own knowledge or to engage students in an activity that relates to key points on the slide.

Slide 1: Title Slide

Slide 2: Have You Ever Gotten Sick from Drinking Impure Water? (Question Slide)

Discuss with your students what their experiences have been (or that they have known about) when someone drinks impure water. This discussion is intended to draw on students' personal understanding of the negative effects of not drinking pure water, so as to better peak their interest in the topic. In the event that students have not had experiences or heard about them, they may have heard about Montezuma's revenge!

Baytel Associates conducted a study to identify drinking water contaminants that cause health problems worldwide. They found so many different contaminants that they prioritized the list to include the twelve "if eliminated" that would have the greatest impact on public health. The twelve contaminants identified are: cholera, enteric bacteria, Rota- and polio viruses, intestinal protozoan, Ascaris (intestinal roundworm), Dracunculus medinensis (Guinea worm), Trichuris trichiura (whipworm), Enerobious vermicularis (pinworm), fluorides, heavy metals, nitrates, and synthetic chemicals.

From the report "Critical Drinking Water Contaminants: A Global Perspective," as reported by *US Water News* online, June 1995. See http://www.uswaternews.com/archives/arcquality/5drink.html

Slide 3: Clean Water is Necessary for Life

Clean water is needed for these four major areas. Sanitation refers to the ability to provide adequate sewage disposal that separates sewage waste from drinking water supplies. Disease in a community is highly correlated with a lack of public sanitation.

Slide 4: World Water Gap

This slide informs students that many people globally do not have access to clean drinking water. The "gap" is a term to describe the difference between the number of people who need clean drinking water compared with the number of people who need clean drinking water. Later we'll see a global map of fresh water distribution.

Based on data from NASA, the World Health Organization, and other agencies, a report produced by the United Nations Environment Programme predicts:

- Severe water shortages already affect at least 400 million people today and are projected to affect 4 billion people by 2050. Southwestern states such as Arizona will face severe fresh water shortages by 2025.
- Adequate sanitation facilities (bathrooms) are lacking for 2.4 billion people, about 40% of humankind.

See http://www.usatoday.com/news/nation/2003-01-26-water-usat_x.htm

Slide 5: How is the World's Water Distributed? I

Slides 5, 6, and 7 show the distribution of water globally. Many students do not know that most of the world's water is salt water (undrinkable and/or unusable for agriculture). The green box shows a physical depiction of the amount of fresh water relative to salt water, globally.

Why can't we use salt water to drink or for agriculture?

Some students do not understand why we cannot drink salt water. Department of Energy's scientist, Prof Bill's, explanation of why we cannot drink salt water is brief and to the point: "Humans can't drink salt water because the kidneys can only make urine that is less salty than salt water. Therefore, to get rid of all the excess salt taken in by drinking salt water, you have to urinate more water than you drank, so you die of dehydration."

Why can't salt water be used for agriculture? In general, too much salt will interfere with the chemistry in a plant that allows the plant to make food and to obtain energy from food. In addition, plants usually get their water through their root system by a process called osmosis (students who have had biology will know about this process). Osmosis involves the passage of water across the membrane of a cell from an area of greater concentration to an area of lesser concentration. If the plant is surrounded by salt water, the plant will tend to pass fresh water from their inside structures to the soil through the roots, causing the plant to lose, not absorb water.

There is a type of plant, called halophytes, that have special structures that separate the salt in such a way that it is prevented from mingling with the rest of the plant, allowing the plant to survive in a salt water environment.

Slide 6: How is Water Distributed? II

This slide depicts the section in the green box representing the proportion of fresh global water, expanded to show where the 3% of fresh water may be found: 68.7% icecaps and glaciers, 30.1% ground water, and only 0.3% surface water.

Slide 7: How is Water Distributed? III

This slide depicts the distribution of the 0.3% surface water: 87% lakes, 11% swamps, and 2% rivers.

Slide 8: Water is Scarce in Some Regions

This calculated approximation, that 2.4 billion people are living in highly water-stressed areas, comes from N. Utsumi, *Thesis,* The University of Tokyo (2006).

Fresh water scarcity or stress is described in a variety of ways.

This is a map from a global view showing the geographic distribution of fresh water, either as surface water or in underground aquifers, as it relates to the population's need for fresh water in that region. Depending on the area's population density and the climate's ability to renew these water supplies, a geographic area can be described by the percent of its available fresh water being used annually compared to how much fresh water is potentially available for use. The higher the percent of water being used compared to what is potentially available, the more **scarce** the fresh water supply. The total potentially available fresh water cannot be completely used. Water availability depends on the climate, the season, the amount of snowmelt, and the infrastructure to capture, store, clean, and deliver it.

Water scarcity is often described in two ways:

Physical water scarcity is a term used to describe an area whose primary water supply is developed at 60% or greater than the total potential capacity. One must understand that the total potential capacity includes water that can never be entirely accessed. These countries do not have sufficient fresh water to meet their demands for agriculture, domestic water, industrial sectors, and environmental requirements. Food has to be imported or salt water must be treated by an expensive desalination process in order to get enough fresh water for agriculture. Agriculture consumes about 70% of fresh water supplies.

Economic water scarcity is a term describing a region that has adequate physical water resources to meet their water supply needs, but must increase the availability of the water through additional storage and conveyance facilities. Most of these countries face severe financial and development capacity problems for increasing the primary water supply, by building the needed infrastructure.

Water shortages are greatest in equatorial regions with increasing populations.

Slide 11 will show freshwater stress simply as the water withdrawal as a percentage of the total available. These are associated with different percentages.

From *Science*, August 25, 2006, published by AAAS:

Water scarcity can be an index defined as Rws = (W-S)/Q where W, S, and Q are the annual water withdrawal by all the sectors, the water use from desalinated water, and the annual renewable fresh water resources (RFWR), respectively.

Slide 9: No Single Cause for the Water Crisis

This slide highlights the major causes for the water crisis. An arid climate does not produce much rainfall. Areas with sufficient rainfall and fresh water supply often lack systems to clean and deliver water to the people, especially in rural areas. It is estimated by the World Health Organization that 40% of the world's population lack sufficient sanitation systems to keep the potable (drinking) water separate from human wastes.

Arsenic and fluoride are pollutants that leach out of rocks into the water in some areas. While small quantities of fluoride are good for teeth, larger quantities are bad. These must be removed before the water is considered to be safe for drinking.

Slide 10: Pollution is a Big Problem Too

The most common type of pollution is untreated sewage that mixes with the drinkable water supply. Sewage contains disease-causing bacteria. Secondly, agriculture contributes pesticides and fertilizer. The pesticides contain poisonous substances that dissolve in water and the fertilizer breaks down to release nitrates into the water. Industrial pollutants contribute heavy metals to the water supply in some areas. All of these must be removed from water, according to clean water standards, for water to be safe to drink.

Slide 11: Water Scarcity is Projected to Worsen

This slide depicts the global distribution of fresh water in the year 1995 and the predicted water distribution in the year 2025. The colors represent the percentage of water withdrawn compared with the total amount of water available. The light orange represents mild water stress and the darker orange represents extreme water stress. The blue areas are considered to be free from freshwater stress.

The graph in the lower right corner shows the amount of people, in billions, suffering from water stress and scarcity, in 1995, then as projected to the year 2050.

It is important to keep in mind that the total possible amount of fresh water can never be fully used. There is high variability of water resources in space and time. River flow depends upon the seasonal climate. An example would be that what is available as snowmelt into the rivers will not be available in the dry season.

Slide 12: Why is the Water Shortage Projected to Worsen? (Question Slide)

Discussion Question for Students: Ask your students why they think that water shortages are predicted to become worse over time.

Although there are current supply problems that need to be solved, as shown by slides 9 and 10, the increase in demand for water is an even bigger factor.

This predicted increase in demand for water is based largely on projected population growth. The larger the population, the more agriculture is required to feed people. Agriculture currently accounts for about 70% of the fresh water usage. The other factor that enters into this prediction is the increasing economics of currently underdeveloped countries.

Slide 13: World Population is Increasing

This graph presents the latest estimates and projections of world population from the U.S. Census Bureau. The world population increased from 3 billion in 1959 to 6 billion in 1999, a doubling that occurred over 40 years. The Census Bureau's latest projections imply that population growth will continue into the 21st century, although more slowly. The world population is projected to grow from 6 billion in 1999 to 9 billion by 2042, an increase of 50% that is in approximately 43 years.

Slide 14: In What Ways Would an Increasing World Population Affect Water Consumption? (Question Slide)

This is a good time for students to brainstorm what water is used for and relatively how much water is used. The next slide depicts an increase in population.

Slide 15: Where Clean Water Use is Rising

This slide depicts the number of cubic kilometers of water withdrawn for municipal, industrial, and agricultural purposes over a period of 100 years, from 1900 to 2000.

The most important point is that agriculture requires at least two-thirds of all of the water withdrawn. As the graph indicates, all uses of water rise as population increases.

Slide 16: Trends in Population and Water Use

This figure shows the two graphs, previously seen, side-by-side, in order to facilitate easier comparisons. Students can easily notice that the trends in the increase of population over time parallel the increase in water consumption.

Slide 17: Is There a Relationship Between Poverty and a Lack of Clean Drinkable Water? (Question Slide)

Answer: There are strong correlations between a country's financial wealth and the presence of clean, drinkable water. To clean and deliver drinkable water requires expensive infrastructures of cleaning systems and pipes to transport the water in areas where water is present in sufficient quantities to meet the populations' needs. In areas where there is not enough natural fresh water sources to meet the needs (drinking water, sanitation, industry, and agriculture) an expensive system must be employed to remove the salt, (desalination), from the water. The World's Water Report says that 1 in 6 people on earth suffer from extreme poverty.[1]

The distribution of access to adequate water and sanitation in many countries mirrors the distribution of wealth. Access to piped water into the household averages about 85% for the wealthiest 20% of the population, compared with 25% for the poorest 20%.

As an optional activity, you may want students to examine a set of tables with information on different countries' water in cubic meters per person and each country's gross national product. Students could work in groups to produce a line graph for these two variables. They could share their interpretation of the graphs. As a less time-consuming alternative activity, students could simply scan the tables with partners to notice the patterns shown by these two variables.

An important understanding to be developed by students during this study of nanofiltration is that the current world water crisis reflects the economic and political decisions made by countries and people.

Information to design an activity like this is available at: https://cia.gov/library/publications/the-world-factbook/index.html.

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[1] *Water: A Shared Responsibility.* UN Report, produced by Berghahn Books and United Nations Education, Scientific and Cultural Organization (UNESCO).

Select a country from the menu at the top.

Slide 18: Countries Differ Widely in their Water Usage

The next three slides are shown to give students an opportunity to make the connection between a country's water usage and per capita wealth. Though for the higher amounts of water usage, there is not an exact correlation with wealth; the low wealth countries consistently show low per person water usage.

This slide depicts a variety of countries' average daily water usage per person between the years of 1998 and 2002. Some of the countries with especially high water usage and some of the countries with low water usage are displayed. For a list of all of the countries' average daily water usage during this same time frame, refer to http://www.cia.com.

Slide 19: Countries Differ Widely in Wealth

This slide shows the same countries' wealth depicted in terms of purchasing power per person for each country in 2005. These figures are from http://www.cia.com.

Slide 20: Notice Any Correlations?

This slide displays the countries' average daily water use per person graph, seen on slide 18, superimposed on the wealth graph (depicted as purchasing power per person).

This is a good opportunity for students to look at the data displayed and make statements about the relationships from the two variables displayed. If students disagree, it is an opportunity for them to choose evidence to support their argument. You might ask them what other information they would need to draw a conclusion.

Question for Students: Is there any evidence that a country's per person water usage has anything to do with a country's per person purchasing power?

Slide 21: Many Without Access Live in Poverty

This graph shows the approximate total number of people, in millions, who don't have access to sanitation (bar on the left) and to clean water (bar on the right). More than two-thirds of the people who don't have access to clean water make less than $2 a day. A little over half of the people who don't have access to sanitation make less than $2 a day.

Slide 22: Impact of Water Scarcity I

This slide highlights the impact of water scarcity on the human condition, globally. This is a good teachable moment. This slide says that 2.3 billion people lack adequate sanitation; slide 9 mentions the estimate of 2.6 billion people.

Question for Students: How hard is it to estimate this phenomenon?

Sanitation and a lack of clean drinking water are related because human feces and urine contain and grow bacteria that cause disease in humans. If there is no way of separating this sewage from a fresh water source, people will become diseased when drinking this water.

Slide 23: Impact of Water Scarcity II

This slide presents additional information from the World Health Organization regarding the impact of water scarcity. It also includes a prediction for 2020 if population continues to rise**,** and fresh water availability continues to be scarce.

The leading cause of death for children in general is associated with respiratory illnesses. The second leading cause of death is diarrhea, which is related to unclean water.

Slide 24: Impact of Water Scarcity III

This slide shows young women and children carrying water to their homes. The impact on a child's or a woman's time in water scarce areas is greater than that on an adult's or a man's, as it is a cultural tradition in many regions to assign the task to children (or more often to very young women) of bringing water from its source to the home. This can require up to 6 miles of walking a day.

Question for Students: How would carrying water a few hours each day for your family impact your life? What would you have to give up?

Slide 25: Children Carrying Water

This is a slide that shows just a few of the amazing pictures publicly available of children carrying water.

Slide 26: War for Diminishing Resources?

This slide highlights a controversial prediction among many authorities. Water is not always a renewable resource. Most of the water used is found stored naturally underground in aqueducts that have been the result of rainwater accumulated over decades, if not centuries. In some regions, like Los Angeles, California, the water is being drained from these aqueducts at a faster rate than natural rainwater can replace. Further, draining the aqueducts at a fast rate can cause subsidence, the collapsing of the land, allowing the ocean to infiltrate and contaminate fresh underground water areas.

Slide 27: How Can We Address the Water Crisis?

Agriculture consumes about 70% of fresh water supplies, so efficiencies there—like more efficient irrigation methods—could have the most impact. But there are a lot of things that we can do on the smaller scale, too, like conserving water at home and in our gardens. Lots of web sites offer water saving tips. A good example is http://www.wateruseitwisely.com

Even eating less meat saves a lot of water. Livestock consume huge resources. Author of *The Food Revolution*, John Robbins, estimates that "you'd save more water by not eating a pound of California beef than you would by not showering for an entire year."

Can we find new sources of water? Not really, but we could treat the undrinkable water that we have. But treatment takes energy and requires technology, so it costs money.

We can't drink salt water or use it for agriculture, but we could treat it to take out the salt using reverse osmosis techniques. This is a particularly expensive process, because it requires a lot of pressure (which means a lot of energy).

Ground water and waste water this is contaminated can also be cleaned. For example, bacteria can be killed by exposing the bacteria-laden water to UV light and chlorine. We can also clean water by filtering it.

Slide 28: Use Filters to Clean Water

Water can be cleaned by pouring it through pebbles, sand, and charcoal. Membranes can also be used to filter out small particles. A membrane is a structure that lets some things through and others not. You may want to check that your students know what a membrane is.

An efficient method of cleaning water is to use a series of increasingly smaller filters that filter out increasingly smaller particles. This picture highlights the membranes that clean water and the particles that each type of membrane removes. In general, the smaller the membrane, the more pressure is needed to push the water through the membrane, and the more expensive is the process. Usually larger membranes are used as prefilters to filter out the larger particles that would easily clog or "foul" the smaller membranes.

Slide 29: Can Nanotechnology Help?

Nanotechnology is a new area of engineering in which many laboratories are working to create innovatively designed membranes that have a hope of filtering water more cheaply and more flexibly that those currently on the market.

Slide 30: Questions

The questions on this slide guide this unit. Though the unit is built around solving the polluted water problem for the town of Jarny, students should also learn something about water purification processes and the basic science of water. This understanding will help them to reflect knowledgably on the global health problem of a lack of clean drinking water.

Resources

The World Water Forum is a group that has met for the fourth time to consider issues related to global water scarcity and fresh water sustainability. The fourth one was attended by governmental delegations from 148 countries, 200 legislators, 160 representatives of local authorities, 185 children, and a plethora of non-governmental organizations, UN agencies, experts, academia, water managers, and media representatives who met in Mexico City from March 16 through March 22 to share their local experiences, in order to make a difference in a world in which billions of people still lack access to safe water and sanitation. This group has published a report that highlights the conclusions and agreements made during this conference. The final report can be found at http://www.worldwaterforum4.org.mx/files/report/FinalReport.pdf.

Water Crisis: Student Data Worksheet
Teacher Instructions & Answer Key

This activity allows student to become actively involved in interpreting the different figures and graphs that are used in the Water Crisis PowerPoint presentation. Providing them with an opportunity to think about what each representation means before presenting the slides will allow for greater engagement on the part of your students and develop their graph interpretation skills. You may want to assign this worksheet as a homework assignment before you show the slides, or have students fill out the worksheet as you come to each of the slides, but before discussing them.

Note: Figure 2 is more easily distinguished in color, so you may want to pass out color copies of the student worksheet to your students. Otherwise, students may need to see the slide presentation to answer the questions associated with Figure 2.

Directions

Using the graphs and maps, answer the following questions. This activity will give you the opportunity to interpret some of the graphs and maps that you'll see during the Water Crisis slide presentation during class.

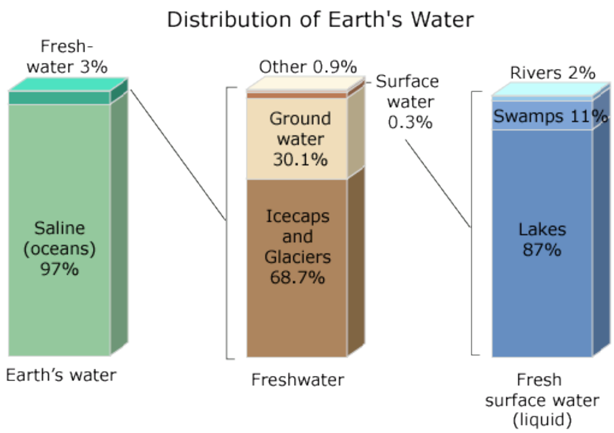

Figure 1. Distribution of earth's water.

1. According to the bar graphs in Figure 1, **what percentage** of the world's water is **fresh water**?

   3%

2. What do these three divided bar graphs tell you about **where** the Earth's fresh water resides?

   The earth's fresh water resides in icecaps and glaciers, ground water, lakes and swamps and rivers.

Physical water scarcity refers to the lack of water to meet domestic, industrial, and agricultural needs. Areas of physical water scarcity are shown in red on the map in Figure 2 below. Economic water scarcity means that an area or country has insufficient financial resources to deliver safe, clean water to those areas that need it for drinking or agriculture. Areas of economic water scarcity are shown in orange in Figure 2.

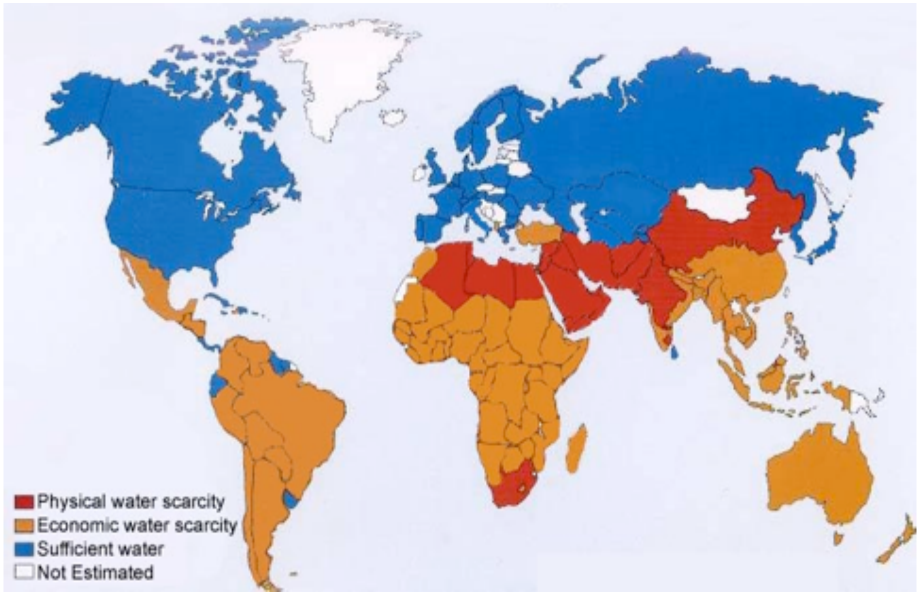

Figure 2. Global map of water scarcity in 2006.

Answer questions 3-8 based on information from the map in Figure 2.

2. Name the countries or global areas that are experiencing **physical water scarcity**.

In Northern Africa: Algeria, Libya, and Egypt. In the Middle East: Saudi Arabia, Iraq, Turkey, Iran, Pakistan, Afghanistan, much of India, Northern China and some smaller countries.

3. What would you predict the climate to be in these areas and why?

These areas would most likely have hot and dry climates, because the map indicates they have a physical water scarcity.

4. Name the countries or global areas that are experiencing **economic water scarcity**.

Central and most of South American, central and much of southern Africa, China, Viet Nam, Laos, Cambodia, the Philippines and the rest of the East Indies, and Australia.

5. Name the countries or global areas that are **not** experiencing any water scarcity.

North American countries and Northern Eurasia.

6. What do you predict the difference in per capita income (average income per person) would be between regions with plenty of water and regions with economic water scarcity?

Because water is needed for personal, industrial and agricultural use, it makes sense that those countries with greatest access to water are among the wealthiest nations as well.

7. The southwestern United States is typically characterized as having a dry, arid climate. Why might this region be shown as having plenty of water even if it is dry and arid?

Students may guess, correctly, that we divert water from northern rivers to the southern drier lands. They may also guess that there are rich sources of underground aquifers that supply water.

When water is taken from a natural source for human use, it is called "water withdrawal." However, a country can never withdraw all of the fresh water that is theoretically available within its borders. Much of it is seasonal, or part of flood runoff, or rain that cannot possibly all be captured. Countries that withdraw a high percentage of their available fresh water are said to be under "freshwater stress" and are in danger of becoming considered "water scarce." In the map in Figure 3, the light orange represents mild freshwater stress and the darker orange represents extreme fresh water stress. Blue areas are considered to be free from freshwater stress.

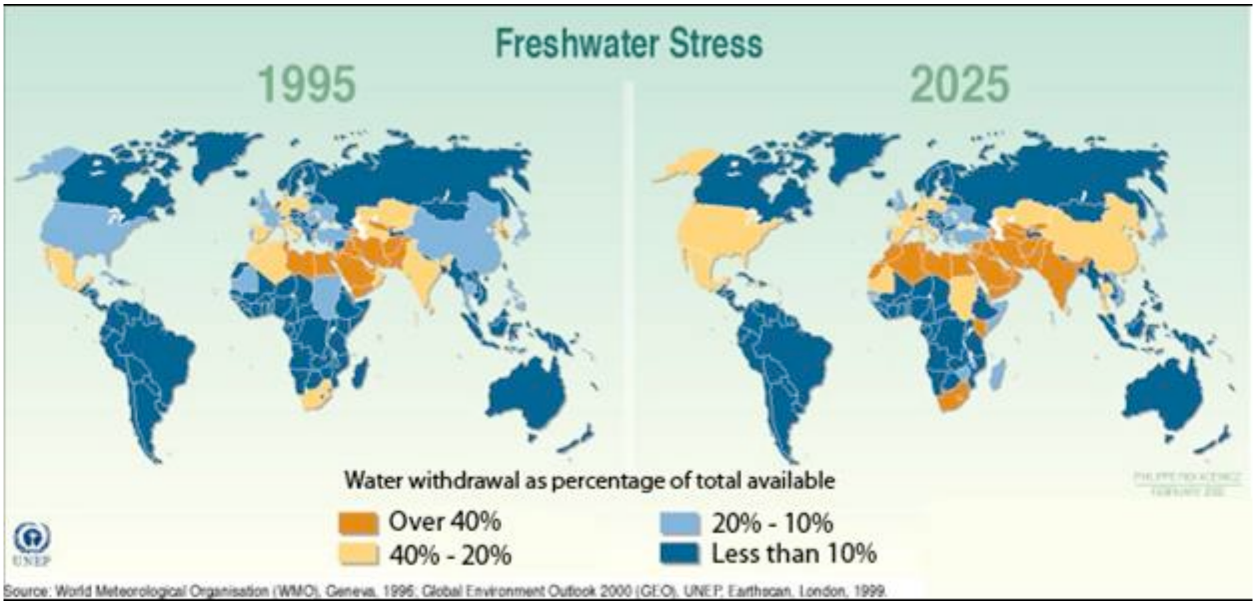

Figure 3. Global map of freshwater stress, 1995 and 2025 (predicted).

8. Compare the two maps above, showing freshwater stress from the year 1995 and projected to the year 2025. What are the changes that you see happening in which areas?

America and Alaska go from a water withdrawal of 10-20% to 20-40%, as does Mauritania and the Sudan in Central Africa. China also increases its' water use. Experiencing over 40% of water withdrawal now is Uganda, South Africa, and India.

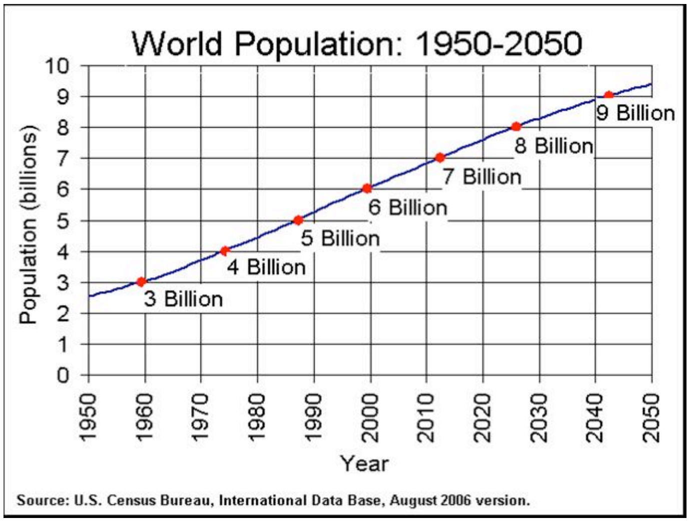

Figure 4. World population from 1950 to 2050 (predicted).

9. In Figure 4, what trend do you see in for the global population?

The population increases by three times from 1950 - 2050.

10. What would you predict the global population to be in 2060? Justify your prediction.

The population would likely increase to 10 billion people, based on the trend depicted for the previous two decades.

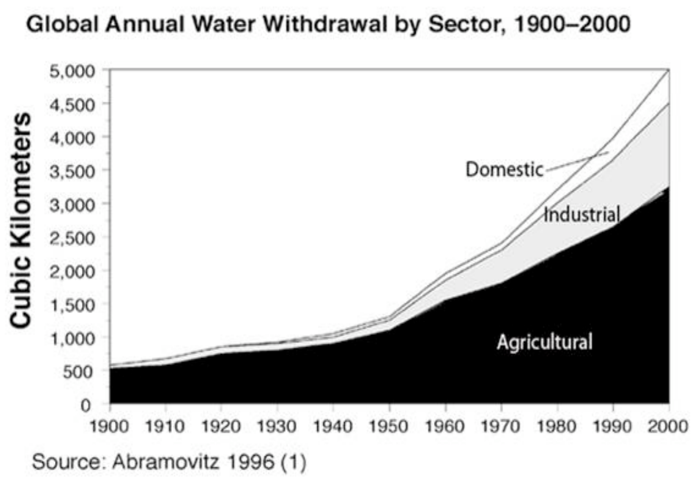

Figure 5. Global annual water withdrawal by sector, 1900-2000.

11. According to the graph in Figure 5, which sector uses the most water?

Agriculture

12. Which sector uses the least amount of water?

Domestic

13. How does the trend in water consumption (Figure 5) compare to the trend in population (Figure 4) for the time period 1950-2000?

The trends parallel each other.

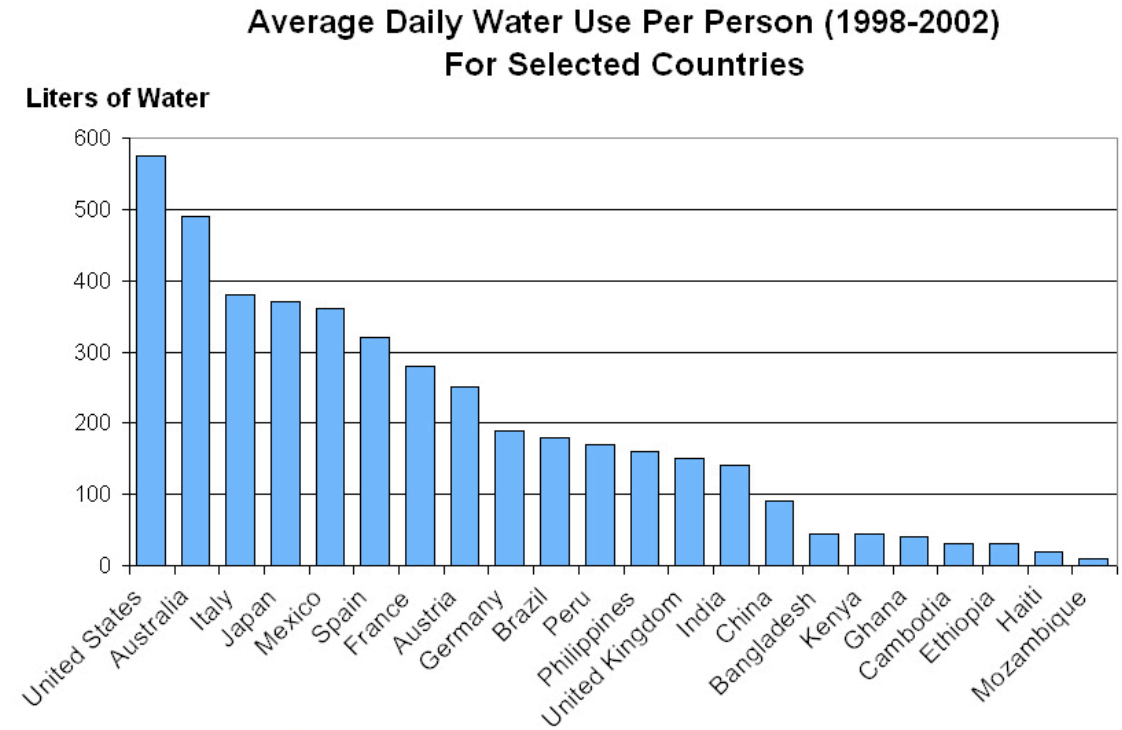

Figure 6. Average daily water use per person for selected countries, from 1998 to 2002.

14. According to Figure 6, which countries consume the most water?

United States, Australia, Italy, Japan, Mexico, Spain, France and Austria.

15. Which countries consume the least water?

China, Bangladesh, Kenya, Ghana, Cambodia, Ethiopia, Haiti, and Mozambique.

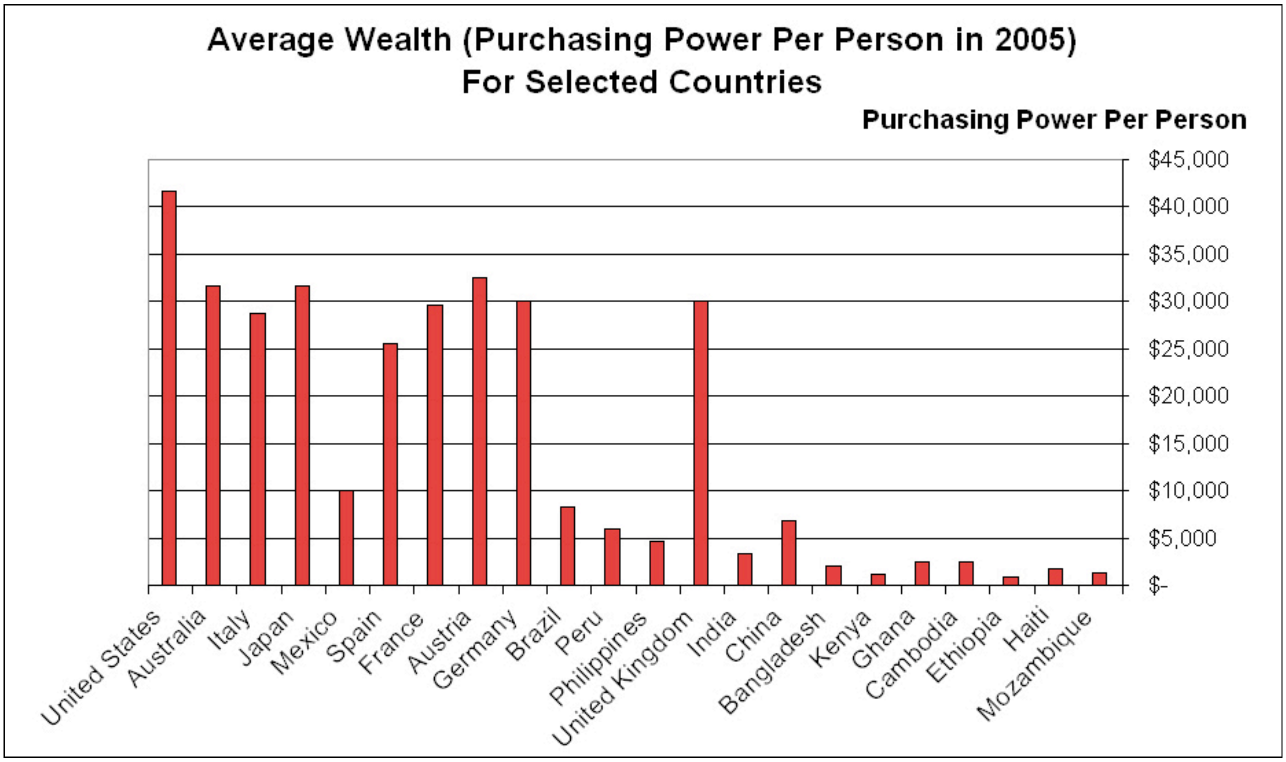

Figure 7. Average wealth for selected countries (purchasing power by person in 2005).

Answer questions 16-19 based on information from the graph in Figure 7.

16. How many countries have an average per person purchasing power of less than $10,000?

13

17. How many countries have an average per person purchasing power of more than $25,000?

9

18. How many countries have an average per person purchasing power of $10,000-$25,000?

Zero

19. What is the difference between the average per person purchasing power in the highest wealth country and the lowest wealth country?

About $41,000/year

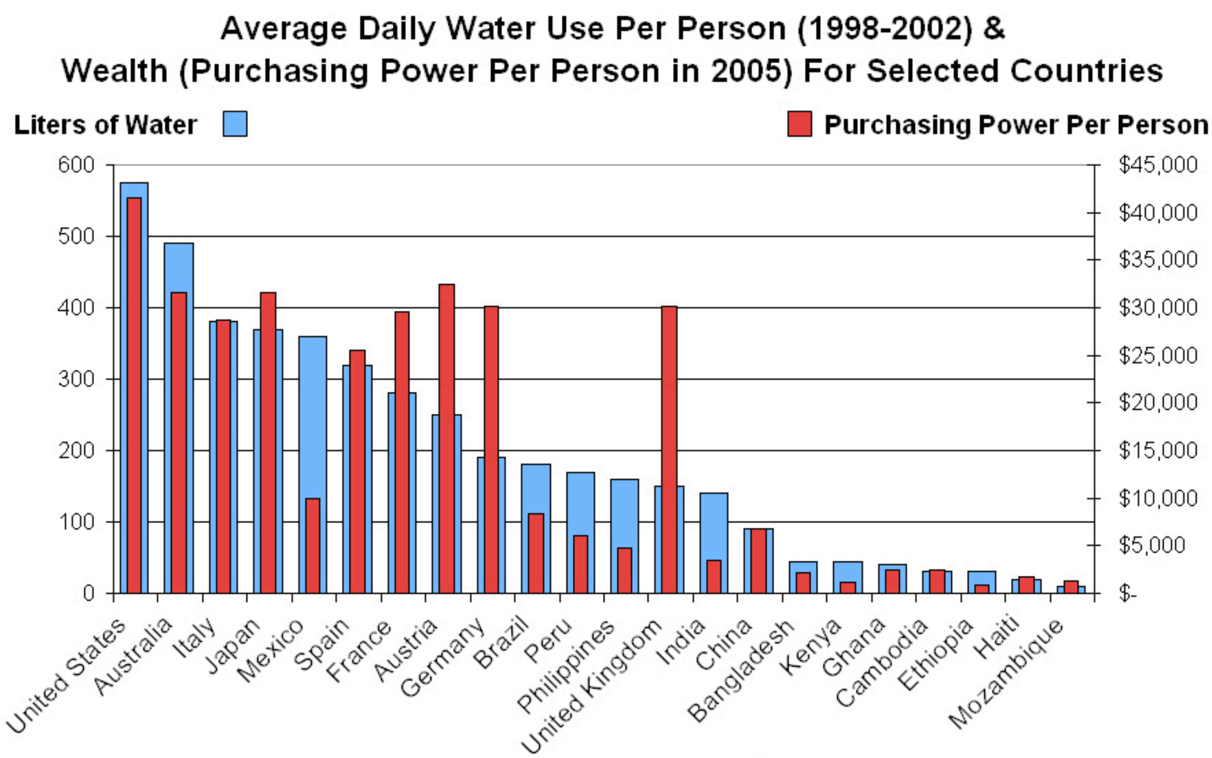

Figure 8. Average daily water use per person and wealth.

20. According to Figure 8, does there seem to be a relationship between a country's wealth and their average daily water consumption? If so, what is the relationship?

In most cases, with a few exceptions, the amount of wealth determines the amount of water consumption. In other words, the greater the wealth of a nation, the more water it consumes, and conversely, the less wealth a nation has, the less water it consumes.

Fine Filters Initial Ideas: Teacher Instructions

The goal of this exercise is to have your students "expose" their current ideas about the current and future availability of water on a global basis before they engage in learning activities that will explore these questions. You should let your students know that this is not a test of what they know and encourage them to make guesses which they will be able to evaluate based on what they learn in the unit. You may also want to have your students share their ideas with the class (there are no "bad" ideas at this stage) and create a giant class worksheet of ideas. Students can then discuss whether or not they think each of these statements is true and why.

Write down your initial ideas about each question below and then evaluate how confident you feel that each idea is true. At the end of the unit, we'll revisit this sheet and you'll get a chance to see if and how your ideas have changed.

	How sure are you that this is true?			
1. Why are water's unique properties so important for life as we know it?	Not Sure	Kind-of Sure	Very Sure	**End of Unit Evaluation**
2. How do we make water safe to drink?	**How sure are you that this is true?** Not Sure	Kind-of Sure	Very Sure	**End of Unit Evaluation**
3. How can nanotechnology help provide unique solutions to the water shortage?	**How sure are you that this is true?** Not Sure	Kind-of Sure	Very Sure	**End of Unit Evaluation**
4. Can we solve our global water shortage problems? Why or why not?	**How sure are you that this is true?** Not Sure	Kind-of Sure	Very Sure	**End of Unit Evaluation**

The Water Crisis: Quiz Answer Key

Write down your ideas about each question below.

1. What does it mean to have "clean fresh drinking water"?

   Drinking water that does not contain salt or other contaminants that would be harmful to human health.

2. Explain the term "water scarcity."

   Water scarcity means that there is not enough water to support water for drinking, industry, agriculture or environmental ecosystems.

3. Does water scarcity have an impact on human health? If so, what are some of the consequences?

   Yes. In places of water scarcity, 80% of all child death under the age of five is related to diseases associated with a lack of clean water. Contaminated drinking water can cause severe diarrhea, a variety of other gastrointestinal disorders, and cause the accumulation of life disabling or fatal toxins in body tissues.

4. Describe three reasons why some nations are experiencing a scarcity of clean drinking water.

   1. There is not enough physical water available to support a nation's needs for its population.
   2. There is not enough money to deliver the water to the places that need it for drinking or for agriculture.
   3. There is not enough money to clean the water to make it usable for drinking or for agriculture.

5. Why is the water scarcity problem projected to increase?

   Water scarcity is projected to increase as population increases and puts more demands on water to meet the basic needs of people.

   As underdeveloped countries become more industrialized, the trend is to consume more food that requires more water to produce.

6. Which sector—domestic, industrial, or agriculture—consumes the most water?

   Agriculture.

Lesson 1:
The Water Crisis

Student Materials

Contents

Name________________________________ Date_____________________ Period ______

Water Crisis: Student Data Worksheet

Directions

Using the graphs and maps, answer the following questions. This activity will give you the opportunity to interpret some of the graphs and maps that you'll see during the Water Crisis slide presentation during class.

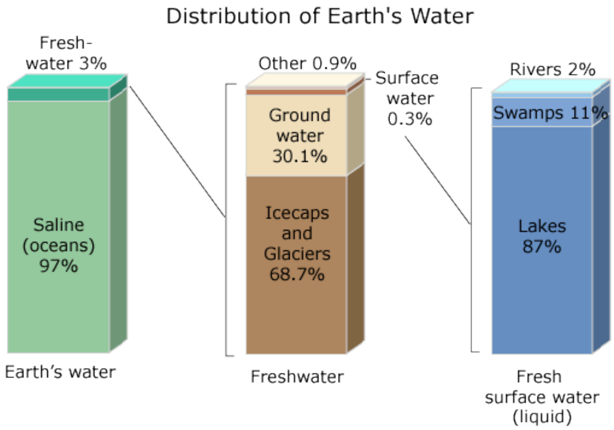

Figure 1. Distribution of earth's water.

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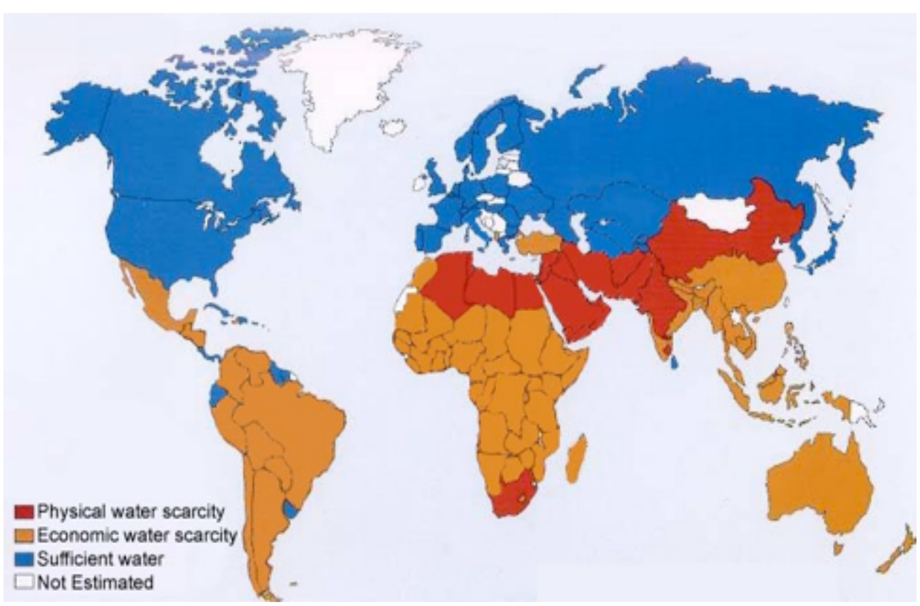


Figure 2. Global map of water scarcity in 2006.

Answer questions 3-8 based on information from the map in Figure 2.

2. Name the countries or global areas that are experiencing **physical water scarcity**.

3. What would you predict the climate to be in these areas and why?

4. Name the countries or global areas that are experiencing **economic water scarcity**.

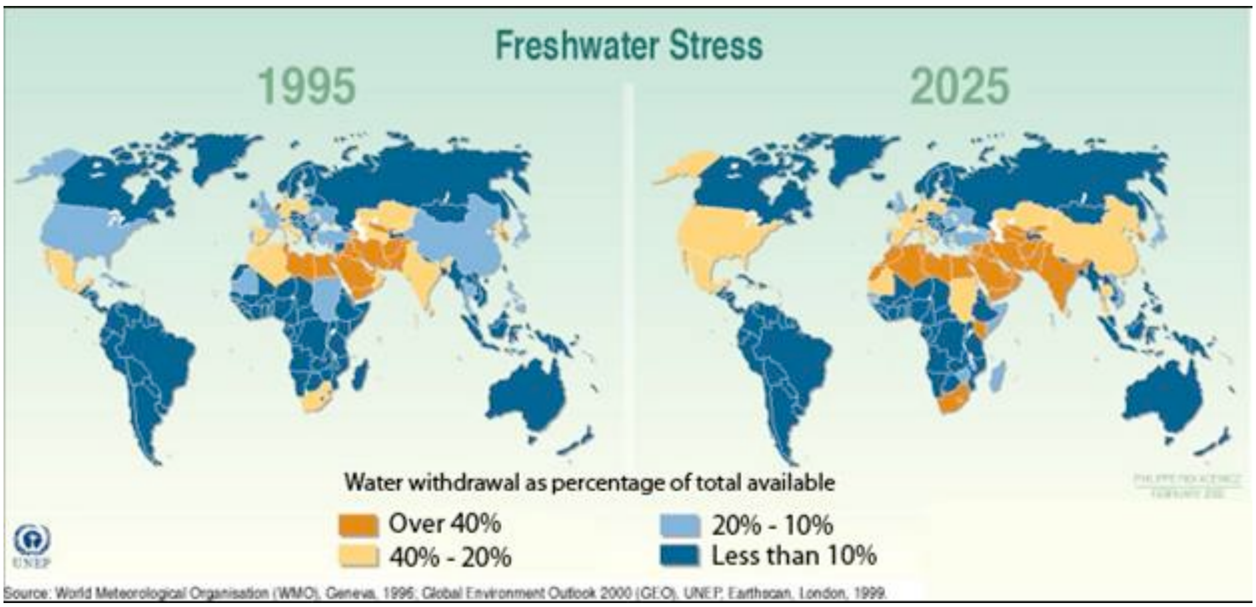
5. Name the countries or global areas that are **not** experiencing any water scarcity.

.

6. What do you predict the difference in per capita income (average income per person) would be between regions with plenty of water and regions with economic water scarcity?

7. The southwestern United States is typically characterized as having a dry, arid climate. Why might this region be shown as having plenty of water even if it is dry and arid?

When water is taken from a natural source for human use, it is called “water withdrawal.” However, a country can never withdraw all of the fresh water that is theoretically available within its borders. Much of it is seasonal, or part of flood runoff, or rain that cannot possibly all be captured. Countries that withdraw a high percentage of their available fresh water are said to be under “freshwater stress” and are in danger of becoming considered "water scarce." In the map in Figure 3, the light orange represents mild freshwater stress and the darker orange represents extreme fresh water stress. Blue areas are considered to be free from freshwater stress.



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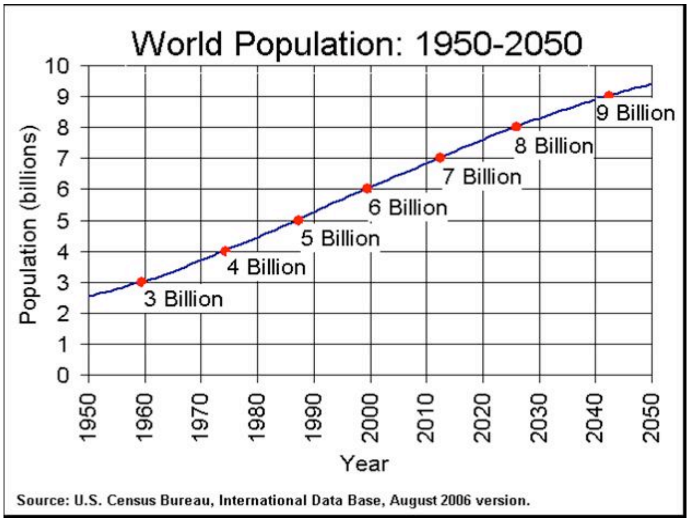

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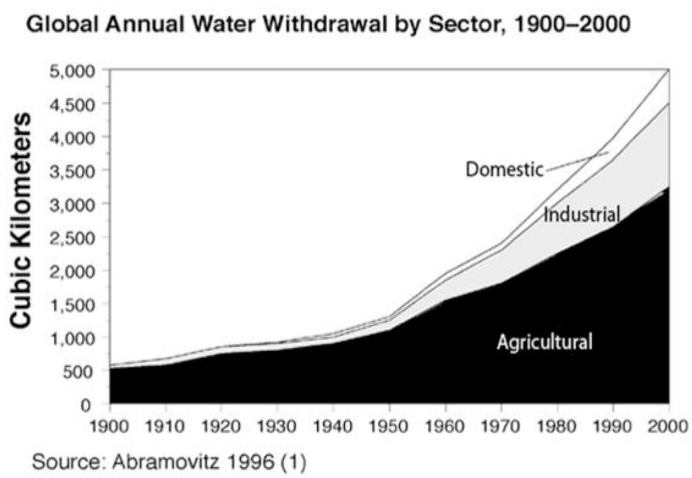

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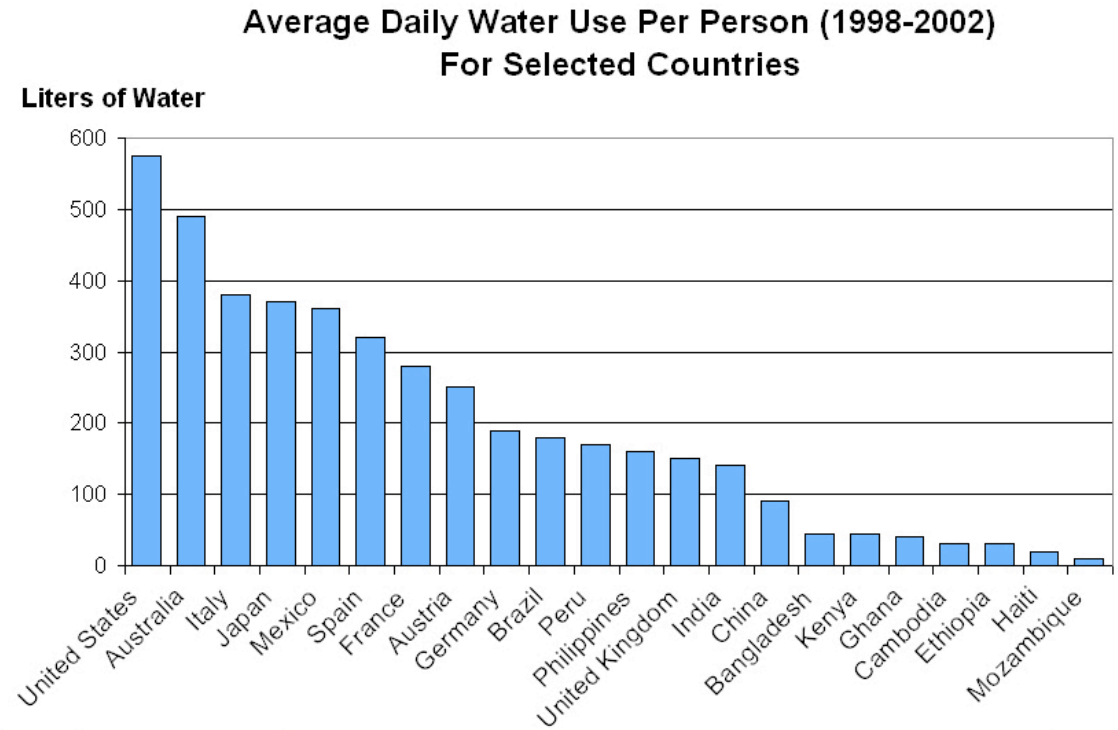
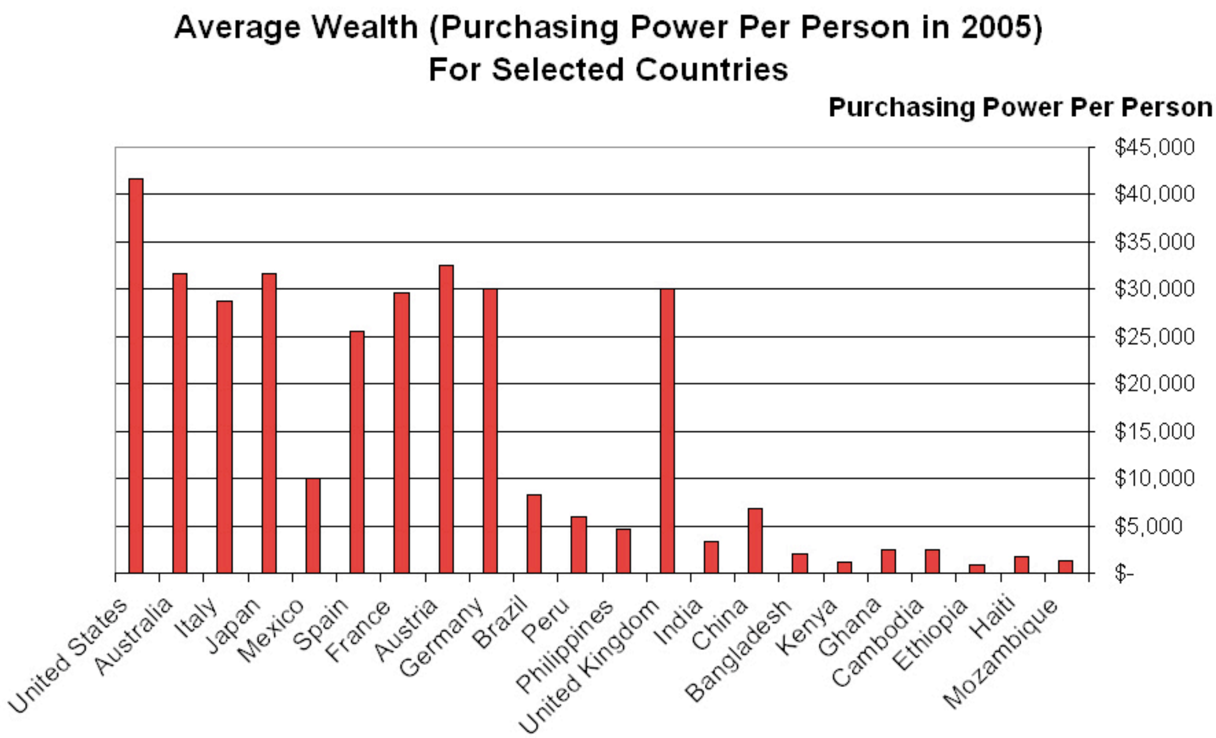


Figure 6. Average daily water use per person for selected countries, from 1998 to 2002.

14. According to Figure 6, which countries consume the most water?

15. Which countries consume the least water?



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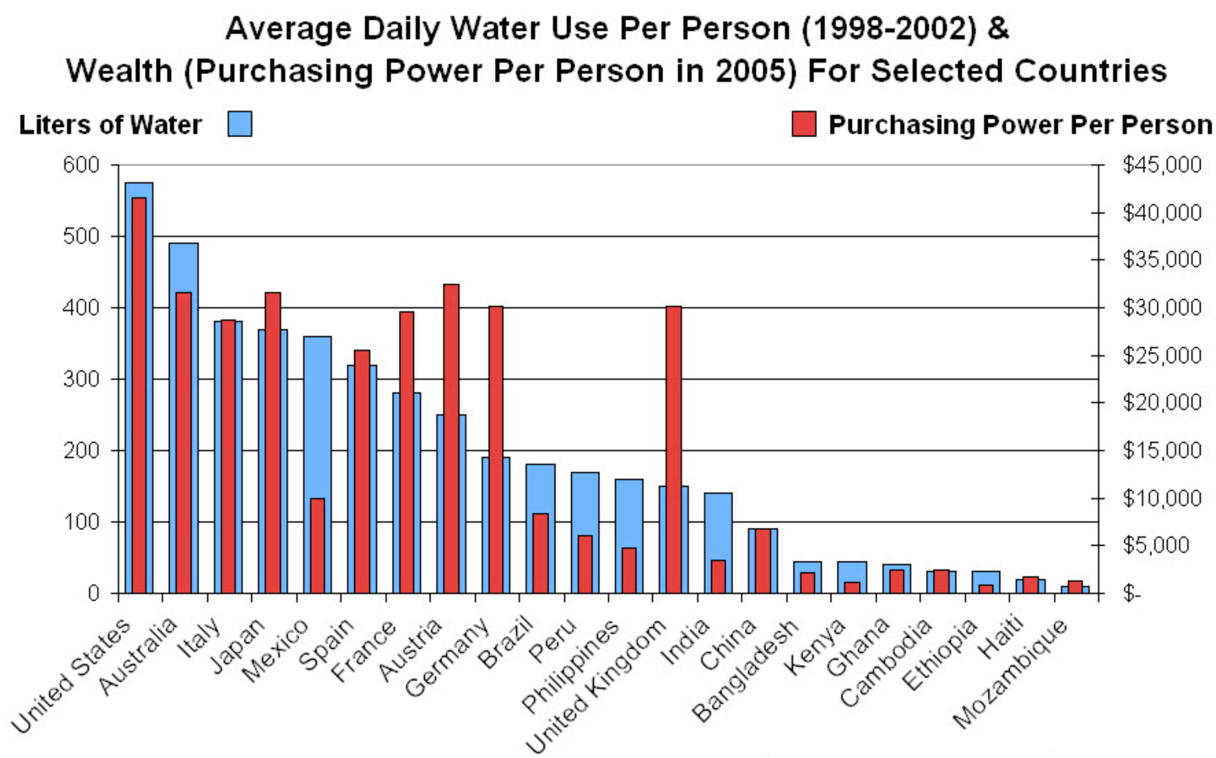

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Name______________________________ **Date**____________________ **Period** ______

Fine Filters Initial Ideas: Student Worksheet

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1. Why are water's unique properties so important for life as we know it?	**How sure are you that this is true?** Not Sure	Kind-of Sure	Very Sure	**End of Unit Evaluation**
2. How do we make water safe to drink?	**How sure are you that this is true?** Not Sure	Kind-of Sure	Very Sure	**End of Unit Evaluation**
3. How can nanotechnology help provide unique solutions to the water shortage?	**How sure are you that this is true?** Not Sure	Kind-of Sure	Very Sure	**End of Unit Evaluation**
4. Can we solve our global water shortage problems? Why or why not?	**How sure are you that this is true?** Not Sure	Kind-of Sure	Very Sure	**End of Unit Evaluation**

Name__________________________________ Date______________________ Period ______

The Water Crisis: Student Quiz

Write down your ideas about each question below.

1. What does it mean to have "clean fresh drinking water"?

2. Explain the term "water scarcity."

3. Does water scarcity have an impact on human health? If so, what are some of the consequences?

4. Describe three reasons why some nations are experiencing a scarcity of clean drinking water.

5. Why is the water scarcity problem projected to increase?

6. Which sector—domestic, industrial, or agriculture—consumes the most water?

Lesson 2: The Science of Water

Teacher Materials

Contents

The Science of Water: Teacher Lesson Plan

Orientation

Water is one of the most unique and ubiquitous substances on our earth. Water's structure and properties account for many of the phenomena in our bodies and on our earth. This lesson reviews some of the science basics of water. If your students have not yet had a chemistry class, they may find some of this information overwhelming. These lessons are not intended to take the place of chemistry, where more intensive study is devoted to the variety of topics reviewed here.

- The Science of Water PowerPoint slide set introduces the structure of water that accounts for water's unique properties based on the quantum mechanical model of the atom, the shape of the water molecule and the distribution of charge.
- The Science of Water Lab Activities are set-up as lab stations. Their overall purpose is to give the students hands-on opportunities to experience some of the properties of water. Students may move through the stations throughout one or two periods, depending upon your schedule. You may also choose to eliminate one more of the stations to save time. Two of the stations are paper-pencil activities, and have no special requirements for lab equipment.
- The Reflecting on the Guiding Questions Worksheet asks students to connect their learning from the activities in the lesson to the driving questions of the unit.
- The Science of Water Student Quiz can be used as a formative or summative assessment of student learning through homework, an in-class group activity, or as an in-class individual assessment, depending on your goals.

Essential Questions (EQ)

What essential questions will guide this unit and focus teaching and learning?

(Numbers correspond to learning goals overview document)

1. Why are water's unique properties so important for life as we know it?

Enduring Understandings (EU)

Students will understand:

(Numbers correspond to learning goals overview document)

2. As a result of water's bent shape and polarity, water has unique properties, such as an ability to dissolve most substances. These properties are responsible for many important characteristics of nature.

Key Knowledge and Skills (KKS)

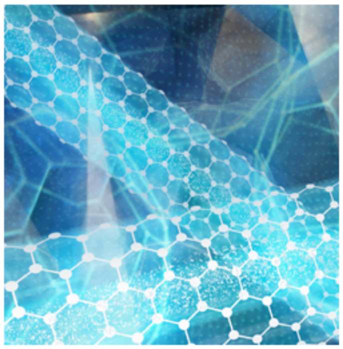
Students will be able to:

(Numbers correspond to learning goals overview document)

4. Describe the basic structure and charge distribution of water.
5. Explain how hydrogen bonding accounts for many of water's unique properties.

The Science Of Water Timeline

Day	Activity	Time	Materials
Day 1 (50 min)	Show the Science of Water PowerPoint Slides, using the question slides and teacher's notes to start class discussion.	50 min	The Science of Water PowerPoint Slides & Teacher Notes Computer and projector
Day 2 (50 min)	Students work in pairs or small groups at the Science of Water Lab Activities. Tell students to follow the posted directions to complete the lab at each station, moving to the next station when the current one is completed. Each student should complete their own Student Worksheet, although they may consult with other group members or the teacher.	50 min	The Science of Water Lab Activities: Student Directions posted at each Lab Station. Photocopies of the Science of Water: Student Worksheet
	Homework: Have students fill out the Reflecting on the Guiding Questions: Student Worksheet	*10 min*	Photocopies of Reflecting on the Guiding Questions: Student Worksheet
Day 3 (35 min)	Have students work in pairs or small groups to discuss their reflections on the Guiding Questions	10 min	Student's copies of their Reflecting on the Guiding Questions Worksheet
	Bring the class together to have students share their reflections with the class. This is also a good opportunity for you to address any misconceptions or incorrect assumptions from students that you have identified in the unit up till now.	10 min	
	Administer the Science of Water: Student Quiz during class, as an individual or group exercise, or as homework.	15 min	Photocopies of The Science of Water: Student Quiz



The Science of Water

We are surrounded by water; we are made of water

NanoSense
the basic sense behind nanoscience

Water in our World

- Water is necessary for life
- Water in our atmosphere helps to keep the planet warm
- Our bodies are composed of and dependent on water

Source: http://nssdc.gsfc.nasa.gov/photo_gallery/photogallery-earth.html

NanoSense 3

A Quick Overview

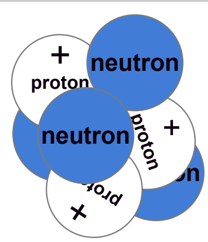
Of some of the science basics

What are some of the properties of water that make it so essential to life on our planet?

NanoSense 4

All Matter is Composed of Atoms

- **The atom is composed of**
  - A nucleus made of neutrons and protons
  - An electron "cloud" composed of electrons



Representation of a nucleus

- **Protons and neutrons have nearly identical masses, but their charge is different**
  - Protons have a positive (+) electrical charge and neutrons do not have an electrical charge

NanoSense 5

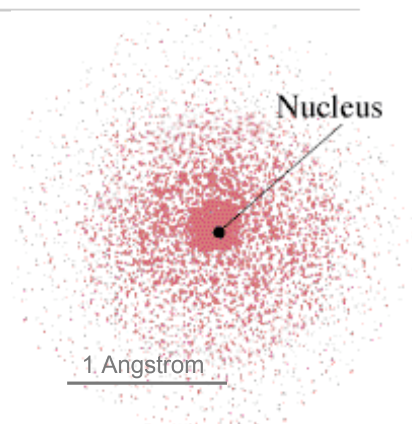
Subatomic Particles Composing the Atom

Subatomic Particle	Charge	Size	Location
Proton	+1	1	Part of the nucleus
Neutron	0	1	Part of the nucleus
Electron	-1	0	Electron "cloud" (outside of the nucleus)

NanoSense 6

The Quantum Atom

- **We can only describe areas of probability where we might find an electron**
  - Electrons are constantly moving
  - Electrons have a specific amount (quantum) of energy, related to their position from the nucleus



Red dots represent areas of probability

Source: http://physics.usc.edu/~bars/135/LectureNotes/QuantumMechanics.htm

Probability

- **Suppose you had a new dartboard. What would it look like after you had played darts with it for six months?**
  – Can you predict accurately where the next dart you throw will go?
  – Can you predict an area where the next dart is likely to go?

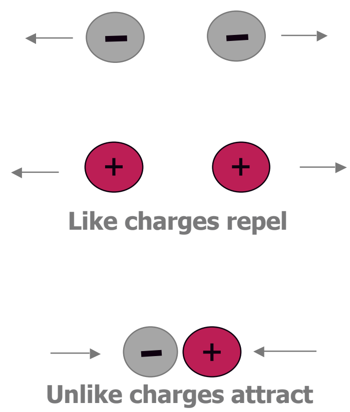
Source: www.amisane.org/images/dartboard2.jpg

Question

Why do we care about what atoms are made of?

Electric Charge

- **Electric charge is a basic force that causes movement**



Net Charge of an Atom or Ion

- **The charge on any substance is a result of the total number (#) of**
  - Protons (p) + charges, in the nucleus, and
  - Electrons (e-) - charges, outside the nucleus

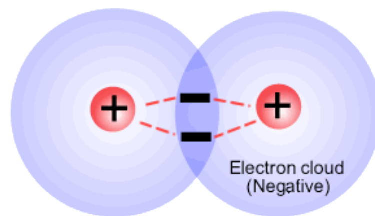
- **If the # of.... then the net charge is....**
  - p = e- neutral (atom)
  - p > e- positive (ion)
  - e- > p negative (ion)

NanoSense 11

Atoms Bond

- **The outer electrons of both atoms are mutually attracted to the nuclei**
  - Oppositely charged particles form a bond, representing a lower energy state for each of the atoms, ***releasing energy***

The electrons experience a force of attraction from both nuclei. This negative - positive - negative attraction holds the two particles together



This attraction is called a chemical bond
one pair of electrons constitutes ONE bond

Nature always wants to be in the lowest energy state!

Source: ibchem.com/IB/ibfiles/ bonding/bon_img/cov3.gif

NanoSense 12

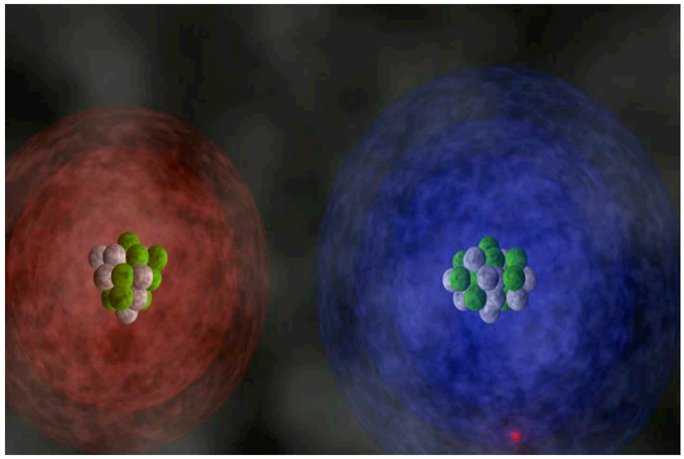
Why are Bonds Formed?

Bonds are formed because of the electrostatic attraction between atoms.

In doing so, the atoms achieve a lower energy state.

NanoSense 13

Ionic Bond: Chlorine (Blue) Grabs Electron from Sodium (Red)



Click the image above to view the animation in your web browser, or go to http://nanosense.org/download/finefilters/Nacl_SD.mov

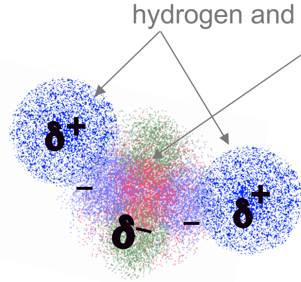
Source: http://visservices.sdsc.edu/projects/discovery/Nacl_SD.mov

NanoSense 14

Forming a Water Molecule

- **Unequal attraction to bonding electrons**
  - Oxygen is a strong electron grabber (high electronegativity)
  - Hydrogen's electron cloud tends to hang out close to oxygen, leaving H's positively charged nucleus all by itself

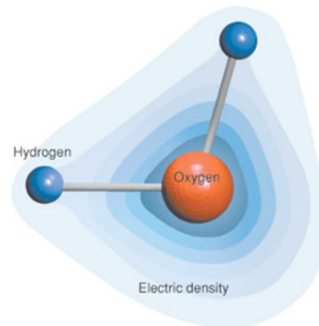
Orbital representations of hydrogen and oxygen



A water molecule

Electron Density is Uneven

- **The average electron density around the oxygen atom in a water molecule is about 10 times greater than the density around the hydrogen atoms**
  - This non-uniform distribution of positive and negative charges, called a dipole, leads to the substance's unusual behavior

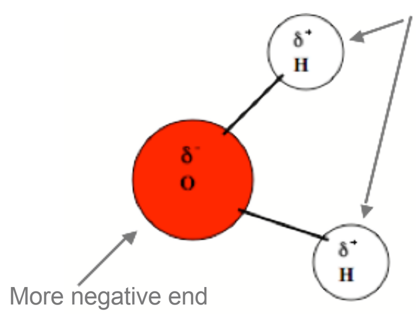


A water molecule, with electron density represented by the shaded blue areas

Source: http://www.llnl.gov/str/October05/Mundy.html

Water is a Polar Molecule

- **The unequal distribution of charges on the water molecule make it a *polar* molecule**
  - One end is more negative, and one end is more positive



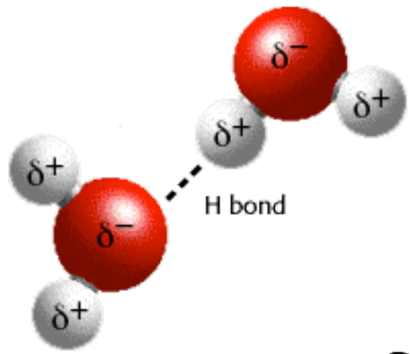
A water molecule

δ- means partial negative charge
δ+ means partial positive charge

Hydrogen Bonding I

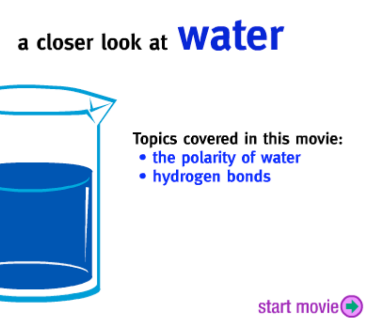
- **The partial negative end of the oxygen atom is attracted to the partial positive end of the H atom on an adjacent molecule**
- **Hydrogen bonds give water its unique properties**

Hydrogen bonding between water molecules



Source: http://www.biology.arizona.edu/biochemistry/tutorials/chemistry/page3.html

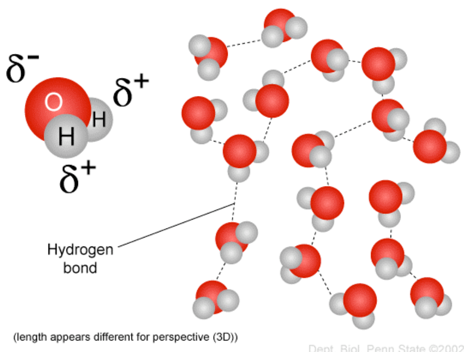
Hydrogen Bonding II



Click the image above to view the animation in your web browser, or go to http://www.northland.cc.mn.us/biology/Biology1111/animations/hydrogenbonds.html

Hydrogen Bonding Representation

- In water, hydrogen bonds form between the partially negatively charged oxygen atom and the partially positively charged hydrogen atom



Water molecules, with the hydrogen bonds represented by the dotted lines

Source: www.personal.psu.edu/.../ bonddiagram.gif

Unique Properties of Water

- Universal solvent
- Exists in nature as a solid, liquid, and gas
- The density of ice is less than liquid water
- High surface tension
- High heat capacity
- Exists as a liquid at room temperature

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High Surface Tension

- Allows water to form drops
- Allows water to form waves
- Water drops can "adhere" to surfaces even though gravity is pulling on them

Source: Photo 2004 Edward Tsang

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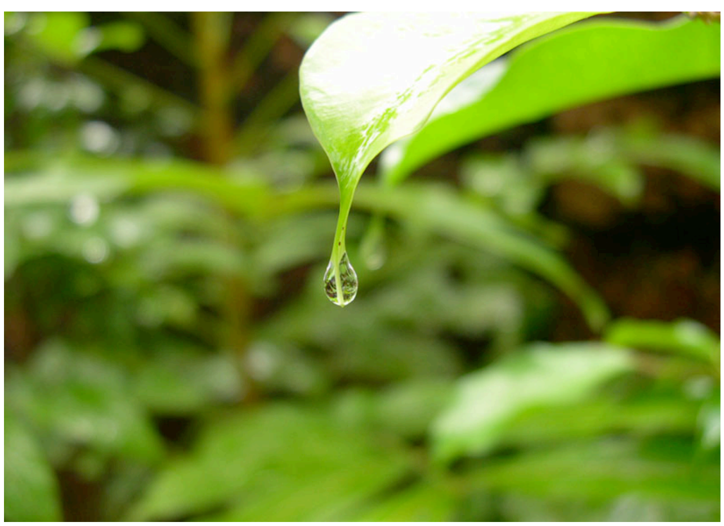
Can You Explain Why this Drop Sticks to the Leaf and Grows Larger?



Source: http://www.azeemazeez.com/photos/wallpaper/water800.jpg

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Or How this Spider Can Walk on Water?

Source: http://static.flickr.com/82/237875014_4d579d57c5.jpg

NanoSense 24

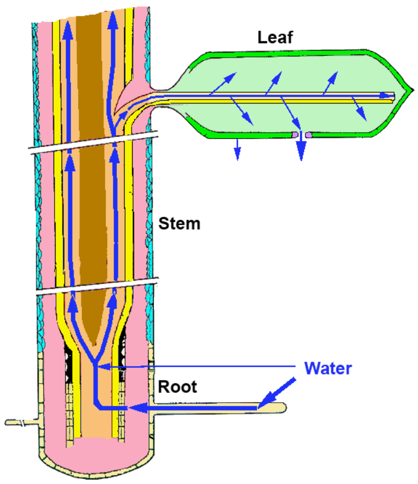
Adhesion

- **Adhesive forces are attractive forces that occur between two unlike substances**
- **In a narrow glass tube**
  - Water molecules are more strongly attracted to the tube than they are to each other (cohesion)
  - The cup shape formed at the top of the water is called a **meniscus**

Source: http://www.wtamu.edu/~crobinson/SoilWater/meniscus2.jpg

Water Climbs Trees!

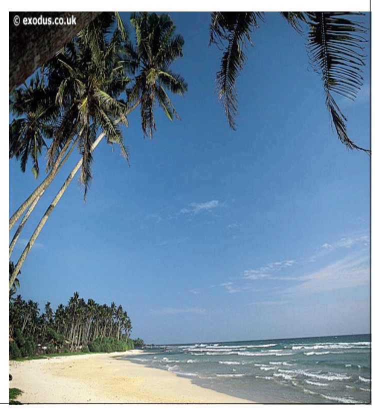
- **Evapotranspiration**
  - The tiny tubes in the root hairs suck up water from the soil
  - Inside the plant are more hollow tubes (xylem) for transporting water through the plant
  - Finally, water exits the plant through the tiny openings in its leaves (stomata)



Source: Adapted from http://www.ualr.edu/botany/transpiration2.gif

High Specific Heat Keeps Beaches Cooler in the Day and Warmer at Night!

- **Specific heat**
  - The amount of energy required to change 1 gram of a substance 1 °C
- **Water has high specific heat**
  - Absorbs large amounts of heat energy before it begins to get hot
  - Releases heat energy slowly
  - Moderates the Earth's climate and helps living organisms regulate their body temperature



Source: http://www.exodus.co.uk/pictures/d03hp120c.jpg

Solid, Liquid, and Gas

- Water is the only substance which exists under normal conditions on earth as a solid, a liquid, and a gas

Source: http://www.eskimo.com/~captain/slidesho/Lake_Twenty_Two_Partly_Frozen_Over_and_Snow_Covered.jpg

Ice is Less Dense than Water I

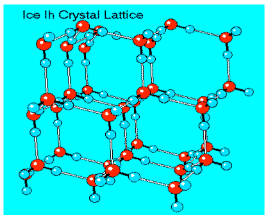
Density of H_2O at different temperatures

Temperature ºC	Density g/cm^3
0 (solid)	0.9150
0 (liquid)	0.9999
4	1.0000
20	0.9982
100 (gas)	0.0006

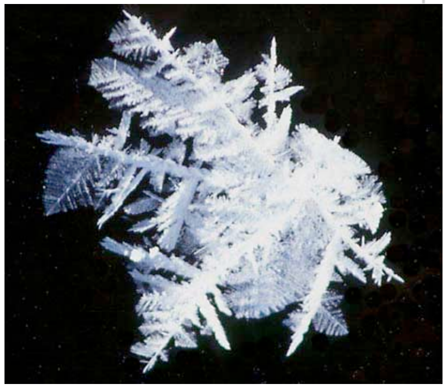
Source: http://www.wildthingsphotography.com

Ice is Less Dense than Water II

- **This is a very rare property!**



Crystal lattice structure of ice



Ice crystal

Sources: http://www.learner.org/jnorth/images/graphics/t/ice_crystal_Greg_Rob.jpg
http://www.solarnavigator.net/images/ice_crystal_lattice.gif

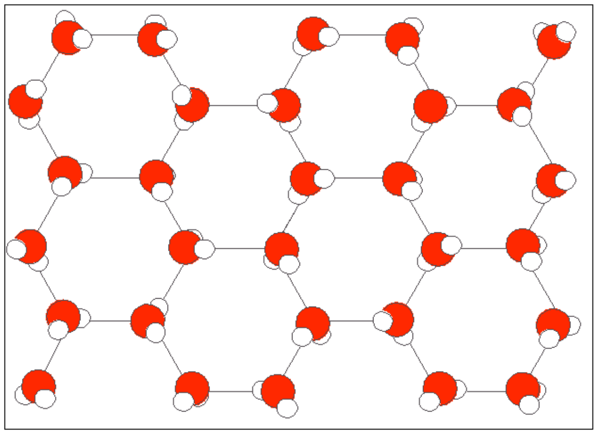
Questions

Can you imagine if ice did not float?

How do you think that would affect the world?

Ice Melting

- **Notice that ice has an open lattice structure that collapses when it melts**



Click the image above to view the animation in your web browser, or go to http://nanosense.org/download/finefilters/MeltingIce.mov

Water is a Universal Solvent

- **Water is a polar molecule with one end more positive and one end more negative**
  - Being polar allows water to dissolve nearly any substance with an unequal distribution of charges
  - Water is the best substance that is universally used for transporting dissolved substances

Water dissolves more substances than any other liquid

Source: http://www.chemistryland.com/CHM107Lab/Lab7/Slime/PourStirPoly2.jpg

Important Points

- What are water's unique properties?
- What is water's structure, and how does it cause these properties?
- What would our world or life be like without water?

The Science of Water: Teacher Notes

Overview

This presentation gives students a sense of the structure of water in terms of its shape and charges. The traditions of science have been represented here to give students a picture of how modern science talks about the structure of atoms and charge distribution. Several representations of water are included in this slide set. The big "take away" for students is that hydrogen bonding creates stronger than normal (for substances of a similar molecular mass) bonds between water molecules. Those relatively strong bonds are the reason we see water's unusual properties: high surface tension, high boiling temperature, adhesion, cohesion, low vapor pressure, high specific heat, "universal solvent," the density of the solid form being less than that of the liquid form, and being a liquid at room temperature.

Students may have difficulty with some of the ideas represented in these slides, depending on their background. If students have a weak background in chemistry, it is suggested that the emphasis in these slides be on the shape and charge distribution of the water molecule as it relates to the above-mentioned properties of water.

Slide 1: The Science of Water

Ask students to think about where water is in this world, and what forms water comes in (solid, liquid, gas). Tell students that the focus of this lesson is on the special structure and characteristics of water that make it such a unique substance, a substance that we all depend upon for living.

Slide 2: Water in our World

Our planet is habitably warm because the sun's rays (electromagnetic radiation), filtered through the atmosphere, collide into the earth. When they reach the surface of the earth, the earth absorbs some of the rays, heating the earth. Some of the sun's rays are radiated back into the atmosphere as longer energy waves, infrared rays or heat. The gases in our atmosphere "trap" these energy waves, preventing them from escaping our atmosphere. The earth would be impossibly cold to live upon without this phenomenon, known as the "greenhouse" effect. Water is one of the greenhouse gases. There is much current concern over the amount of greenhouse gases entering the atmosphere and heating our planet to a growing degree. The emphasis of this attention has been mostly on the gases emitted from the combustion of fossil fuels, in other words, man's contribution to greenhouse gases as a result of using gasoline to fuel vehicles.

The human body is composed of water, among other substances. The total amount of water ranges from 50-80%, depending on age, amount of fat present, and other factors. The usual figure used for the amount of water in the normal adult body is 70%. Water is a major component of our blood, our lymph, our serous membranes, and other structures.

Slide 3: A Quick Overview

This set of slides presents a quick overview of the science of water. Each of the topics touched upon, such as models of the atom, bonding, charge distribution, physical properties, and chemical properties are big topics themselves. This set of slides is intended to present an overview only.

Discussion Question for Students: What are some of the properties of water that make it so essential to life on our planet?

You may want your students to brainstorm what they already know about water's unique properties. This is a good way to reveal students' prior knowledge and to uncover any misconceptions about the properties of water.

Slide 4: All Matter is Composed of Atoms

Most students have heard about the particles that compose the atom, as well as the basic structure. They probably will know that the nucleus, while being very, very small compared with the overall volume of an atom, comprises the mass of an atom. The neutron and proton are nearly identical masses compared with the negligible mass of an electron.

The purpose of this slide is to build knowledge about water's unique structure, starting from the basics, with an emphasis on the charge characteristics of a water molecule. The structure to emphasize in this slide is the positively charged nucleus (of a "generic" atom). This will determine the overall charge distribution as well as the net charge on atoms joined together to form molecules.

Slide 5: Subatomic Particles Composing the Atom

This chart represents a simplified version of the relative size, location, and charges of the proton, neutron, and electron.

For reference, a proton has a mass of 1.672×10^{-27} kg and a charge of +1, a neutron has a mass of 1.675×10^{-27} kg and no charge. An electron has a charge of -1 (the same magnitude as a proton's charge, but opposite in direction). The electron is described as having characteristics of a particle and a wave, depending upon the situation. (The photoelectric effect demonstrated by Einstein illustrates the particle behavior of an electron and Young's double slit experiment demonstrated an electron's wave behavior.)

All things point to the electron having no measurable size at this time, although our ability to measure incredibly small objects is limited.

Slide 6: The Quantum Atom

Again, the electron cloud representation as determined by quantum mechanics is shown here. The big points are:

1. The dots that represent the orbital cloud indicate a probability distribution of where an electron might be found. The more dense areas of the cloud represent areas of higher probability. The less dense, as depicted by the decreasing density of dots as one moves farther away from the nucleus, the less probability there is of finding an electron.

2. Electrons are constantly moving really, really fast. That means that the electric charge they carry is moving really, really fast as well. This overall or "net" electric charge distribution is what determines all bonding.
3. Electrons have a "quanta" of energy. Bohr learned that electrons could gain or lose only a specific quantum of energy. To illustrate this, think about a glass that you can fill with water, and stop filling at any position. Electrons are not like that. You may only "fill" by specific increments. These increments are individual to each electron in each atom. They can be measured when an electron "loses" energy by releasing a photon of light. This photon of light can be measured in terms of its wavelength, making it possible to determine its energy.

Slide 7: Probability

This slide is to help students to visualize the idea of a probability distribution in a more concrete way.

Slide 8: Question Slide

Questions for Students: What do students think? Why do we care about what atoms are made of?

This is another time that, within a class discussion, you may be afforded the opportunity to see what students understand and the discussion may allow any misconceptions to surface. Misconceptions are important to address, as they are very powerfully embedded in students' understanding of the world. They are resistant to being replaced with more accurate scientific information.

Slide 9: Electric Charge

Traditional curriculum underemphasizes the role of electric charge in chemistry. Often forces are addressed in physical science curriculum during middle school classes or in physics as an advanced course in high school. It is important for students to realize that these "swarms" of electrons represent an attractive (to positive charges) and repulsive (to negative charges) moving force. This is a very dynamic concept.

Slide 10: Net Charge of an Atom or Ion

This slide is to remind students that the net charge of an atom comes from the total amount of protons (positive charge) in the nucleus and the total amount of electrons (negative charge) in that atom. In addition to that, there may be an equal distribution of electric charge around some atoms, resulting in a polar molecule (a molecule that has a separation of charges).

Slide 11: Atoms Bond

This slide focuses on how opposite charges will form a bond and that a bond between two atoms represents a *lower energy state* for both of the atoms bonded together than if they were not bonded. Students may or may not know this. One of the laws of nature is that matter will always move to the lowest energy state possible. The lowest energy state is the most stable position for matter to obtain.

Slide 12: Why are Bonds Formed?

This slide highlights again that bonds are formed because of the attraction of oppositely charged particles. What causes atoms or particles to have opposite charges is not covered by this unit. That is another extensive subject that is beyond the scope of this slide set. This subject is a typical component in college preparatory chemistry.

Slide 13: Ionic Bond: Chlorine (Blue) Grabs Electron from Sodium (Red)

This is an animation that depicts a bond forming between sodium and chlorine. It is just to give students a sense of the swirling, moving electrons as the two atoms are held in close proximity. The video clip should play automatically when in the "view presentation" mode. If it does not play, click on the image to view the animation in your web browser.

Slide 14: Forming a Water Molecule

This is a depiction of the orbital representation of two hydrogen atoms and an oxygen atom, bonded, and their distribution of charges when they come together to form a water molecule.

The slide mentions "electronegativity." Electronegativity is a man-made composite value of the relative amount of each of the elements to attract an electron to itself. To obtain this value, several measures of each of the atoms are considered: first and second ionization energies, disassociation energy, and electron affinities. Linus Pauling was the first among many others to create this value. It has trends in the periodic table. Four is the highest electronegative number, assigned to fluorine, while one is the lowest.

To determine the type of bond that two atoms make, one must subtract the electronegative value of each atom. Though this is a continuum scale, if this difference is approximately 0.5, the bond is considered a non-polar covalent. If the difference is between 0.5 and 1.6 (this varies), then the bond between the two atoms is a polar covalent one. If the difference in the electronegativity values of the two atoms is greater than 1.6 (or so) then the bond is an ionic bond.

Slide 15: Electron Density is Uneven

This slide depicts the density of the distribution of negative charges on the water molecule. This representation is somewhat controversial on the part of teachers. Some students expressed liking this representation, however, because it helped them to visualize an uneven distribution of electrons. The shaded area represents the strongest distribution of negative charges and the lighter areas represent the lower distribution of negative charges. The big point of this slide is to communicate the idea that on the water molecule there is a partial positive end and a partial negative end.

Slide 16: Water is a Polar Molecule

A more detailed picture of the water molecule further illustrates the previous slide.

If students have not seen the symbol δ^+ (partial positive charge) and δ^- (partial negative charge), this would be a good time to explain these commonly used symbols.

Slide 17: Hydrogen Bonding I

Hydrogen bonding occurs in small molecules with a highly electronegative nonmetal element (N, Cl, O, F) that bonds with hydrogen. The attraction of hydrogen's lone electrons toward the highly electronegative atom results in a separation of charge on the molecule. Water is the most famous case of this. Hydrogen bonding occurs ***between*** adjacent molecules. While it is weaker than ionic or covalent bonding, which occurs between atoms to form molecules or ionic compounds, it is a stronger bond than Van der Walls forces that occur between adjacent molecules.

Slide 18: Hydrogen Bonding II

This is a clever animation that illustrates hydrogen bonding. If you have a hard time enabling the link embedded into this PowerPoint slide, try:

http://www.northland.cc.mn.us/biology/Biology1111/animations/hydrogenbonds.html

Slide 19: Hydrogen Bonding Representation

The water molecule in the center shows the partial positive and negative charges. The illustration on the right depicts these charges among several individual water molecules that are bonded (represented by the dotted line) negative end to positive end.

Slide 20: Unique Properties of Water

Although there are more unique properties of water, the ones listed on this slide are generally thought to be the most important. This slide will serve as an introduction to these properties. Each of these properties is explained further in the following slides.

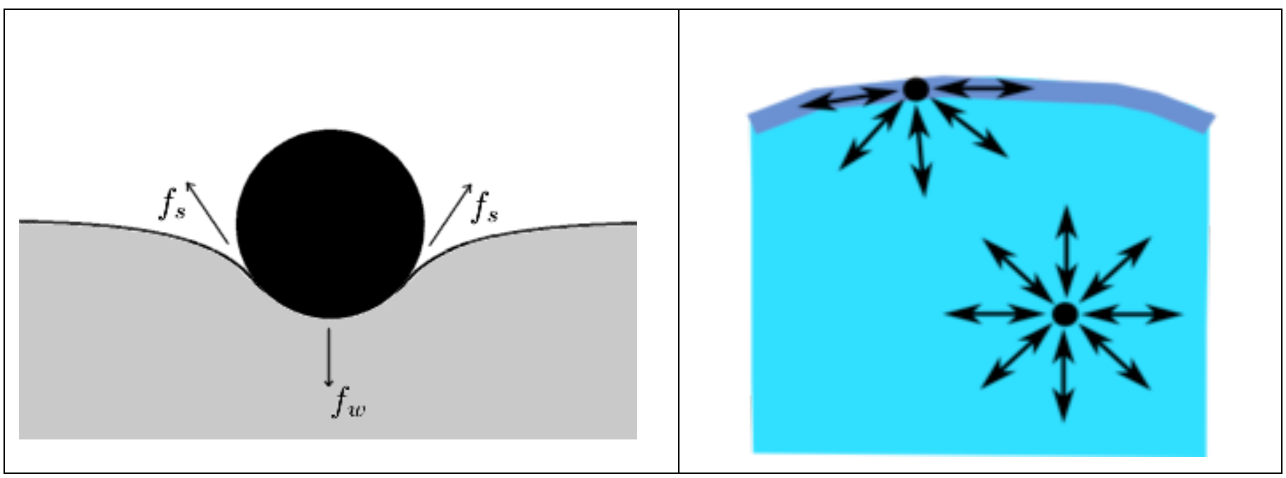


Figure 1. Surface of water with forces that prevent a particle from sinking (left) and forces of two water molecules (right).

Slide 21: High Surface Tension

This slide introduces the concept of surface tension. One way of describing surface tension is to point out that sometimes water acts like a "skin." This results from the surface water molecules clinging to each other and NOT to the air molecules over them.

The images in Figure 1 above are two different representations of surface tension. The image on the left shows the surface of water with forces strong enough to prevent a particle from sinking. The image on the right shows the forces of two water molecules. The water molecule at the surface has fewer force arrows attracting it to the other water molecules than the water molecule below it that is surrounded on all sides by other water molecules.

Slide 22: Question Slide

Question for Students: Can you explain why this drop sticks to the leaf and grows larger?

Ask students to explain how water forms drops AND how water sticks to the leaf, instead of gravity pulling it down.

Slide 23: Question Slide

Question for Students: Or how this spider can walk on water?

The spider has very light feet that don't "puncture" the water. The water behaves like a skin, buoying up the spider.

Slide 24: Adhesion

Adhesion occurs when the water molecules are more attracted to the sides of a small diameter tube than they are to each other. This accounts for phenomena like the meniscus in tubular glassware, or for the capillary action that draws water up into the xylem (small tubes throughout a plant that transmit water) of a plant.

Slide 25: Water Climbs Trees!

The basis of water moving through plants is that, like a small graduated cylinder, water is more attracted to the sides of the plants than to other water molecules. The water climbs up the plants' tubes for transporting water (xylem), and the water molecules attach to each other, pulling them along as well (cohesion).

An additional assignment would be to have students use ChemSense (chemsense.org) to animate water molecules moving through a plant. Another would be to have students illustrate, at the molecular level, water moving through a plant.

Slide 26: High Specific Heat Keeps Beaches Cooler in the Day and Warmer at Night!

Definition: Specific heat is the amount of energy required to change 1 gram of a substance 1^{o} Celsius.

Water has a relatively high specific heat. This means that it will absorb a lot of heat energy before raising the temperature of the water. If you live near a large body of water, the air temperature will not be as hot during the day. The water absorbs a lot of the heat, making air temperature milder than it is inland. When the sun goes down, the water slowly releases the heat that it has absorbed during the daytime. The night air temperature is warmer than the air inland. Climates are milder near large bodies of water than they are away from water.

Warm-blooded animals regulate their internal temperatures by being composed of large amounts of water. This water is slow to heat and slow to cool, moderating temperatures from outside of the body to inside the body. During periods of extreme heat, animals can release heat by sweating. The sweat on the outside of the skin absorbs energy as it evaporates off of the skin, cooling the temperature of the skin beneath the sweat.

Slide 27: Solid, Liquid, and Gas

Have students think about any other substance that is found naturally on earth in more than one phase of matter. Water is the only one to exist naturally in all three phases.

Slide 28: Ice is Less Dense than Water I

This table illustrates that water is the most dense at 4^oC. Have students examine the figures for the density of water at different temperatures.

Slide 29: Ice is Less Dense than Water II

This slide is just a visual to illustrate a macro-picture of an ice crystal and a nano-picture of ice as a solid. The crystal lattice structure of ice literally expands the structure of water as a solid, which will then collapse and become denser when melted.

Slide 30: Question Slide

Questions for Students: Can you imagine if ice did not float? How do you think that would affect the world?

Slide 31: Ice Melting

Click on the image to view the animation in your web browser. This will show the water molecules losing the bonds between them, collapsing and moving faster as the phase changes from solid to liquid.

Slide 32: Water is a Universal Solvent

Water is often described as a universal solvent. This is not really accurate. Water can dissolve polar or ionic substances. Water cannot dissolve nonpolar substances. Water's positive end and negative end have nothing to be differentially attracted to in a nonpolar substance. Water also cannot dissolve ionic substances that are more attracted to each other than they are to the overall force of the water molecules that surround the ions. This process of dissolving is known as solvation.

Slide 33: Important Points

Have students discuss these questions and review the important concepts presented in this lesson.

The Science of Water Lab Activities: Teacher Instructions

Overview

There are three sets of curricular materials for these labs:

1. **The Science of Water Lab Activities: Teacher Instructions.** This document, which includes the purpose, safety precautions, and procedures for each lab station, and a complete list of materials for each station.
2. **The Science of Water Lab Activities: Student Instructions.** The set of directions for students is to be printed and posted at each of the appropriate lab stations. They include a statement of purpose, safety precautions, materials needed, and procedures for the students to follow.
3. **The Science of Water Lab Activities: Student Worksheet.** Each student should be given this worksheet onto which they will record their observations. The worksheet also includes questions about each lab, designed to stimulate the student to think about how the lab demonstrates concepts fundamental to the mechanisms that make water a unique substance.

Each of the following labs is designed to demonstrate a specific aspect of the unique chemistry of water. The lab is set up at multiple stations. Each student or group of students will conduct investigations at each station.

Post the appropriate student instructions at each station for students to follow. There needs to be running tap water and paper towels at each lab station. No dangerous substances are recommended for this lab.

The lab stations are:

- Lab Station A: Surface Tension Lab
- Lab Station B: Adhesion/Cohesion Lab
- Lab Station C: Can You Take the Heat?
- Lab Station D: Liquid at Room Temperature Data Activity
- Lab Station E: Now You See It, Now You Don't, A Dissolving Lab
- Lab Station F: Predict a New World! Inquiry Activity

Materials

A complete list of materials can be found at the end of the set of teacher instructions.

Time Duration

Although the set of laboratory experiences is designed to occupy an entire class period, each lab will vary in the time that it takes to complete. If time is short, you may have students share their data with each other at the end of the class period. Also Lab Stations D and F are paper and pencil labs. You may want to assign these to students as homework or as a warm-up rather than as a separate lab station.

Lab Station A: Surface Tension Lab

Purpose

The purpose of this lab is to investigate the property of the surface tension of water. This lab will look at the way that water sticks to itself to make a rounded shape, the way that water behaves as a "skin" at the surface, and a comparison of water's surface tension with two other liquids, oil and soapy water.

Safety Precautions

- Wearing goggles is dependent on your school's safety criteria.
- Caution needs to be exercised around hot plates and the alcohol burner.
- Caution needs to be exercised around hot water and hot glassware.
- Do not eat or drink anything in the lab.
- Do not wear open-toed sandals in the lab.
- Wear long hair tied back to prevent touching the substances at the lab stations.

Materials

- 3 pennies
- Available water
- Small containers of water, oil, and soapy water
- A dropper for each of the containers
- A square, about 4" x 4", of wax paper

Procedures

Counting Drops on a Penny

1. Check to make sure all of the materials needed are at your lab station.
2. Using a dropper bottle containing only water, count the number of drops of water that you can balance on top of a penny. When the water falls off of the penny, record the number of drops. Wipe the water off of the penny.
3. Repeat this procedure of counting and recording drops with oil and then with the soapy water.

Comparing the Shape of a Drop

1. Drop a small sample of each of the liquids—water, oil, and soapy water—on the wax paper. Draw the shape and label the shape of the drops made by each of the liquids on your worksheet. Wipe off the wax paper.
2. Answer the questions on your worksheet.

Lab Station B: Adhesion/Cohesion Lab

Purpose

The purpose of this lab is to investigate the property of **cohesion** and **adhesion** of water.

- **Cohesion** is the molecular attraction exerted between molecules that are the same, such as water molecules.
- **Adhesion** is the molecular attraction exerted between unlike substances in contact.

Cohesion causes water to form drops, surface tension causes them to be nearly spherical, and adhesion keeps the drops in place (http://en.wikipedia.org/wiki/Adhesion).

This lab will work with capillary tubing of various diameters to see the rate at which water is able to "climb" up the tubes. This is very similar to the way that water enters a plant and travels upward in the small tubes throughout the plant's body. The "stickiness" of the water molecule allows the water to cling to the surface of the inside of the tubes.

You will see how the diameter of the tube correlates with the rate of traveling up the tube by measuring how high the dye-colored water column is at the end of the time intervals.

Safety Precautions

- COOL GLASSWARE FOR A FEW MINUTES BEFORE PUTTING INTO THE COOLING BATH OR THE GLASSWARE WILL BREAK.
- Wearing goggles is dependent on your school's safety criterion.
- Do not eat or drink anything in the lab.
- Do not wear open-toed sandals in the lab.
- Wear long hair tied back.

Materials

- 4 pieces of capillary tubing of varying small sized diameters (no greater than 7mm in diameter), 8-24 inches in length
- Metric ruler
- Pan of dyed (with food coloring) water into which to set the capillary tubing
- Clamps on ring stands to stabilize the tubing so that it remains upright in a straight position

Procedures

1. Check to make sure all of the materials needed are at your lab station.
2. Set the capillary tubing into the dye-colored water from the largest diameter tubing to the smallest. Make certain they are all upright and secure.
3. Record the height of each of the tubes in the table on your worksheet every 2 minutes.

4. After 10 minutes, release the capillary tubing, wrap the tubing in paper towels, and deposit them in an area designated by your teacher.
5. Answer the questions about this experiment on your lab sheet.

Teacher Notes

Try to obtain five different diameters of tubing. These are available through many different suppliers.

Lab Station C: Can You Take the Heat?

Purpose

The purpose of this lab is to investigate the heat capacity of water. You will measure the temperature of water (specific heat of water is 4.19 kJ/kg.K) and vegetable oil (specific heat of vegetable oil is 1.67 kJ/kg.K) over equal intervals of time, and will record your data and findings on your lab sheet.

Specific heat is the amount of energy required to raise 1.0 gram of a substance 1.0^{o} C.

Safety Precautions

- Cool hot glassware slowly. Wait a few minutes before placing in cold water or the glass will break.
- Wearing goggles is dependent on your school's safety criterion.
- Do not eat or drink anything in the lab.
- Do not wear open-toed sandals in the lab.
- Wear long hair tied back.
- Use caution when working with fire or heat. Do not touch hot glassware.

Materials

Assemble two Erlenmeyer flasks or beakers, each containing one of the liquids, with a thermometer held by a thermometer clamp that is to be inserted about midway into the liquid.

- 2 equal amounts, about 100-mL, of water and vegetable oil
- 2 250-mL Erlenmeyer flasks or 2 250-mL beakers
- 2 thermometers
- 2 Bunsen burners or 1-2 hot plates
- 2 ring stands: each ring stand will have a clamp to hold the thermometer. Use a screen if using a Bunsen burner rather than hot plate(s).
- Cold water bath for cooling the Erlenmeyer flasks or beakers

Procedures

1. Set the cooled flasks containing their solutions on the ring stands or hot plate.
2. Take the initial temperature reading of each of the liquids.
3. Turn on the hot plate to a medium temperature, or, if using Bunsen burners instead, light them, adjusting the flame of each to the same level.
4. Record the temperature of the liquid in each flask every 2 minutes until 4 minutes after each liquid boils. Record the temperature in the table on your lab sheet.

5. After recording the final temperatures, move the Erlenmeyer flasks or beakers with tongs or a heat-resistant set of gloves into the cooling bath. Add small amounts of ice as needed to keep the water temperature cold.

DO NOT THRUST HOT GLASSWARE DIRECTLY INTO ICY WATER BEFORE COOLING BECAUSE THE GLASS WILL BREAK!

6. Answer the questions about this experiment on your lab sheet.

Lab Station D: Liquid at Room Temperature Data Activity

Purpose

The purpose of this activity is to discover how unusual it is, based on a substance's molecular weight, that water is a liquid at room temperature.

Safety Precautions

None are needed, since this is a paper and pencil activity.

Materials

- Water is Weird! Data Table
- Lab worksheet for recording trends

Procedures

Data Table 1 shows the physical properties of a variety of substances. This table is typical of one that a chemist would examine to look for trends in the data. For instance, is there any correlation with the color of the substance and its state of matter? Is there any correlation between the state-of-matter of a substance and its density? How does water compare to other substances?

1. Examine the data table. Look for relationships between the physical properties of some of these substances.
2. Discuss the trends with your lab partner. Record your thoughts on your lab worksheet.
3. Answer the questions about this experiment on your lab worksheet.

Teacher Notes

If you are short of time, this activity can be done as homework or as a warm-up assignment. If you need extra lab station space, this activity can be conducted at the students' desks.

Water is Weird!
Data Analysis Activity

Water is Weird! How Do We Know?

We have been discussing the many ways that water is weird. Water seems pretty common to us. How do we know that it is unusual? Let's compare water to some other substances and see what we can find, using the data table below.

Record the trends that you notice on your lab worksheet.

Data Table 1: Physical Properties of Some Substances

Substance	Formula	Molar mass, grams	State of matter at normal room conditions	Color	Specific Heat J/g K	Density of gas, liquid, or solid	Boiling Temperature, °C
Water	H_2O	18.0	liquid	colorless	4.19	0.997 g/cm^3	100
Methane	CH_4	16.0	gas	colorless		0.423^{-162} g/cm^3	-161.5
Ammonia	NH_3	17.0	gas	colorless		0.70 g/L	-33
Propane	C_3H_8	44.1	gas	colorless		0.493^{25} g/cm^3	-42.1
Oxygen	O_2	32.0	gas	colorless	0.92	1.308 g/L	-182.9
Carbon dioxide	CO_2	44.0	gas	colorless		1.799 g/L	-78.5
Bromine	Br_2	159.8	liquid	red	0.47	4.04	58.8
Lithium	Li	6.94	solid	silvery, white metal	3.58	0.534 g/cm^3	1342
Magnesium	Mg	24.3	solid	silvery, white metal	1.02	1.74 g/cm^3	1090

Lab Station E: Now You See It, Now You Don't
A Dissolving Lab

Purpose

The purpose of this activity is to introduce the idea that different types of liquids may dissolve different substances.

Safety Precautions

- Wearing goggles is dependent on your school's safety criterion.
- Do not eat or drink anything in the lab.
- Do not wear open-toed shoes.
- Tie long hair back.

Materials

- 6 plastic cups
- 6 plastic spoons
- Water
- Oil
- Granulated salt
- Granulated sugar
- Iodine crystals

Procedures

1. Fill 3 plastic cups 1/3 to 1/2 full with water.
2. Fill 3 plastic cups 1/3 to 1/2 full with oil.
3. Put about a half-teaspoon of salt into the water in one cup and another half-teaspoon of salt into the oil in one cup.
4. Stir each for about 20 seconds or until dissolved.
5. Record your observations in the table on your lab sheet.
6. Repeat this procedure with sugar.
7. Repeat this procedure using iodine crystals BUT only drop 2 or 3 crystals into the water and into the oil.
8. Record your observations and answer the questions about this experiment on your lab sheet.

Lab Station F: Predict a New World!
Inquiry Activity

Purpose

We all know that ice floats; we take it for granted. However, in nature, the solid form of a substance being less dense than the liquid form is extraordinary. What we don't know or think about much is how our world would be affected if ice did not float in water. This "thought" activity explores the worldly implications if ice had a greater density than water.

Safety Precautions

None are required because this is a paper and pencil activity.

Materials

- Place a fish bowl with some fish and live plants at this station

Procedures

1. Read the following. Look at the fish bowl. Think. Write your thoughts on your lab worksheet.

   Assume that there will be one change in the way that nature behaves: On the day after tomorrow, worldwide, ice (the solid form of water) will now become denser than water, rather than its current state, which is less dense.

   What will be the impact of this change?

Figure 1. Beautiful lake in early winter. [1]

2. Discuss this with your lab partner.
3. Answer the questions about this experiment on your lab worksheet.

Reference

1. http://snow.reports.co.nz/snow_ida_800.jpg

Teacher Notes

This assignment can be homework assigned before this lesson, if there is not sufficient time to do this as a lab activity, or if you prefer.

Materials List

- 3 pennies
- Available water
- Small containers of water, oil, and soapy water, and a dropper for each
- A square, about 4” x 4”, of wax paper
- Hot plate
- Thermometer
- Ice water (without the ice)
- 4 pieces of 8-24 inches of capillary tubing of varying small sized dimensions, no greater than 7mm
- Metric ruler
- Pan of dyed (with food coloring) water into which to set the capillary tubing
- Clamps on stands that will stabilize the tubing to remain upright in a straight position
- 2 equal amounts, about 100-mL, of water and vegetable oil
- 2 250-mL Erlenmeyer flasks or beakers
- 2 thermometers
- 2 Bunsen burners or a hot plate
- 2 ring stands, with screens if needed, to hold Erlenmeyer flasks or beakers
- 2 additional clamps to hold the thermometers in place
- Cold water bath for cooling the Erlenmeyer flasks
- 6 plastic cups
- 6 plastic spoons
- Water at room temperature
- Oil at room temperature
- Granulated salt
- Granulated sugar
- Iodine crystals
- A timer with a second hand
- Glassware tongs or heat resistant mitts
- 100-mL graduated cylinder

The Science of Water: Quiz Answer Key

Write down your ideas about each question below.

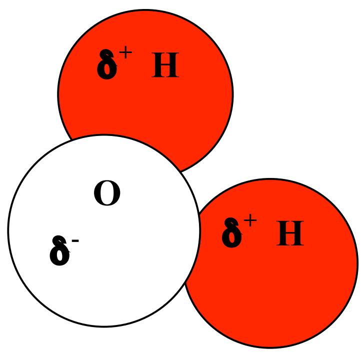
1. Why does all bonding occur between atoms, ions, and molecules?

All bonding occurs because of the attraction of opposite charges.

2. Draw a water molecule. Label the atoms that make up the water molecule with their chemical symbol. If there is an electrical charge or a partial electrical charge on any of the atoms, indicate that by writing the symbols on the atoms:

+ = positive charge — = negative charge

δ^+ = partial positive charge δ^- = partial negative charge



3. Explain the term "polar" molecule.

A polar molecule has a more positive end and a more negative end. These can be permanent or they can be temporary.

4. Why does water have an increased surface tension compared to most other liquids?

A water molecule has a greater surface tension relative to other liquids because the water molecules are more strongly attracted to the other water molecules surrounding them on all sides, as compared with the water molecules at the surface, which are surrounded by air (mostly nitrogen and oxygen gases). Water is not attracted to air molecules.

5. What is "hydrogen bonding"? What makes these bonds unique?

Hydrogen bonding is the bonding that occurs between adjacent water molecules. (Alhough our focus is on water, there are other molecules that exhibit hydrogen bonding as well as water.) The positive end of one water molecule is attracted to the negative end of the next water molecule. This is why water is a liquid at room temperature. A definition of hydrogen bonding is: The attraction of one end of a small, highly electronegative nonmetal atom in a molecule to the hydrogen end, more electropositive, end of an adjacent molecule.

6. a. Define or describe "specific heat."

Specific heat is the amount of energy required to raise 1.0 gram of a substance 1.0° C.

b. How does water's specific heat have an impact on our climate?

The temperature of the air near large bodies of water is more moderate than the temperature of air that is not near a large body of water. For instance, for cities bordering the ocean, the ocean absorbs heat during the day, making air temperatures cooler than they would be inland. At night, the ocean slowly releases the heat absorbed during the day, making the air temperatures warmer than they are inland.

7. Is water's specific heat, compared to other liquids:

High ☒ or Average ☐ or Low ☐ ?

8. Are water's melting and boiling temperatures, compared to other liquids:

High ☒ or Average ☐ or Low ☐ ?

9. a. What happens to the temperature of the water in a pot on a heated stove as it continues to boil?

The temperature of the water stays at 100° C during boiling.

b. Explain what the energy is being used for that is heating the water at the boiling temperature.

The heat energy being continually added to a pot of water during boiling is used to break the bonds of attraction (hydrogen bonding) between water molecules, so that each individual water molecule may change from the liquid phase to the gas phase.

10. Explain how a spider can walk on water.

The surface tension of the water is greater than the pull of the gravity on the spider's little feet.

11. Fill out the following table: Name and explain five of water's unique properties, and provide an example of the phenomenon in nature caused by each of these properties.

Property of Water	**Explanation of Property**	**Phenomenon Property Causes**
High boiling temperature	It takes a relatively large amount of energy to boil water compared with other small nonmetal liquids.	Water at sea level must reach 100^{o}C before it will boil.
High surface tension	The surface of water acts like a "skin."	Spiders can walk on water.
High specific heat	Water absorbs a relatively large amount of energy to raise its temperature 1^{o} C.	Climate near large bodies of water is moderate compared with climate further away from large bodies of water.
Solid is less dense than liquid	Water expands in volume when frozen.	Ice floats rather than sinks.
Universal solvent	Water dissolves positive and negatively charged particles.	Water is not found "pure" in nature because it dissolves so much of what it comes into contact with.

Reflecting on the Guiding Questions: Teacher Instructions

You may want to have your students keep these in a folder to use at the end of the unit, or collect them to see how your students' thinking is progressing.

Think about the activity you just completed. What did you learn that will help you answer the guiding questions? Jot down notes in the spaces below.

1. Why are water's unique properties so important for life as we know it?

What I learned in these activities:

What I still want to know:

2. How do we make water safe to drink?

What I learned in these activities:

What I still want to know:

3. How can nanotechnology help provide unique solutions to the water shortage?

What I learned in these activities:

What I still want to know:

4. Can we solve our global water shortage problems? Why or why not?

What I learned in these activities:

What I still want to know:

Lesson 2:
The Science of Water

Student Materials

Contents

The Science of Water Lab Activities: Student Directions

Lab Station A: Surface Tension Lab

Purpose

The purpose of this lab is to investigate the property of the surface tension of water. This lab will look at the way that water sticks to itself to make a rounded shape, the way that water behaves as a "skin" at the surface, and a comparison of water's surface tension with two other liquids, oil and soapy water.

Safety Precautions

- Wearing goggles is dependent on your school's safety criteria.
- Caution needs to be exercised around hot plates and the alcohol burner.
- Caution needs to be exercised around hot water and hot glassware.
- Do not eat or drink anything in the lab.
- Do not wear open-toed sandals in the lab.
- Wear long hair tied back to prevent touching the substances at the lab stations.

Materials

- 3 pennies
- Available water
- Small containers of water, oil, and soapy water
- A dropper for each of the containers
- A square, about 4" x 4", of wax paper

Procedures

Counting Drops on a Penny

1. Check to make sure all of the materials needed are at your lab station.
2. Using a dropper bottle containing only water, count the number of drops of water that you can balance on top of a penny. When the water falls off of the penny, record the number of drops. Wipe the water off of the penny.
3. Repeat this procedure of counting and recording drops with oil and then with the soapy water.

Comparing the Shape of a Drop

4. Drop a small sample of each of the liquids—water, oil, and soapy water—on the wax paper. Draw the shape and label the shape of the drops made by each of the liquids on your worksheet. Wipe off the wax paper.
5. Answer the questions on your worksheet.

Lab Station B: Adhesion/Cohesion Lab

Purpose

The purpose of this lab is to investigate the property of **cohesion** and **adhesion** of water.

- **Cohesion** is the molecular attraction exerted between molecules that are the same, such as water molecules.
- **Adhesion** is the molecular attraction exerted between unlike substances in contact.

Cohesion causes water to form drops, surface tension causes them to be nearly spherical, and adhesion keeps the drops in place (http://en.wikipedia.org/wiki/Adhesion).

This lab will work with capillary tubing of various diameters to see the rate at which water is able to "climb" up the tubes. This is very similar to the way that water enters a plant and travels upward in the small tubes throughout the plant's body. The "stickiness" of the water molecule allows the water to cling to the surface of the inside of the tubes.

You will see how the diameter of the tube correlates with the rate of traveling up the tube by measuring how high the dye-colored water column is at the end of the time intervals.

Safety Precautions

- COOL GLASSWARE FOR A FEW MINUTES BEFORE PUTTING INTO THE COOLING BATH OR THE GLASSWARE WILL BREAK.
- Wearing goggles is dependent on your school's safety criterion.
- Do not eat or drink anything in the lab.
- Do not wear open-toed sandals in the lab.
- Wear long hair tied back.

Materials

- 4 pieces of capillary tubing of varying small sized diameters (no greater than 7mm in diameter), 8-24 inches in length
- Metric ruler
- Pan of dyed (with food coloring) water into which to set the capillary tubing
- Clamps on ring stands to stabilize the tubing so that it remains upright in a straight position

Procedures

1. Check to make sure all of the materials needed are at your lab station.
2. Set the capillary tubing into the dye-colored water from the largest diameter tubing to the smallest. Make certain they are all upright and secure.
3. Record the height of each of the tubes in the table on your worksheet every 2 minutes.

4. After 10 minutes, release the capillary tubing, wrap the tubing in paper towels, and deposit them in an area designated by your teacher.
5. Answer the questions about this experiment on your lab sheet.

Lab Station C: Can You Take the Heat?

Purpose

The purpose of this lab is to investigate the heat capacity of water. You will measure the temperature of water (specific heat of water is 4.19 kJ/kg.K) and vegetable oil (specific heat of vegetable oil is 1.67 kJ/kg.K) over equal intervals of time, and will record your data and findings on your lab sheet.

Specific heat is the amount of energy required to raise 1.0 gram of a substance 1.0^{o} C.

Safety Precautions

- Cool hot glassware slowly. Wait a few minutes before placing in cold water or the glass will break.
- Wearing goggles is dependent on your school's safety criterion.
- Do not eat or drink anything in the lab.
- Do not wear open-toed sandals in the lab.
- Wear long hair tied back.
- Use caution when working with fire or heat. Do not touch hot glassware.

Materials

Assemble two Erlenmeyer flasks or beakers, each containing one of the liquids, with a thermometer suspended into each liquid, from a clasp attached to a stand, inserted about midway into the liquid.

- 2 equal amounts, about 100 mL, of water and vegetable oil
- 2 250-mL Erlenmeyer flasks or 2 250-mL beakers
- 2 thermometers
- 2 Bunsen burners or 1-2 hot plates
- 2 ring stands: each ring stand will have a clamp to hold the thermometer. Use a screen if using a Bunsen burner rather than hot plate(s).
- Cold water bath for cooling the Erlenmeyer flasks or beakers

Procedures

1. Set the cooled flasks containing their solutions on the ring stands or hot plate.
2. Take the initial temperature reading of each of the liquids.
3. Turn on the hot plate to a medium temperature, or, if using Bunsen burners instead, light them, adjusting the flame of each to the same level.
4. Record the temperature of the liquid in each flask every 2 minutes until 4 minutes after each liquid boils. Record the temperature in the table on your lab sheet.

5. After recording the final temperatures, move the Erlenmeyer flasks or beakers with tongs or a heat-resistant set of gloves into the cooling bath. Add small amounts of ice as needed to keep the water temperature cold.

DO NOT THRUST HOT GLASSWARE DIRECTLY INTO ICY WATER BEFORE COOLING BECAUSE THE GLASS WILL BREAK!

6. Answer the questions about this experiment on your lab sheet.

Lab Station D: Liquid at Room Temperature Data Activity

Purpose

The purpose of this activity is to discover how unusual it is, based on a substance's molecular weight, that water is a liquid at room temperature.

Safety Precautions

None are needed, since this is a paper and pencil activity.

Materials

- Water is Weird! Data Table
- Lab worksheet for recording trends

Procedures

Data table 1 shows the physical properties of a variety of substances. This table is typical of one that a chemist would examine to look for trends in the data. For instance, is there any correlation with the color of the substance and its state of matter? Is there any correlation between the state-of-matter of a substance and its density? How does water compare to other substances?

1. Examine the data table. Look for relationships between the physical properties of some of these substances. What do you notice that fits into any patterns? What is the opposite or is unusual to the most common pattern?
2. Discuss the trends with your lab partner. Record your thoughts on your lab worksheet.
3. Answer the questions about this experiment on your lab worksheet.

Water is Weird!
Data Analysis Activity

Water is Weird! How Do We Know?

We have been discussing the many ways that water is weird. Water seems pretty common to us. How do we know that it is unusual? Let's compare water to some other substances and see what we can find, using the data table below.

Record the trends that you notice on your lab worksheet.

Data Table 1: Physical Properties of Some Substances

Substance	Formula	Molar mass, grams	State of matter at normal room conditions	Color	Specific Heat J/g K	Density of gas, liquid, or solid	Boiling Temperature, °C
Water	H_2O	18.0	liquid	colorless	4.19	0.997 g/cm^3	100
Methane	CH_4	16.0	gas	colorless		0.423^{-162} g/cm^3	-161.5
Ammonia	NH_3	17.0	gas	colorless		0.70 g/L	-33
Propane	C_3H_8	44.1	gas	colorless		0.493^{25} g/cm^3	-42.1
Oxygen	O_2	32.0	gas	colorless	0.92	1.308 g/L	-182.9
Carbon dioxide	CO_2	44.0	gas	colorless		1.799 g/L	-78.5
Bromine	Br_2	159.8	liquid	red	0.47	4.04	58.8
Lithium	Li	6.94	solid	silvery, white metal	3.58	0.534 g/cm^3	1342
Magnesium	Mg	24.3	solid	silvery, white metal	1.02	1.74 g/cm^3	1090

Lab Station E: Now You See It, Now You Don't
A Dissolving Lab

Purpose

The purpose of this activity is to introduce the idea that different types of liquids may dissolve different substances.

Safety Precautions

- Wearing goggles is dependent on your school's safety criterion.
- Do not eat or drink anything in the lab.
- Do not wear open-toed shoes.
- Tie long hair back.

Materials

- 6 plastic cups
- 6 plastic spoons
- Water
- Oil
- Granulated salt
- Granulated sugar
- Iodine crystals

Procedures

1. Fill 3 plastic cups 1/3 to 1/2 full with water.
2. Fill 3 plastic cups 1/3 to 1/2 full with oil.
3. Put about a half-teaspoon of salt into the water in one cup and another half-teaspoon of salt into the oil in one cup.
4. Stir each for about 20 seconds or until dissolved.
5. Record your observations in the table on your lab sheet.
6. Repeat this procedure with sugar.
7. Repeat this procedure using iodine crystals BUT only drop 2 or 3 crystals into the water and into the oil.
8. Record your observations and answer the questions about this experiment on your lab sheet.

Lab Station F: Predict a New World!
Inquiry Activity

Purpose

We all know that ice floats; we take it for granted. However, in nature, the solid form of a substance being less dense than the liquid form is extraordinary. What we don't know or think about much is how our world would be affected if ice did not float in water. This "thought" activity is explores the worldly implications if ice had a greater density than water.

Safety Precautions

None are required because this is a paper and pencil activity.

Materials

- A fish bowl with some fish and live plants

Procedures

1. Read the following. Look at the fish bowl. Think. Write your thoughts on your lab worksheet.

   Assume that there will be one change in the way that nature behaves: On the day after tomorrow, worldwide, ice (the solid form of water) will now become denser than water, rather than its current state, which is less dense.

   What will be the impact of this change?

Figure 1. Beautiful lake in early winter. [1]

2. Discuss this with your lab partner.
3. Answer the questions about this experiment on your lab worksheet.

Reference

1. http://snow.reports.co.nz/snow_ida_800.jpg

Name__________________________________ Date______________________ Period ______

The Science of Water Lab Activities: Student Worksheets

Directions: Go to the lab stations assigned by your teacher. Follow the directions for each lab that are posted at each of the lab stations. Conduct the lab activity and record your data on the lab write-up sheet. Answer the questions asked on the lab sheet. Be sure to pay special attention to the purpose of each lab before beginning the lab. You are encouraged to talk to your lab partners about the lab and to ask your teacher questions.

Lab Station A: Surface Tension Lab

Drops of Water

Fill in the table below with the number of drops you added to the penny of each substance before the liquid spilled over.

	Water	Oil	Soapy Water
Number of Drops			

Questions

1. What does a high surface tension do to the number of liquid molecules that can stay together?

2. Based on your evidence, compare the surface tension of these four substances.

3. After placing a few drops of each of the liquids on the wax paper, draw what the drops look like from the side view. Be sure to capture the relative height/flatness of the drop

Water Oil Soapy Water

Name__________________________________ Date______________________ Period ______

Lab Station B: Adhesion/Cohesion Lab

Questions

1. Define adhesion

2. Define cohesion

3. Ask your teacher to provide you with the diameter of the capillary tubes if they are not labeled. In the table below, record the height of the liquid in capillary tubing of different diameters as you take your measurements.

Diameter of capillary tubing				
2 minutes				
4 minutes				
6 minutes				
8 minutes				
10 minutes				

4. Based on your evidence, what statement can you make about water's speed of climbing a capillary tube relative to the diameter (size of the opening) of the capillary?

5. What does this mean about how fast water is able to "climb" tubes within plants?

Name___________________________________ Date_______________________ Period ______

Lab Station C: Can You Take the Heat?
Student Lab Sheet

Specific heat is the amount of energy that it takes to raise 1.0 gram of a substance 1.0^{o} C. Fill out the table as you conduct your experiment.

Liquids	Water Temperature	Vegetable Oil Temperature
2 minutes		
4 minutes		
6 minutes		
8 minutes		
10 minutes		
12 minutes		
14 minutes		

Questions

1. Based on your evidence, which substance has the highest specific heat? The lowest?

2. Think about and explain the relationship between high specific heat of a liquid and hydrogen bonding.

3. Compare the boiling temperatures of water and of oil. What is the relationship between hydrogen bonding and boiling temperature?

4. What happened to the temperature of the water and the oil after boiling? Explain why.

Name__________________________________ Date______________________ Period ______

Lab Station D:
Liquid at Room Temperature Data Activity

Questions

1. What trends do you notice in the data table? Explain.

2. What is unusual about the most common pattern? Explain.

3. How does water compare to other substances?

Name________________________________ Date_____________________ Period ______

Lab Station E: Now You See It, Now You Don't
A Dissolving Lab

A **solvent** is the liquid that is doing the dissolving. A **solute** is the substance that will be dissolved in the liquid.

Record your observations about how quickly and thoroughly each of the solutes dissolves in water and oil in the table below.

SOLVENT	**SOLUTES**		
	Salt	**Sugar**	**Iodine Crystals**
Water			
Oil			

Questions

1. Summarize what you found in your experiment, based on your recorded observations.

2. Why do you think that some substances dissolve easier in one type of liquid than in another?

Name__________________________________ Date______________________ Period ______

Lab Station F: Predict a New World!
Inquiry Activity

Questions

1. Summarize your thoughts about the impact on the world if ice were denser than water.

Name________________________________ Date_____________________ Period ______

The Science of Water: Student Quiz

Write down your ideas about each question below.

1. Why does all bonding occur between atoms, ions, and molecules?

2. Draw a water molecule. Label the atoms that make up the water molecule with their chemical symbol. If there is an electrical charge or a partial electrical charge on any of the atoms, indicate that by writing the symbols on the atoms:

   + = positive charge — = negative charge

   δ^+ = partial positive charge δ^- = partial negative charge

3. Explain the term "polar" molecule.

4. Why does water have an increased surface tension compared to most other liquids?

5. What is “hydrogen bonding”? What makes these bonds unique?

6. a. Define or describe “specific heat.”

   b. How does water’s specific heat have an impact on our climate?

7. Is water’s specific heat, compared to other liquids:

   High ☐ or Average ☐ or Low ☐ ?

8. Are water’s melting and boiling temperatures, compared to other liquids:

   High ☐ or Average ☐ or Low ☐ ?

9. a. What happens to the temperature of the water in a pot on a heated stove as it continues to boil?

   b. Explain what the energy is being used for that is heating the water at the boiling temperature.

10. Explain how a spider can walk on water.

11. Fill out the following table: Name and explain five of water's unique properties, and provide an example of the phenomenon in nature caused by each of these properties.

Property of Water	Explanation of Property	Phenomenon Property Causes

Name_________________________________ Date_____________________ Period ______

Reflecting on the Guiding Questions: Student Worksheet

Think about the activity you just completed. What did you learn that will help you answer the guiding questions? Jot down notes in the spaces below.

1. Why are water's unique properties so important for life as we know it?

What I learned in these activities: What I still want to know:

2. How do we make water safe to drink?

What I learned in these activities: What I still want to know:

3. How can nanotechnology help provide unique solutions to the water shortage?

What I learned in these activities: What I still want to know:

4. Can we solve our global water shortage problems? Why or why not?

What I learned in these activities: What I still want to know:

Lesson 3: Nanofiltration

Teacher Materials

Contents

Nanofiltration: Teacher Lesson Plan

Orientation

As a dynamic, evolving area of science, nanotechnology can provide an exciting learning opportunity for students, offering them the opportunity to learn about current science and technology innovations that may improve our world. The use of nanofiltration for cleaning water is one such innovation. Scientists are working to develop newer, cheaper and more effective membrane technologies to clean water. Much of the current work has focused on new designs of nanofilters, and nanofiltration systems are currently deployed in a few metropolitan areas.

Learning about nanofiltration also reinforces important fundamental chemistry concepts that are sometimes difficult for students to grasp. Students must understand differences in solution types to understand how different filtration systems work on a small scale. The topic of nanofiltration also has the potential to help students see interdisciplinary connections between biology, chemistry, and engineering.

The lessons in the Fine Filters unit focus conceptually on the role of membrane technology for filtering water. The presentation, notes, activities and readings focus on key aspects of filtration such as underlying technologies, particle filtration sizes, and applications.

- The Nanofiltration Teacher and Student Readings provide background on how nanofiltration works. The teacher reading is recommended prior to presenting the Nanofiltration PowerPoint slides and other activities.
- The Nanofiltration PowerPoint slide set provides a brief introduction to the different types of filtration and how they work, with emphasis on nanofiltration methods.
- The Which Method is Best exercise is a worksheet activity that allows students to explore some of the basic ideas of filtration, such as membranes and particle size, and prepares them for the more involved lab activity.
- The Comparing Nanofilters to Conventional Filters lab activity gives students a hands-on opportunity to better understand two types of filtration.
- The Cleaning Jarny’s Water exercise allows students to explore ideas of filtration in a real-world application.
- The New Nano-Membranes Reading introduces students to current research in creating nanotechnology membranes
- The Reflecting on the Guiding Questions Worksheet asks students to connect their learning from the activities in the lesson to the driving questions of the unit.

Essential Questions (EQ)

What essential question(s) will guide this unit and focus teaching and learning?

(Numbers correspond to learning goals overview document)

2. How do we make water safe to drink?
3. How can nanotechnology help provide unique solutions to the water shortage?

Enduring Understandings (EU)

Students will understand:

(Numbers correspond to learning goals overview document)

3. Pollutants can be separated from water using a variety of filtration methods. The smaller the particle that is to be separated from a solution, the smaller the required pore size of the filter and the higher the cost of the process.

4. Innovations using nanotechnology to create a new generation of membranes for water filtration are designed to solve some critical problems in a cost-effective way that allows for widespread use.

Key Knowledge and Skills (KKS)

Students will be able to:

(Numbers correspond to learning goals overview document)

2. Describe different types of filtration in terms of the pore size of the filter, substances it can separate, and cost of use.

3. Use laboratory procedures to compare the relative effectiveness of different filtration methods on particle separation.

Nanofiltration Timeline

Day	Activity	Time	Materials
	Homework: Nanofiltration: Student Reading	*20 min*	Photocopies of Nanofiltration: Student Reading
Day 1 (50 min)	Show the Nanofiltration PowerPoint slides, using the teacher's notes to start class discussion.	30 min	Nanofiltration PowerPoint Slides & Teacher Notes Computer and projector
	Hand out the Which Method is Best? Student Worksheet and The Filtration Spectrum: Student Handout and have students work in small groups to answer the questions.	10 min	Photocopies of Which Method is Best? Student Worksheet Photocopies of The Filtration Spectrum: Student Handout
	Return to whole class discussion and have students share their ideas on which types of membrane can filter which type of particles. You may want to have different students each draw a particular membrane and related filtrated particles to help drive class discussion. This activity is a preparation exercise for the lab that will take place on day 2 of this lesson. Pre-read the lab and give students an indication of what to expect during the next class session.	10 min	Comparing Nanofilters to Conventional Filters Lab Activity: Teacher Instructions
	Homework: Read the Comparing Nanofilters to Conventional Filter Lab Activity: Student Instructions in preparation for the next class.	*25 min*	Photocopies of the Comparing Nanofilters to Conventional Filters Lab Activity: Student Instructions

Day 2 (50 min)	Have students work in pairs or small groups on the Comparing Nanofilters to Conventional Filters Lab Activity. Each student should complete their own Student Worksheet, although they may consult with other group members or the teacher.	50 min	Photocopies of the Comparing Nanofilters to Conventional Filters Lab Activity: Student Worksheet
	Homework: New Nano-Membranes: Student Reading	*15 min*	Photocopies of New Nano-Membranes: Student Reading
Day 3 (50 min)	Have students work on the Cleaning Jarny's Water activity in small groups.	25 min	Photocopies of Cleaning Jarny's Water: Student Instructions & Report
	Have students discuss the New Nano-Membranes: Student Reading in small groups.	10 min	Photocopies of the New Nano-Membranes: Student Reading
	Have students work individually or in small groups to fill out the Reflecting on the Guiding Questions: Student Worksheet.	10 min	Photocopies of Reflecting on the Guiding Questions: Student Worksheet
	Discuss the Essential Questions and the group's collective ability to answer them based on the work done in the unit and answer any remaining student questions.	5 min	

Nanofiltration: Teacher Reading

How is Water Cleaned?

Water cleansing is complex. There are many methods for making water safe to drink. In addition, new technologies are being researched and patented at a relatively rapid rate. Typically, water is cleaned through multi-step processes that balance efficacy (i.e. contaminant removal) with cost-effectiveness.

Non-Filtration Techniques

While filtration is the main technique used to clean water, there are several common methods of cleaning water that are used independently and/or in addition to filtration.

- **Distillation** processes use heat to evaporate water. The gas then condenses, leaving all impurities behind except those (some pesticides and fertilizers) with boiling points lower than water that get evaporated and then condensed along with the water. This method is expensive. It also leaves the water tasteless, and without minerals.
- **Ion exchange** methods work by passing ion-containing water through resin beads, which exchange OH^- and H^+ ions for the unwanted ions.
- **UV** methods use ultraviolet light as a germicide to kill bacteria and other microorganisms in water. These methods do not remove particulates or ions.
- **Chemical-based** methods are used to cause flocculation (the formation of small clumps of particles, making them easier to remove), precipitation or oxidation of particles.

Water Filtration

Filtration is the process of passing a fluid through a porous object or objects (for example cheesecloth or sand) in order to separate out matter in suspension [1]. Filtration is the primary process used to clean water for human use.

Some Vocabulary Clarification

Many words with similar meanings are used to describe parts of the filtration process. These words are used interchangeably in the water filtration literature. These words and their meanings are illustrated in Figure 1.

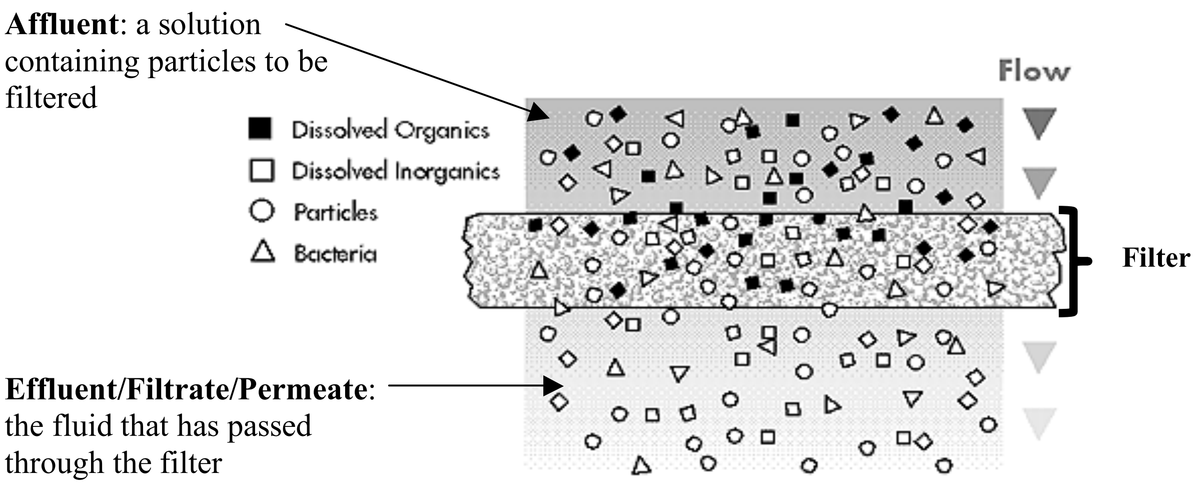


Figure 1. Particles passing through a carbon filter [2].

Kinds of Filtration

The following is a list of commonly used filtration types. All of them use membrane technologies, except for carbon filtration which uses a collection of small grains. Each of these filter types are expanded upon in Table 1, including examples of particle types they can remove and diagrams of the filters. A simplified version of Table 1 is also provided as a student handout (Types of Filtration Systems and their Traits: Student Handout).

- **Carbon filtration** traps larger organic particles on the surface of small carbon grains. Different types of filters are capable of trapping different substances.
- **Microfiltration** methods employ depth, screen or surface membranes:
  - **Depth filters** consist of matted fibers that retain particles as they pass through the filter. About 98% of the particles passing through this type of microfilter are retained, protecting finer-scale membranes farther down the chain. Depth microfilters are considered good prefilters for this reason.
  - **Surface filters** are multilayered structures that remove 99.99% of suspended solids, and are also used as prefilters.
  - **Screen filters** are microporous membranes that trap particles based on the specific pore size of the membrane.
- **Ultrafiltration** methods employ a thin, yet tough, membrane with a very small pore size.
- **Nanofiltration** methods focus on pore size, charge (repulsion), and shape characteristics of the membrane. A moderate amount of pressure is required for nanofilters to operate effectively.

- **Reverse osmosis** methods use a selectively-permeable membrane to separate water from dissolved substances. Relatively high pressure is required to make water flow against normal osmotic pressure.

Filtration Trade-offs

Generally, the smaller the filter, the more pressure is needed to push the water through it. Greater pressure means a greater cost, and so filters that remove very small particles are the most expensive to use. To be cost-effective, filtration is usually done as a multi-step process. Bigger contaminants are first removed using large-pore (and thus less expensive) filters, then filters with decreasing pore sizes are used to remove smaller and smaller particles. Using a sequence of filters also keeps the small-pore filters from getting clogged up with the large contaminants. This clogging is called "fouling." Filters must be cleaned regularly to remain usable

State of the Art?

While constantly improving, our current water purification technology is inadequate to meet the current or the projected needs of the world's population for clean drinking water. New nanofilters are being explored with much anticipation and excitement for their potential to address the global water crisis.

References

(Accessed December 2007.)

[1] http://www.m-w.com/dictionary/filter

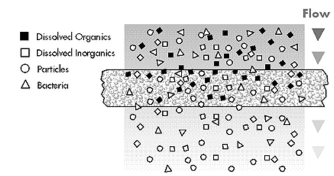
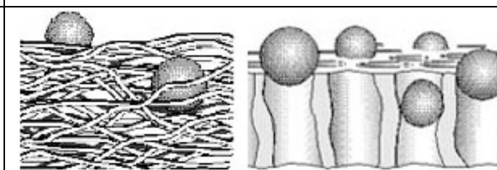
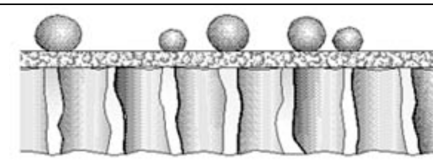
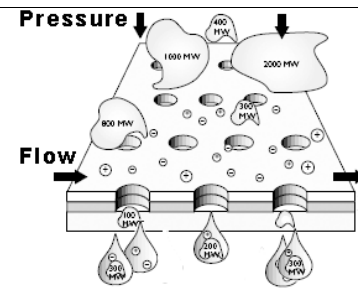
[2] Adapted from http://www.freedrinkingwater.com/water-education/quality-water-filtration-method.htm

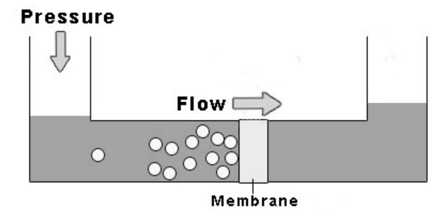
[3] Adapted from http://www.homecents.com/images/h2o-imgs/nano_f_l.gif

[4] Adapted from http://www.zenon.com/image/resources/glossary/reverse_osmosis/reverse_osmosis.jpg

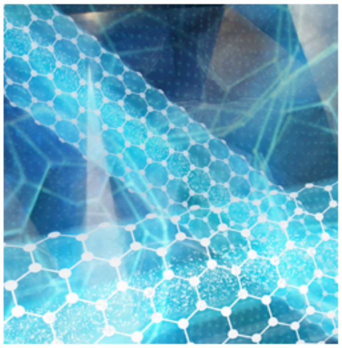
[5] http://www.nesc.wvu.edu/ndwc/

Table 1. Types of Filtration Systems and their Traits

Type of Filtration	Max Particle Size (meters)	Characterization	Example Particles	Disadvantages	Diagram
Carbon Filtration **(CF)**	Above 10^{-6}	Large organic particles are trapped on the surface of small carbon grains. Used in combination with other filtration processes.	Removes bad tastes and odors (organic matter) and chlorine Varies widely	No effect on total dissolved solids, hardness, or heavy metals.	 [2]
Microfiltration **(MF)**	10^{-5} to 10^{-7}	Removal based on relatively large pore size, retains contaminants on surface. Very low water pressure needed. Often used as a pre-filter.	Sand, silt, clays, *Giardia lamblia, Cryptospoidium*, cysts, algae and some bacteria	Removes little or no organic matter. Does not remove viruses.	 Depth Filter Surface Filter [2]
Ultrafiltration **(UF)**	10^{-7} to 10^{-8}	Removal based on smaller pore size, retains contaminants on surface. Low water pressure needed.	Suspended organic solids Partial removal of bacteria Most viruses removed	Most problems are with fouling. Cannot remove iron or manganese ions (multivalent ions).	 [2]
Nanofiltration **(NF)**	10^{-8} to 10^{-10}	Removal based on very small pore size and shape and charge characteristics of membrane. Moderate pressure needed.	Suspended solids Bacteria Viruses Some multivalent ions	Currently most are susceptible to high fouling. Cost is relatively high (currently).	 [3]

Reverse Osmosis **(RO)**	10^{-9} to 10^{-11}	High pressure process that pushes water against the concentration gradient Different membranes have different pore sizes and different characteristics.	Suspended solids Bacteria Viruses Most multivalent ions Monovalent ions	Membranes are prone to fouling. Cost is high.	 [4]

Note: Relative Pressure needed for operation: RO > NF > UF > MF **Relative Cost**: RO > NF > UF > MF [5]



Nanofiltration

Environmental scientists and engineers are creating nanomembranes to filter contaminants from water cheaply and effectively

NanoSense
the basic sense behind nanoscience

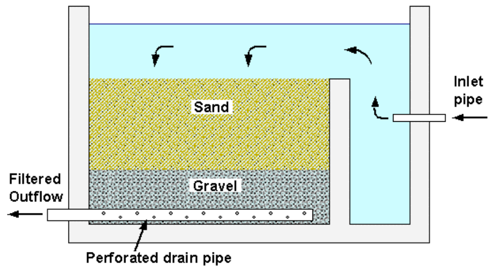
Water Filtration Methods

There are simple and cheap ways to filter contaminants out of water

NanoSense 3

Sand, Gravel, and Charcoal Filtration

- **Pouring water through sand, gravel, or charcoal are simple and inexpensive methods of cleaning water**



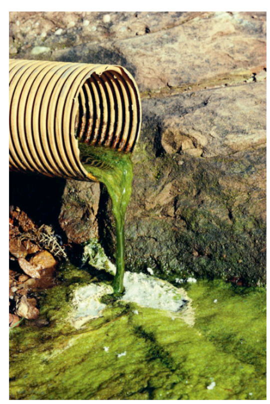
Sand and gravel filtration

Source: http://www.worldhungeryear.org/why_speaks/19_files/image014.gif

NanoSense 4

Small Contaminants Pass Through

- **Sand, gravel, and charcoal don't filter out some contaminants, like**
  - bacteria
  - viruses
  - industrial pollutants
  - agricultural pollutants
  - salt

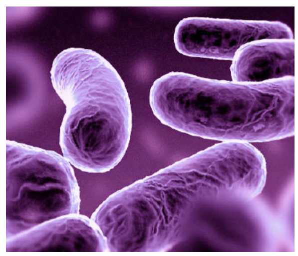


Sources: http://www.liverpool.nsw.gov.au/LCC/INTERNET/RESOURCES/IMAGES/Water-pollution.jpg

NanoSense 5

Question

How Can We Trap Smaller Contaminants?

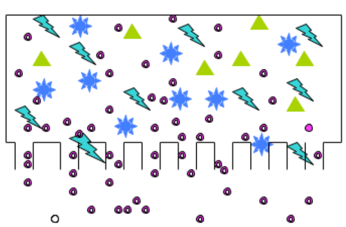


Sources: http://www.turbosquid.com/FullPreview/Index.cfm/ID/274625

NanoSense 6

Membrane Filter Technology I

- A membrane is a thin material that has pores (holes) of a specific size
- Membranes trap larger particles that won't fit through the pores of the membrane, letting water and other smaller substances through to the other side



Membrane Filter Technology II

- **There are four general categories of membrane filtration systems**
  - Microfiltration
  - Ultrafiltration
  - Nanofiltration
  - Reverse Osmosis

Membrane Filter Technology III

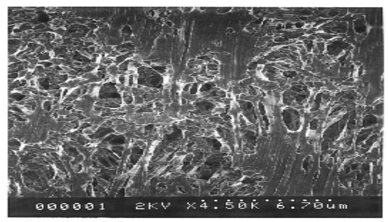
Filter type	Symbol	Pore Size, µm	Operating Pressure, psi	Types of Materials Removed
Microfilter	MF	1.0-0.01	<30	Clay, bacteria, large viruses, suspended solids
Ultrafilter	UF	0.01-0.001	20-100	Viruses, proteins, starches, colloids, silica, organics, dye, fat
Nanofilter	NF	0.001-0.0001	50-300	Sugar, pesticides, herbicides, divalent anions
Reverse Osmosis	RO	< 0.0001	225-1,000	Monovalent salts

Source: http://web.evs.anl.gov/pwmis/techdesc/membrane/index.cfm

Microfiltration

- **Typical pore size: 0.1 microns (10^{-7}m)**
- **Very low pressure**
- **Removes bacteria, some large viruses**
- **Does not filter**
  - small viruses, protein molecules, sugar, and salts

Microfiltration water plant, Petrolia, PA



A microfilter membrane

Sources: http://www.waterworksmw.com/rack%201%20&%202b.jpg http://www.imc.cas.cz/sympo/41micros/Image126.gif

Ultrafiltration

- **Typical pore size: 0.01 microns (10^{-8}m)**
- **Moderately low pressure**
- **Removes viruses, protein, and other organic molecules**
- **Does not filter ionic particles like**
  - lead, iron, chloride ions; nitrates, nitrites; other charged particles

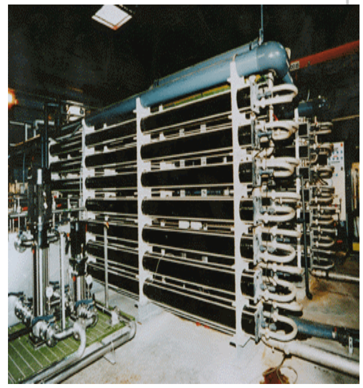
An ultrafiltration plant in Jachenhausen, Germany

Source: http://www.inge.ag/bilder/presse/bildmaterial/referenzen/jachenhausen.jpg

NanoSense 11

Nanofiltration

- **Typical pore size: 0.001 micron (10^{-9}m)**
- **Moderate pressure**
- **Removes toxic or unwanted bivalent ions (ions with 2 or more charges), such as**
  - Lead
  - Iron
  - Nickel
  - Mercury (II)



Nanofiltration water cleaning serving Mery-sur-Oise, a suburb of Paris, France

Source: http://www.wateronline.com/crlive/files/Images/10899070-E891-11D3-8C1F-009027DE0829/newwater1.gif

NanoSense 12

Reverse Osmosis (RO)

- **Typical pore size: 0.0001 micron (10^{-10}m)**
- **Very high pressure**
- **Only economically feasible large scale method to remove salt from water**
  - Salty water cannot support life
  - People can't drink it and plants can't use it to grow

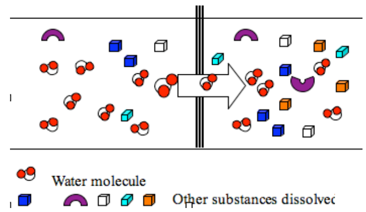
Reverse osmosis (or desalination) water treatment plants, like this one, are often located close to the ocean

Source: http://iclaro.com/users/18342/pictures/Desalination%20Plant.jpg

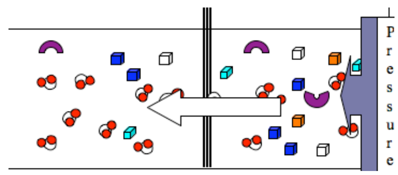
NanoSense 13

How RO Works

- Osmosis is a natural process that moves water across a semipermeable membrane, from an area of ***greater concentration to an area of lesser concentration*** until the concentrations are equal
- To move water from a ***more concentrated area to a less concentrated area*** requires high pressure to push the water in the opposite direction that it flows naturally



Osmosis



Reverse Osmosis

NanoSense 14

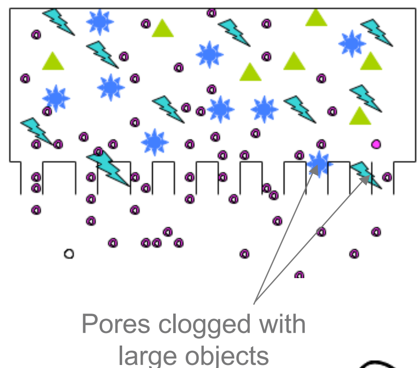
Question

If RO Can Get Everything Out That Would Make Water Undrinkable, Why Not Just Use RO Membranes by Themselves?

RO is Not for Everything!

- **High pressure is required to push the water through the smallest pores**
  - RO is the most $$$ filtration system
- **Because pores are so small, big particles can clog them (called fouling)**
  - This makes the filtering membrane unusable

Fouling of RO pores

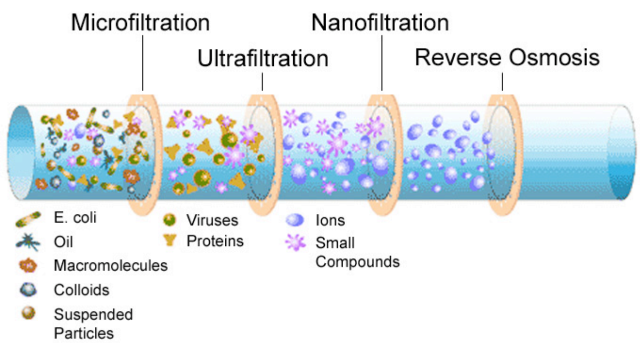


Question

How Can We Keep Large Particles from Fouling Membranes with Small Holes?

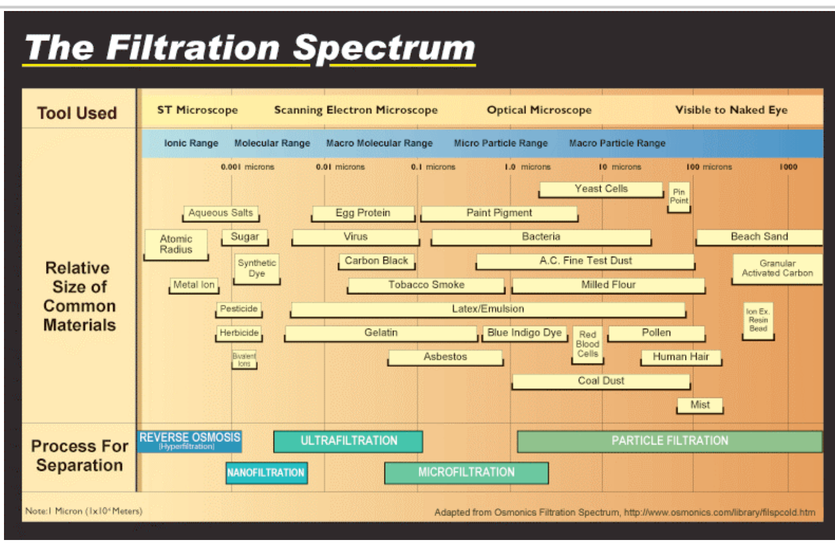
A Series of Filtrations Increases Efficiency

- **Filters can be sequenced from large to small pore size to decrease fouling**
  - They must still be cleaned regularly to remain usable



Source: Adapted from http://www.alting.fr/images/cross_flow_details.gif

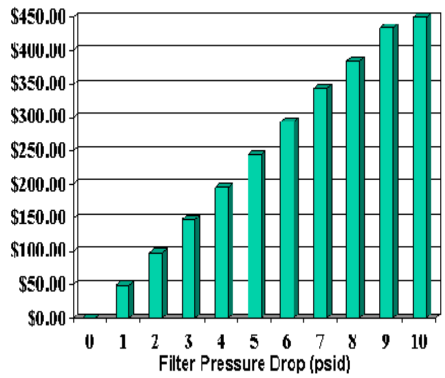
Water Filtration Chart



Source: Adapted from http://http://www.sasconsulting.ca/Files/Spectrum.jpg

Nanofiltration vs. Reverse Osmosis

- **Using RO to get rid of very small particles is very expensive**
  - Could we do it more cheaply?
- **Nanofiltration requires much less pressure than reverse osmosis**
  - Less pressure means lower operating costs!



What does this chart say about the cost of pressure used for filtration?

Source: http:/www.ecompressedair.com/images/library/kf_filter_f13.gif

Advantages of Nanofiltration

- **Nanofilters are close in size to RO filters, but cost much less to run**
- **And special properties of nanosized particles can be exploited!**
  - We can design new nanofilters that catch particles smaller than they would catch based on size alone
- **Scientists are exploring a variety of methods to build new nanomembranes with unique properties to filter in new and different ways**

New Nanofilters are Unique!

- **Nanomembranes can be uniquely designed in layers with a particular chemistry and specific purpose**
  - Insert particles toxic to bacteria
  - Embed tubes that "pull" water through and keep everything else out
  - Signal to self-clean

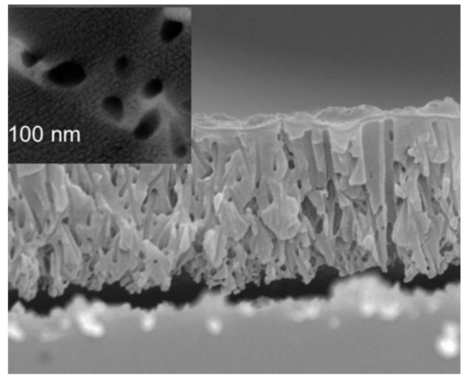


Image of a nanomembrane

Source: http://sciencematters.berkeley.edu/archives/volume2/issue10/images/story2-2.jpg

New Nanomembranes I

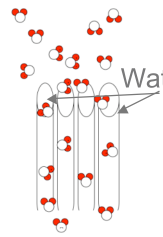
- **Imagine having layers of membranes into which specialized substances are placed to do specific jobs**
  - You can put a chemical in the filter that will kill bacteria upon contact!

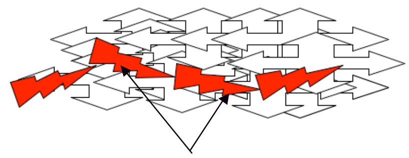
Chemicals toxic to bacteria could be implanted in nanomembranes

Source: Unknown

New Nanomembranes II

- **Embed "tubes" composed of a type of chemical that strongly attracts ("loves") water**
- **Weave into the membrane a type of molecule that can conduct electricity and repel oppositely charged particles, but let water through**

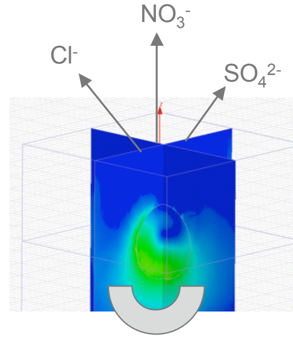




Electricity moving through a membrane

1 nm Sized Nanopores Repel Electronegative Objects

- **1-2 nm sized pores create an electric field over the opening**
  - This electric field is negative, and repels negatively charged particles dissolved in water
  - Most pollutants from agriculture, industry, and rivers are negatively charged
- **But water can get through!**



Representation of an electric field above a nanopore pushing away negative ions

Nanofiltration Summary

- **At the nanoscale, filters can be constructed to have properties designed to serve a particular purpose**
- **Scientists and engineers are now experimenting to create membranes that are low-cost yet very effective for filtering water to make it drinkable!**
- **These inventions may help to solve the global water shortage**

Questions

- **How do you determine what filtration method to use to remove contaminants in a water sample?**
  - Consider the size of the contaminants, the relative cost of the filtration methods, and the water use
- **What are two benefits that nanomembranes bring to the filtration of water?**
  - Consider how they can help to address the world's problem of a scarcity of clean drinking water
- **Describe three ways that current or experimental nanofiltration membranes may be different than previous generation membranes**

Nanofiltration: Teacher Notes

Overview

This set of slides provides some general background about the processes of water filtration. Common processes involve a sequence of filtrations through different kinds of membranes designed to remove different sizes of particles. Water is also often treated chemically, is sometimes irradiated, and even has substances added back into the water to improve its flavor. These slides give students a broad background in water filtration so that they can appreciate the innovations being explored by scientists and engineers who are designing nanomembranes for water filtration.

Slide 1: Title Slide

Slide 2: Water Filtration Methods

Removing contaminants to make water drinkable can be complex. Although the focus of this lesson is on membrane filtering technologies, there are simple and cheap methods for removing large contaminants in water, such as passing water through gravel, sand, and/or charcoal.

Slide 3: Sand, Gravel, and Charcoal Filtration

Students will be working with sand, gravel, and charcoal filtration in their lab activities. These are the very simple, inexpensive methods for cleaning large-sized contaminants out of water.

Slide 4: Small Contaminants Pass Through

However, sand, gravel, and charcoal filtration methods are not able to remove bacteria, viruses, and industrial or agricultural pollutants from water. If a water source has any of these contaminants, other filtration or cleaning methods must be used as well to produce safe drinking water.

Slide 5: How Can We Trap Smaller Contaminants? (Question Slide)

Have your students brainstorm ideas about ways to trap small contaminants like bacteria or viruses, which are not trapped by sand, gravel, or charcoal filtration.

Slide 6: Membrane Filter Technology I

This slide introduces students to the idea of a membrane blocking some (e.g., smaller) substances while allowing others to pass through. The basis of most membrane blockage is pore size. The size of the pore will determine what substances pass through the membrane and which ones remain on the other side.

Slide 7: Membrane Filter Technology II

This slide lists the four common types of membranes used for filtering water for drinking. There are many types of filters and methods of cleaning water, but this slide set focuses primarily on membrane technology, leading into a discussion of nanomembranes.

Slide 8: Membrane Filter Technology III

This is a quick overview that compares the four types of membrane filters on the basis of pore size, operating pressure, and type of substances that each of the membranes can remove. Students will look at these in more detail during the Cleaning Jarny's Water activity.

Slide 9: Microfiltration

The pore diameter of microfiltration membranes is typically in the range of 0.01 to 1.0 micrometers, with a typical diameter of 0.1 microns. Thus, microfiltration can be used to filter bacteria and some large viruses from water. It cannot filter out smaller contaminants like small viruses, proteins, molecules, sugar, and salts. The pressure required to push water through a microfiltration membrane is minimal. This slide shows a picture of a microfiltration water treatment plant and a close-up of a microfiltration membrane. You can see the pores in this membrane!

Slide 10: Ultrafiltration

Ultrafiltration can remove viruses, proteins, and other organic molecules from water using a moderately low amount of pressure. Ultrafiltration is an economical choice since not very much pressure is required to operate an ultrafiltration water treatment plant.

This slide would be a good place to point out that ions are charged particles that get dissolved into the water from natural and unnatural sources. Water, as a universal solvent, has the potential to dissolve small amounts of whatever the water passes over. Nitrates and/or nitrites and phosphates in excess in the water can be a sign of agricultural pollutant run-off.

Increased nitrates and/or phosphates in the water can lead to a series of events that ultimately cause a lake to lack sufficient nutrients to support fish life. At first, increased nitrates and phosphates provide basic nourishment to plants that will stimulate plant growth. Plant growth leads to an abundance of food for animals. Animal populations tend to increase as well when plant growth is surging. But too many animals in the water decreases the amount of dissolved oxygen, which is necessary for fish to live. Dead fish in the water decompose, providing nutrients for even more algae to grow. These events can lead to what is known as eutrophication, or a series of cause and effect events that lead to changing the ecosystem of a lake resulting in troubling impacts: decreased biodiversity and changes in the dominant species. This concept is not addressed at all within this lesson, but if appropriate, you may want to mention it.

Slide 11: Nanofiltration

This slide introduces "traditional" nanofiltration, which, like many of the other filtration technologies, has been around for decades. Later slides will talk about some of the new an innovative work occurring in the science and engineering of nanofilters.

Nanofiltration can remove bivalent ions (ions with more than one charge). Several nanofiltration plants have been built worldwide, but they are still relatively uncommon. This membrane technology is typically used when there is a limited amount of salt in the water.

Slide 12: Reverse Osmosis (RO)

Reverse osmosis (RO) is a membrane technology, about 35 years old, that can separate salt from water. RO membranes have essentially remained unchanged in recent decades. Though RO is the only known technology currently capable of desalinizing water, the process requires very high pressure, and is the most expensive membrane filtering system. Cities located by oceans are often good candidates for cleaning salt out of water.

Slide 13: How RO Works

As highlighted in the previous slide, reverse osmosis is the most successful and effective method of removing salt from water. These illustrations show how osmosis, a natural cellular process, pushes water across cell membranes by going in a direction that is more concentrated (and will therefore, be diluted when more water is added), until the concentrations are equal on both sides of the membrane. In our bodies, our kidneys perform this function.

Dialysis tubing is a common piece of lab equipment used in high school biology labs to demonstrate osmosis. Reverse osmosis goes in the "unnatural" direction, from the side that is more concentrated (without as many substances dissolved in the water) through the membrane to the side that is less concentrated. A great deal of pressure must be applied to push the water into an area less concentrated. The greater the pressure required to move the water through the filtration membrane, the higher it costs to operate the filtering system.

Slide 14: If RO Can Get Everything Out That Would Make Water Undrinkable, Why Not Just Use RO Membranes by Themselves? (Question Slide)

Have your students brainstorm about why RO by itself might not be the best solution. Ideas that they may entertain include: high cost (since RO requires high pressure), plugging of the RO membrane from large particles, and that not all water has salt in it that needs to be removed (e.g., fresh or lake water) so RO may be overkill in some cases.

Slide 15: RO is Not for Everything!

This slide points out that high pressure, high cost, and fouling are associated with using RO membranes. More pressure requires more energy use. Designing and maintaining (cleaning) a very small pore size is also very costly. You might point out that in the image, a few of the particles are blocking some of the pores.

Slide 16: How Can We Keep Large Particles from Fouling Membranes with Small Holes? (Question Slide)

Read the question posed on the slide out loud, and have your students brainstorm answers. Fouling can occur with every membrane filter system, when the pores of the filter become plugged with particulate matter that is larger than the pores.

The next two slides address this question, showing how filtering technology can occur in a step-wise fashion to optimize the more expensive filtration systems.

Slide 17: A Series of Filtrations Increases Efficiency

This slide illustrates the consecutive removal of increasingly small contaminants using a series of filters. It is less expensive to remove larger-sized contaminants with gravel, sand, or charcoal, and to use a series of increasingly smaller pore-sized membranes to remove increasingly smaller particles than to remove all sizes of particles with the membranes with the smallest sized pores. The filters would quickly foul and be in frequent need of cleaning. Using nanofiltration or RO to remove only small particles optimizes these expensive membranes for those sized particles that can only be filtered out of water by them.

Slide 18: Water Filtration Chart

This is a picture of the Filtration Spectrum: Student Handout that correlates the types of particles with their size, type of filter required to remove the particle from the water, and the type of microscope needed to view these sizes of particles. It illustrates the filtration methods that have been discussed so far. You might use the chart to quickly review the various methods that have been discussed.

Slide 19: Nanofiltration vs. Reverse Osmosis

This slide points out that RO can get rid of small particles, but it is expensive. Can we remove small particles more cheaply?

This graph demonstrates the correlation between the amount of pressure required and the cost of the water filtration system. The more pressure, the more energy is required, and the higher the operating cost.

Slide 20: Advantages of Nanofiltration

The pores in nanomembranes are close in size to those in RO filters, so can they be used more often as a cheaper alternative to RO? Yes, mainly due to recent advances in nanotechnology.

Nanomembranes have been around for decades, and were usually composed of a homogenous material throughout the fabric of the membrane. Recently, however, scientists have been able to build nanomembranes in layers, inserting substances with a particular chemistry and specific purpose. For example, new nanomembranes can not only filter based on *size* but also based on *charge*. In other words, the membrane can stop very small particles with a particular electrostatic charge while allowing water through.

Such advances have been made possible because of new tools and methods. Emphasize that engineering membranes to be uniquely designed for a specific purpose is a characteristic of nanofiltration and nanotechnology in general.

Slide 21: New Nanofilters are Unique!

Scientists can embed noxious substances in nanomembranes—substances that will kill bacteria on contact! Also, channels can be built into the membranes that are surprisingly hydrophilic, *attracting* water to pass through the membrane, thus reducing the pressure needed to *push* the water through it. Further, scientists envision creating membranes that are self-cleaning: a feedback mechanism initiates a chemical process that removes fouling residue. Using self-cleaning membranes could reduce both maintenance and operating expenses.

Benefits of nanomembranes are elaborated in more detail in the New Nanomembranes: Student Reading.

Slide 22: New Nanomembranes I

Eric Hoek talks about embedding particles into the membrane that are toxic to bacteria in the New Nanomembranes: Student Reading. When the bacteria combine with the toxic embedded substance, the bacteria die.

Slide 23: New Nanomembranes II

Two advances of new nanomembranes include the embedding of hydrophilic tubes through which water travels to the other side of the membrane, and the weaving of a conducting material through a membrane to repel oppositely charged particles.

Slide 24: 1 nm Sized Nanopores Repel Electronegative Objects

Eric Hoek explains this idea in the New Nanomembranes: Student Reading. This discovery was made serendipitously when constructing membranes with 1 to 2 nanometer pores.

Slide 25: Nanofiltration Summary

This slide concludes the introduction of how nanomembranes can be used to filter contaminants out of water. Hopefully students have gained an appreciation for how nanomembranes can be built with selected properties by embedding them with specialized materials. Nanomembranes hold the promise of a new generation of water filtration membrane technology.

Slide 26: Questions for Discussion

This final slide poses further questions for discussion that are related to this lesson. You may want to ask students to discuss their ideas aloud or in writing, to reinforce the central concepts.

Which Method is Best? Teacher Instructions & Answer Key

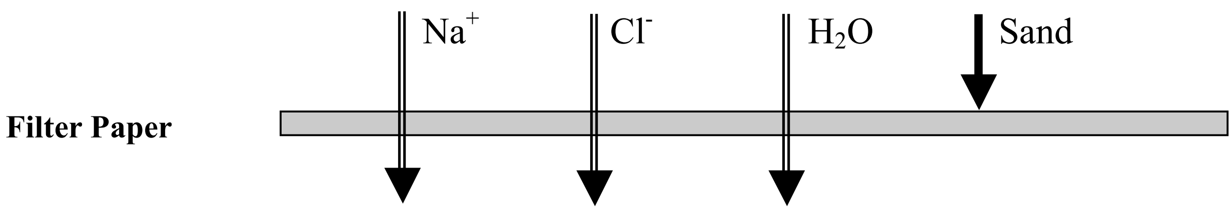
Purpose

Use the Filtration Spectrum: Student Handout to determine which filtration method is best suited to filter a variety of particles.

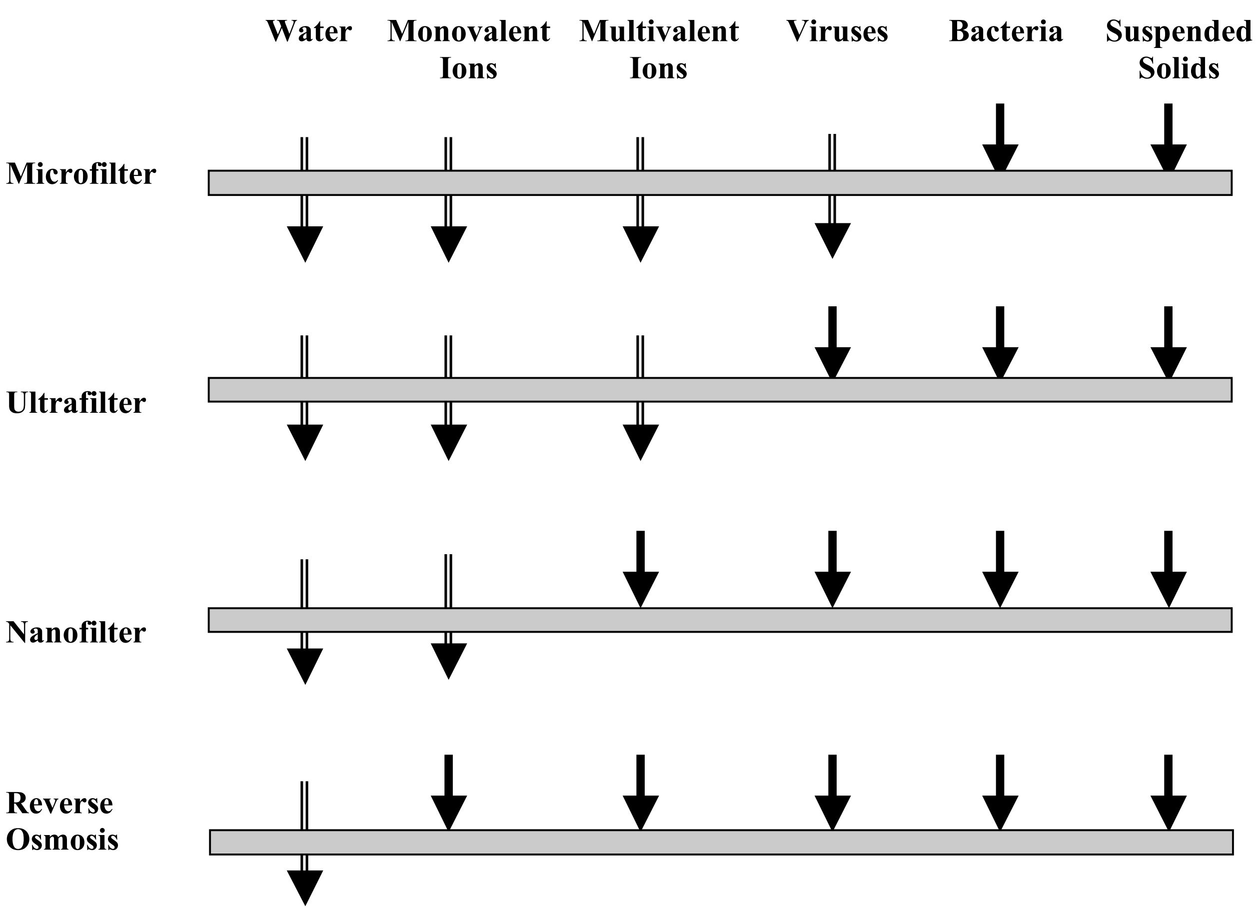
The goal is to have students actively use the information in the handout to become familiar with the limitations of each filtration method. This exercise will also help students visualize the transport of particles, and not others, through different membranes.

Introduction and Example

If you had a filter that was made of paper, it would not let sand pass through but would allow water and dissolved sodium chloride pass through. To demonstrate this, you would draw the following arrows:



Refer to the Filtration Spectrum handout. Based on what you see in the handout, draw arrows that show which particles will pass through each membrane and which will not.



Comparing Nanofilters to Conventional Filters Lab Activity: Teacher Instructions

This lab activity demonstrates the concept of filtration as a means of separating a variety of substances from water using a variety of filtration techniques (Part I), and then compares ultrafiltration with nanofiltration (Part II). In particular, students will observe and test "river water" to identify the substances mixed and dissolved into the water, and then run the water through a series of filtration systems, ending with nanofiltration. They will perform chemical tests and make visual observations to determine if the substances originally identified in the water remain in solution after using various filtration techniques, and report their results on lab sheets.

If you have already conducted this type of investigation using filtration, you may go directly to Part II, comparing ultrafiltration with nanofiltration. Rather than creating the "river water" and testing it according to the directions specified below, you may simply want to purchase a water-testing kit and collect your own sample of river water (pond water, lake water, etc.).

The company Argonide manufactures and sells a nanofiltration kit that contains everything that you need for the nanofiltration activities in this lab. To purchase, contact:

> Henry Frank, Sales and Marketing Manager
> Argonide Corporation (www.argonide.com)
> 291 Power Court, Sanford, FL 32771-1943
> Email: henry@argonide.com, Tel: 407-322-2500, Fax: 407-322-1144

with this order information:

> Product #: MTK-SRI
> Description: NanoCeram Media Test Kit (complete)
> Price: 1-10 kits: $216.50/kit; 11-49 kits: $201.84/kit; 50+ kits: $187.19/kit.

Overview

You are on a backpacking trip in the mountains with a friend. Each of you has brought 2 liters of water with you and you are running very low. You had planned to stay at least for another day, but realize that if you don't find a source of clean drinking water, you will need to turn back and end your trip early. You brought with you some water testing strips and a nanofilter that fits inside of a syringe, just in case you needed to drink the water from the river. Your job is to use your testing strips to find out what else, besides what you can see (such as leaves) is in the water. Once you find what is in the water, you will have to filter out any of the unwanted substances.

The pores of your nanofilter are so small that they will easily plug with large substances. You want to filter as much as you can using the gravel and the sand by the river in a funnel. You have also brought activated charcoal with you.

Can you make the river water clean enough to drink, or do you have to turn around and go home?

Materials for Each Station: Filtration (Part I)

- ½ cup sand
- ½ cup gravel
- About 50 mL of activated charcoal
- 1 25 mm NanoCeram® nanofilter disc
- 1 Luer-Loc filter housing (to hold the nanofilter)
- 2 250 mL beakers
- 1 funnel
- Paper towels
- Syringe
- Test strips for nitrate and nitrite ions
- Test strips for chloride ions
- Test strips for copper
- Test strips or drops for iron(II) and iron(III) ions
- ½ liter of "river water" in a bottle

Materials to Make 1.0 Liter of "River Water" for Two Lab Stations

- 2 half-liter bottles
- 1 liter of distilled water
- ½ teaspoon salt
- A few crushed leaves
- 3 pinches of dirt
- 2 pinches of sand
- 2 teaspoons table salt
- 2.5 mL *No More Algae* liquid by Jungle, 0.05% (by volume) copper sulfate pentahydrate (source of copper liquid)
- 1 crushed tablet of Fe (27 mg) purchased at a drug or grocery store

Materials for Each Station: Comparing Ultrafiltration with Nanofiltration (Part II)

- 1 25 mm NanoCeram® nanofilter disc
- 1 25 mm Millipore VS ultrafilter disc
- 1 Luer-Loc filter housing (to hold the nanofilter and the ultrafilter)
- Syringe
- Bottle of water containing dissolved dye
- (2) small effluent collectors

- Paper towels

Procedures: Filtration (Part I)

Mix together all of the river water ingredients and pour into two half-liter bottles.

Distribute river water and materials to each lab station, and post the student instructions at each lab station for students to follow.

Each student should have their own lab sheet for recording their data and answering questions.

Setup

1. Put the charcoal in water to soak for at least 10 minutes, and proceed with the next step. After 10 minutes, take the charcoal out and rinse it thoroughly to prevent coloring the water.
2. Arrange the ring on the ring stand and put the empty funnel inside of the ring, as shown in Figure 1. Put the 250 ml beaker underneath the funnel so it will catch the effluent.
3. Look at the river water in the bottle. Record your observations of the river water on your lab sheet. Be sure to notice texture, colors, and anything else that stands out.
4. Follow the instructions in the Ion Testing box below to test the river water for the presence of the ions.

Figure 1. Funnel supported by ring with beaker underneath to catch effluent [1].

Ion Testing

1. Label a paper towel with each of the symbols of the ions you will test:
   Fe^{2+} Fe^{3+} Cl^- NO_3^- NO_2^- Cu^{2+}
2. Dip the appropriate strips in the river water to test for these ions.
3. Put the wet strips on a paper towel under their appropriate symbols so you don't forget which strip represents a test for which ion.
4. Match the color of your strip with the color chart on the side of the relevant test strip bottle. The amount of the ion in your river water sample will be listed underneath the matching color square on the bottle.
5. Record on your lab sheet the color of the strip and the amount of each ion indicated by the test strip.

You will repeat this “ion testing” step after each filtration to find out if the ions are still present in the water.

Table 1 summarizes the consequences of the presence of these ions in drinking water.

Table 1. Ions and Consequences in Drinking Water

Ions	Consequences in Drinking Water
Fe^{2+} and Fe^{3+}	These ions indicate that rust from pipes has gotten into the water. While rust is not dangerous, it makes the water taste bad and leaves mineral deposits in sinks and bathtubs.
NO_3^- and NO_2^-	These ions are an indication that pesticides from agriculture have gotten into the water.
Cl^-	This ion indicates that salt has intruded into the water. People cannot use salty water for drinking. Salty water usually cannot be used for agriculture either, although there are a few exceptions.
Cu^{2+}	Copper is normally found in water from natural sources as well as from corrosion of the copper pipes used for water. Copper is not harmful in quantities less than 1000-μm.

Gravel Filtration

1. Put ½ cup of **gravel** into the funnel.
2. Put a clean 250 mL beaker underneath the funnel.
3. Pour the river water supplied by your teacher over the gravel. Notice if the gravel stopped any of the substances that you saw in the water from going into the beaker below.
4. Record your observations on your lab sheets.

Gravel and Sand Filtration

5. Put ½ cup of **sand** on top of the gravel in the funnel.
6. Put a clean 250 mL beaker under the funnel.
7. Pour the contents of the first beaker, the effluent, into the funnel on top of the sand. Notice if the sand and gravel stop any of the substances in the water from going into the beaker below.
8. Record your observations on your lab sheet.
9. Rinse the empty 250 mL beaker and place it underneath the funnel.

Gravel, Sand, and Activated Charcoal Filtration

10. Put the **activated charcoal** into the funnel on top of the sand and the gravel.
11. Pour the remaining water (the effluent) left from the sand filtration step into the funnel on top of the charcoal. Notice if the charcoal removes anything else.

12. Record your observations on your lab sheet.

Conduct Ion Test

13. Using the test strips, test for the presence of the ions in the filtered water by following the instructions in the Ion Testing box above.
14. Record the results of your ion tests on your lab sheet and answer the questions.

Nanofiltration

15. Get a 25 mm NanoCeram® nanofilter disc and a Luer-Loc ceramic filter housing.
16. Open the filter housing and carefully place the disc into the filter housing, place the O-ring on top of the disc, and close securely, making sure the disc is centered in the housing to prevent leakage around the edges of the disc.
17. Rinse the empty 250 mL beaker and place it underneath the filter.
18. Fill the syringe with the effluent collected after filtering with the charcoal, sand, and gravel.
19. Screw the filter housing onto the syringe, taking care not to depress the plunger of the syringe during this operation.
20. Push the effluent through the nanofilter using even, steady pressure.
21. Record your observations of the solution after it has gone through the nanofilter on your lab sheet.

Conduct Ion Test

22. Using the test strips, test for the presence of the ions in the filtered water by following the instructions in the Ion Testing box above.
23. Record the results of your ion tests on your lab sheet and answer the questions.

Procedures: Comparing Ultrafiltration with Nanofiltration (Part II)

You have just used a new nanofilter (the NanoCeram filter) that has recently come to market. An older ultrafilter, called the Millipore VS filter is also available. The NanoCeram® filter is a multilevel woven membrane with various nanoparticles embedded into the layers of membranes. The Millipore VS membrane is a nonwoven, matte-like paper.

The purpose of this part of the lab activity is to compare the nanofilter with the ultrafilter based upon the following two criteria:

- Completeness of filtration
- The relative amount of pressure needed to push the water through each filter

The completeness of filtration will be measured by filtering dissolved dye through each of the filters and looking at the color of the filter and the effluent. The relative pressure needed for filtration will be measured by how hard you have to push the syringe to get the water to pass through the filters.

Compare Millipore VS and NanoCeram® Filtration

1. Open the bottle containing the dissolved dye and draw 2-3 mL into the syringe.
2. Open the Luer-Loc filter housing and carefully place a single 25mm disc of **Millipore VS** membrane material into it. Place the O-ring on top of the disc and close securely, making sure the disc is centered in the housing to prevent leakage around the edges of the disc.
3. Screw the filter housing onto the syringe, taking care not to depress the plunger of the syringe during this operation.
4. Depress plunger of the syringe while holding the syringe over an effluent collector to capture the fluid as it exits the syringe through the filter housing.
5. Apply enough pressure to ensure that the dissolved dye is passing through the filter media. *Typical results for this stage using the Millipore VS membrane material show only several drops coming out of the syringe due to the extreme amount of pressure required to force the dissolved dye through the filter.*
6. Once this is completed, carefully remove and open the filter housing, and remove the filter membrane.
7. Place the membrane aside, next to the effluent collector containing the effluent from this test.
8. Rinse the syringe and repeat the sequence of steps 1-7 above, but with the **NanoCeram®** filter. Push the dissolved dye through gently and steadily; avoid pushing fast.
9. Compare the color of the effluent from the two filters, the color of the filters, and how easy or hard it was to push the dissolved dye through the filters with the syringe.
10. Record your observations on your lab sheet.
11. Answer the questions on your lab sheet.
12. Clean your lab station.

References

(Accessed January 2008.)

[1] http://icn2.umeche.maine.edu/newnav/newnavigator/images/P7280072.JPG

Cleaning Jarny's Water:
Teacher Instructions & Answer Key

This problem-solving activity is based on a real world story about the water of Jarny, France. A problem scenario is presented in which students use data to compare Jarny water quality (i.e. levels of substances) with Environmental Protection Agency fresh drinking water standards. Students will determine which substances need to be filtered from the water to make it safe to drink. Students are asked to design one or more additional water filters to make the water safe to drink for the people of Jarny.

Students may use The Filtration Spectrum: Student Handout, which shows particle size, particle type, and appropriate filtration system as a resource to guide their work. It is recommended that the students work in heterogeneous ability groups of three or four and that they share with the class the water filtration systems that they have designed.

There's a Problem with Our Water…

In the Eastern part of France, in the city of Jarny (see Figure 1), the local people have a serious problem with their drinking water. Their main source of drinking water comes from the ground water table located near an old iron mine. (See Figure 2 for an explanation of ground water.)

The water has always been pumped out of the mine and filtered before being used for drinking water. When the mine was active, this system worked fine. But since closing, the water has flooded up into the mine, creating a pool of standing water that seeps into the ground water used for drinking.

Figure 1. Jarny, France (green arrow) [1].

Over time, the water sitting in the mine reacted with the debris left in the abandoned mine, leaving much of the water contaminated. A local water-monitoring agency has watched the rising contamination levels and determined that the current water cleaning system is not good enough to make the water safe to drink. Even before the water flooded up into the mine, a few substances were slightly above safety limits, but now their levels are even higher.

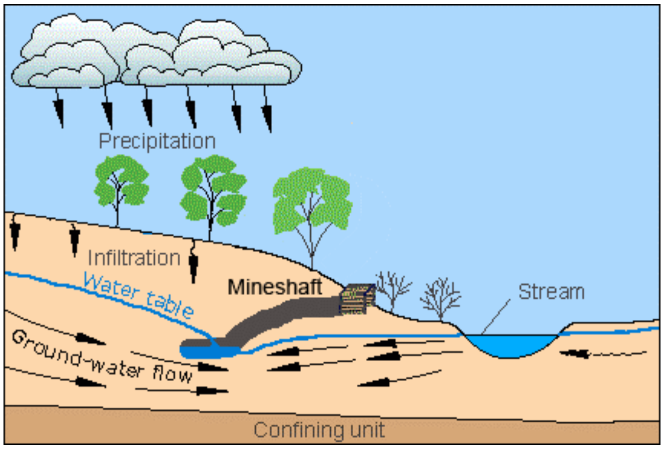


Figure 2. Ground water [2].

Water that comes from rain (precipitation) trickles through the ground (infiltration) until it flows to an area that it can't pass through, such as bedrock. Fresh water accumulates in these places and is referred to as *ground water*. The top of the ground water is the water table. When this underground water is large enough, it is called an aquifer. Aquifers are a commonly used source of fresh drinking water for people all over the world.

Now that you have some background on the water problem facing Jarny, your team's job is to design a system to clean the water to make it drinkable by the local residents. To do this you will need to do the following:

1. Analyze the data in Table 1 to identify what harmful substances are present in the water. This table provides raw water measurements on a set of substances, selected due to their change in concentration before and after the flooding.
2. Complete question 1 in the Student Report. Record the following information for each substance:
    - The name of the substance identified to be filtered out of the water
    - The amount the substance is over the acceptable limit
    - The ranking of substances by size (1 = largest)
    - The least expensive filter needed to filter the substance identified
3. Analyze the data on the current water cleaning system (Table 2), your reading handouts, and relevant charts to help inform your design of a system to clean the water to make it drinkable. Assume that your design will be added on to the system currently in place: a flocculation procedure, a sand filter, and a 1.0 micron microfilter. Remember that the town is poor and your design needs to provide a cost-effective solution. Your design may involve single-step or multiple-step methods.
4. Complete questions 2 and 3 in the Student Report.

Table 1. Water Measurements Before and After Flooding

Substance	Before flooding (mg/L)	After flooding (mg/L)	"Safe" levels (mg/L)	Health hazard or water-taste quality
Ca^{2+}	168	296	160	Contributes to water "hardness"
Mg^{2+}	31	185	15	Contributes to water "hardness"
Na^{+}	50	260	350	Dehydration
CO_3^{2-}	367	500	100	Taste or alkalinity
SO_4^{2-}	192	1794	300	Water taste
Cd^{2+}	.002	.018	.005	Kidney damage
Bacteria (*E. coli*)	0	24	0	Diarrhea, cramps, nausea, or headaches
Asbestos (million fibers/L) from rotting pipes	2	12	7	Increased risk of developing intestinal polyps
Human hair (million hairs/L)	16	48	3	None known, just disgusting

Table 2. Jarny's Current Water Cleaning System

Jarny's current water cleaning system involves treating the water with a flocculent (a material that combines with large-sized particles in the water) and then letting the flocculent (with the large particle combinations) sink to the bottom so it can be removed. The remaining water is filtered through two filters: 1) sand, and then 2) a membrane with 1.0 micrometer diameter holes.

References

[1] http://maps.google.com

[2] Adapted from http://ga.water.usgs.gov/edu/earthgwdecline.html

Student Report

1. Use the water quality information in Table 1 to fill in Table 3 below.

Table 3. Substances Present at Unacceptable Levels

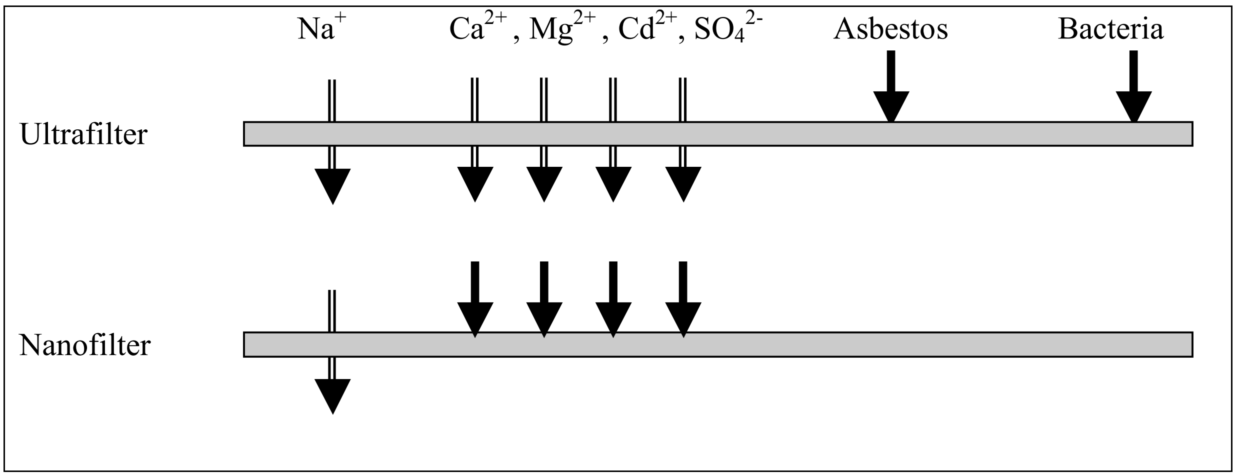
Substance	Amount over acceptable limit	Rank substances by size (1=largest) If there is a range, choose the size at the smallest end of the range Particles of similar size can have the same ranking	Least expensive filter necessary
Ca^{2+}	136 mg/L	4	nanofilter
Mg^{2+}	170 mg/L	4	nanofilter
CO_3^{2-}	400 mg/L	4	nanofilter
SO_4^{2-}	1494 mg/L	4	nanofilter
Cd^{2+}	0.013 mg/L	4	nanofilter
Bacteria (*E coli)*	24	2	microfilter
Asbestos	5	3	ultrafilter
Human hair	45 (between 40-300 microns)	1	particle filter

.

2. The best filter or combination of filters to add to Jarny's water system are the following, in order:

A ultrafilter (filter with a pore size of < 0.1 microns) and then a nanofilter.

3. Draw your design showing the water and its contents before and after passing through each filter in your design.



Reflecting on the Guiding Questions: Teacher Instructions

You may want to have your students keep these in a folder to use at the end of the unit, or collect them after each lesson to see how your students' thinking is progressing.

Think about the activities you just completed. What did you learn that will help you answer the guiding questions? Jot down notes in the spaces below.

1. Why are water's unique properties so important for life as we know it?

What I learned in these activities:

What I still want to know:

2. How do we make water safe to drink?

What I learned in these activities:

What I still want to know:

3. How can nanotechnology help provide unique solutions to the water shortage?

What I learned in these activities:

What I still want to know:

4. Can we solve our global water shortage problems? Why or why not?

What I learned in these activities:

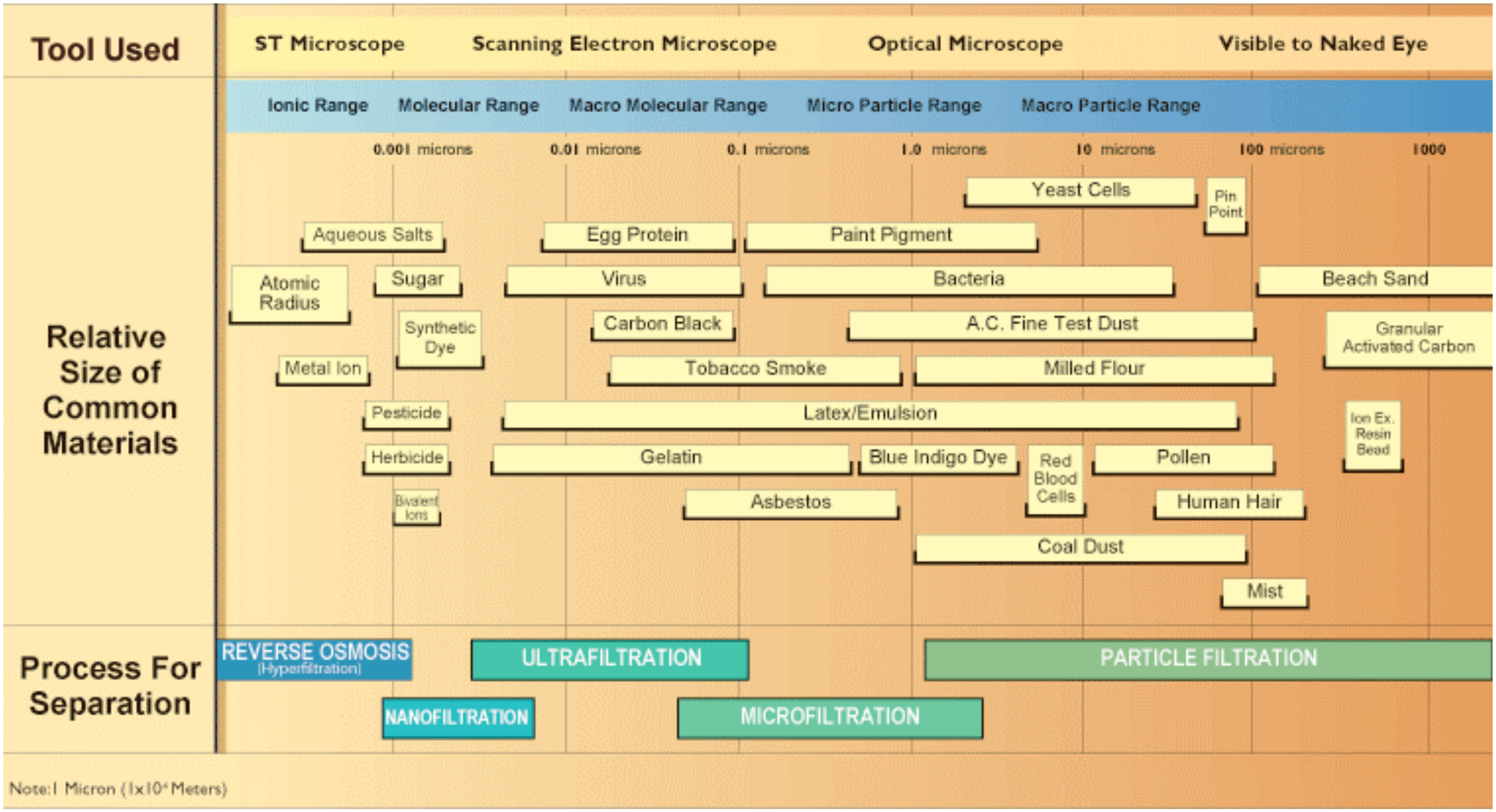
What I still want to know:

Lesson 3: Nanofiltration

Student Materials

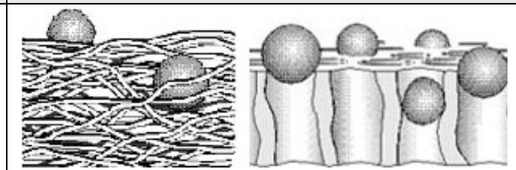
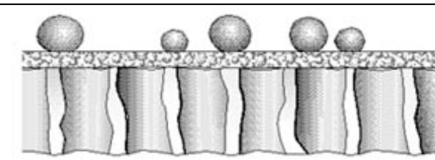
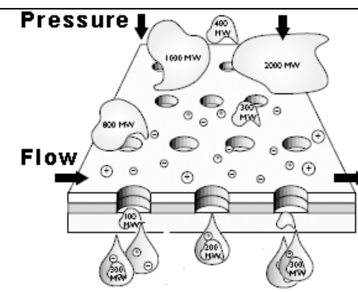
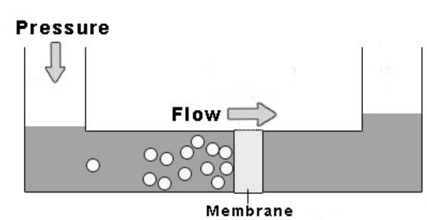
Contents

The Filtration Spectrum: Student Handout



Adapted from Osmonics Filtration Spectrum
Retrieved January 7, 2007, from http://www.sasconsulting.ca/Files/Spectrum.jpg

Types of Filtration Systems and Their Traits: Student Handout

Type of Filtration	Max Particle Size (meters)	Characterization	Example Particles	Disadvantages	Diagram
Microfiltration (MF)	10^{-5} to 10^{-7}	Removal based on relatively large pore size, retains contaminants on surface. Very low water pressure needed. Often used as a pre-filter.	Sand, silt, clays, *Giardia lamblia, Cryptospoidium*, cysts, algae and some bacteria	Removes little or no organic matter. Does not remove viruses.	 Depth Filter Surface Filter [1]
Ultrafiltration (UF)	10^{-7} to 10^{-8}	Removal based on smaller pore size, retains contaminants on surface. Low water pressure needed.	Suspended organic solids Partial removal of bacteria Most viruses removed	Most problems are with fouling. Cannot remove iron or manganese ions (multivalent ions).	 [1]
Nanofiltration (NF)	10^{-8} to 10^{-10}	Removal based on very small pore size and shape and charge characteristics of membrane. Moderate pressure needed.	Suspended solids Bacteria Viruses Some multivalent ions	Currently most are susceptible to high fouling. Cost is relatively high (currently).	 [2]
Reverse Osmosis (RO)	10^{-9} to 10^{-11}	High pressure process that pushes water against the concentration gradient Different membranes have different pore sizes and different characteristics.	Suspended solids Bacteria Viruses Most multivalent ions Monovalent ions	Membranes are prone to fouling. Cost is high.	 [3]

Note: Relative Pressure needed for operation: RO > NF > UF > MF **Relative Cost**: RO > NF > UF > MF [4]

References

(Accessed December 2007.)

[1] http://www.freedrinkingwater.com/water-education/quality-water-filtration-method.htm

[2] Adapted from http://www.homecents.com/images/h2o-imgs/nano_f_1.gif

[3] Adapted from http://www.zenon.com/image/resources/glossary/reverse_osmosis/reverse_osmosis.jpg

[4] http://www.nesc.wvu.edu/ndwc/

Name___________________________________ Date_______________________ Period ______

Which Method is Best? Student Worksheet

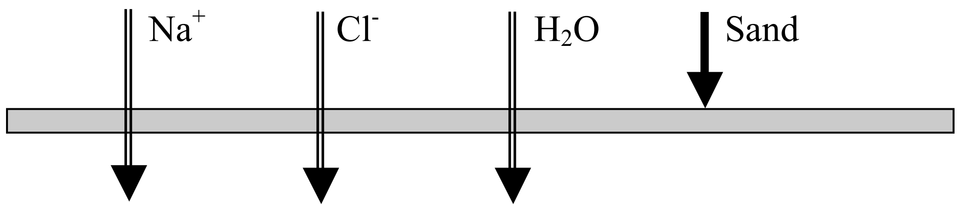
Purpose

Use the Filtration Spectrum: Student Handout to determine which filtration method is best suited to filter a variety of particles.

Introduction and Example

If you had a filter that was made of paper, it would not let sand pass through but would allow water and dissolved sodium chloride pass through. To demonstrate this, you would draw the following arrows:

Filter Paper



Refer to the Filtration Spectrum handout. Based on what you see in the handout, draw arrows that show which particles will pass through each membrane and which will not.

	Water	Monovalent Ions	Multivalent Ions	Viruses	Bacteria	Suspended Solids
Microfilter						
Ultrafilter						
Nanofilter						
Reverse osmosis						

Comparing Nanofilters to Conventional Filters Lab Activity: Student Instructions

Overview

You are on a backpacking trip in the mountains with a friend. Each of you has brought 2 liters of water with you and you are running very low. You had planned to stay at least for another day, but realize that if you don't find a source of clean drinking water, you will need to turn back and end your trip early. You brought with you some water testing strips and a nanofilter that fits inside of a syringe, just in case you needed to drink the water from the river. Your job is to use your testing strips to find out what else, besides what you can see (such as leaves) is in the water. Once you find what is in the water, you will have to filter out any of the unwanted substances.

The pores of your nanofilter are so small that they will easily plug with large substances. You want to filter as much as you can using the gravel and the sand by the river in a funnel. You have also brought activated charcoal with you.

Can you make the river water clean enough to drink, or do you have to turn around and go home?

Materials: Filtration (Part I)

- ½ cup sand
- ½ cup gravel
- About 50 mL of activated charcoal
- 1 25 mm NanoCeram® nanofilter disc
- 1 Luer-Loc ceramic filter housing (to hold the nanofilter)
- 2 250 mL beakers
- 1 funnel
- Paper towels
- Syringe
- Test strips for nitrate and nitrite ions
- Test strips for chloride ions
- Test strips for copper
- Test strips or drops for iron(II) and iron(III) ions
- ½ liter of "river water" in a bottle

Materials: Comparing Ultrafiltration with Nanofiltration (Part II)

- 1 25 mm NanoCeram® nanofilter disc
- 1 25 mm Millipore VS ultrafilter disc
- 1 Luer-Loc ceramic filter housing (to hold the nanofilter and the ultrafilter)

- Syringe
- Bottle of water containing dissolved dye
- (2) small effluent collectors
- Paper towels

Procedures: Filtration (Part I)

Setup

1. Put the charcoal in water to soak for at least 10 minutes, and proceed with the next step. After 10 minutes, take the charcoal out and rinse it thoroughly to prevent coloring the water.
2. Arrange the ring on the ring stand and put the empty funnel inside of the ring, as shown in Figure 1. Put the 250 ml beaker underneath the funnel so it will catch the effluent.
3. Look at the river water in the bottle. Record your observations of the river water on your lab sheet. Be sure to notice texture, colors, and anything else that stands out.
4. Follow the instructions in the Ion Testing box below to test the river water for the presence of the ions.

Figure 1. Funnel supported by ring with beaker underneath to catch effluent [1].

Ion Testing

1. Label a paper towel with each of the symbols of the ions you will test:
   Fe^{2+} Fe^{3+} Cl^{-} NO_3^{-} NO_2^{-} Cu^{2+}
2. Dip the appropriate strips in the river water to test for these ions.
3. Put the wet strips on a paper towel under their appropriate symbols so you don't forget which strip represents a test for which ion.
4. Match the color of your strip with the color chart on the side of the relevant test strip bottle. The amount of the ion in your river water sample will be listed underneath the matching color square on the bottle.
5. Record on your lab sheet the color of the strip and the amount of each ion indicated by the test strip.

You will repeat this "ion testing" step after each filtration to find out if the ions are still present in the water.

Table 1 summarizes the consequences of the presence of these ions in drinking water.

Table 1. Ions and Consequences in Drinking Water

Ions	Consequences in Drinking Water
Fe^{2+} and Fe^{3+}	These ions indicate that rust from pipes has gotten into the water. While rust is not dangerous, it makes the water taste bad and leaves mineral deposits in sinks and bathtubs.
NO_3^- and NO_2^-	These ions are an indication that pesticides from agriculture have gotten into the water.
Cl^-	This ion indicates that salt has intruded into the water. People cannot use salty water for drinking. Salty water usually cannot be used for agriculture either, although there are a few exceptions.
Cu^{2+}	Copper is normally found in water from natural sources as well as from corrosion of the copper pipes used for water. Copper is not harmful in quantities less than 1000-μm.

Gravel Filtration

1. Put ½ cup of **gravel** into the funnel.
2. Put a clean 250 mL beaker underneath the funnel.
3. Pour the river water supplied by your teacher over the gravel. Notice if the gravel stopped any of the substances that you saw in the water from going into the beaker below.
4. Record your observations on your lab sheets.

Gravel and Sand Filtration

5. Put ½ cup of **sand** on top of the gravel in the funnel.
6. Put a clean 250 mL beaker under the funnel.
7. Pour the contents of the first beaker, the effluent, into the funnel on top of the sand. Notice if the sand and gravel stop any of the substances in the water from going into the beaker below.
8. Record your observations on your lab sheet.
9. Rinse the empty 250 mL beaker and place it underneath the funnel.

Gravel, Sand, and Activated Charcoal Filtration

10. Put the **activated charcoal** into the funnel on top of the sand and the gravel.
11. Pour the remaining water (the effluent) left from the sand filtration step into the funnel on top of the charcoal. Notice if the charcoal removes anything else.
12. Record your observations on your lab sheet.

Conduct Ion Test

13. Using the test strips, test for the presence of the ions in the filtered water by following the instructions in the Ion Testing box above.
14. Record the results of your ion tests on your lab sheet and answer the questions.

Nanofiltration

15. Get a 25 mm NanoCeram® nanofilter disc and a Luer-Loc ceramic filter housing.
16. Open the filter housing and carefully place the disc into the filter housing, place the O-ring on top of the disc, and close securely, making sure the disc is centered in the housing to prevent leakage around the edges of the disc.
17. Rinse the empty 250 mL beaker and place it underneath the filter.
18. Fill the syringe with the effluent collected after filtering with the charcoal, sand, and gravel.
19. Screw the filter housing onto the syringe, taking care not to depress the plunger of the syringe during this operation.
20. Push the effluent through the nanofilter using even, steady pressure.
21. Record your observations of the solution after it has gone through the nanofilter on your lab sheet.

Conduct Ion Test

22. Using the test strips, test for the presence of the ions in the filtered water by following the instructions in the Ion Testing box above.
23. Record the results of your ion tests on your lab sheet and answer the questions.

Procedures: Comparing Ultrafiltration with Nanofiltration (Part II)

You have just used a new nanofilter (the NanoCeram filter) that has recently come to market. An older ultrafilter, called the Millipore VS filter is also available. The NanoCeram® filter is a multilevel woven membrane with various nanoparticles embedded into the layers of membranes. The Millipore VS membrane is a nonwoven, matte-like paper.

The purpose of this part of the lab activity is to compare the nanofilter with the ultrafilter based upon the following two criteria:

- Completeness of filtration
- The relative amount of pressure needed to push the water through each filter

The completeness of filtration will be measured by filtering dissolved dye through each of the filters and looking at the color of the filter and the effluent. The relative pressure needed for filtration will be measured by how hard you have to push the syringe to get the water to pass through the filters.

Compare Millipore VS and NanoCeram® Filtration

1. Open the bottle containing the dissolved dye and draw 2-3 mL into the syringe.
2. Open the Luer-Loc filter housing and carefully place a single 25mm disc of **Millipore VS** membrane material into it. Place the O-ring on top of the disc and close securely, making sure the disc is centered in the housing to prevent leakage around the edges of the disc.
3. Screw the filter housing onto the syringe, taking care not to depress the plunger of the syringe during this operation.
4. Depress plunger of the syringe while holding the syringe over an effluent collector to capture the fluid as it exits the syringe through the filter housing.
5. Apply enough pressure to ensure that the dissolved dye is passing through the filter media. *Typical results for this stage using the Millipore VS membrane material show only several drops coming out of the syringe due to the extreme amount of pressure required to force the dissolved dye through the filter.*
6. Once this is completed, carefully remove and open the filter housing, and remove the filter membrane.
7. Place the membrane aside, next to the effluent collector containing the effluent from this test.
8. Rinse the syringe and repeat the sequence of steps 1-7 above, but with the **NanoCeram®** filter. Push the dissolved dye through gently and steadily; avoid pushing fast.
9. Compare the color of the effluent from the two filters, the color of the filters, and how easy or hard it was to push the dissolved dye through the filters with the syringe.
10. Record your observations on your lab sheet.
11. Answer the questions on your lab sheet.
12. Clean your lab station.

References

(Accessed January 2008.)

[1] http://icn2.umeche.maine.edu/newnav/newnavigator/images/P7280072.JPG

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Comparing Nanofilters to Conventional Filters Lab Activity: Student Worksheet

Part 1: Filtration

1. DRAW and DESCRIBE the contents and appearance of your river water. After looking carefully, write down everything that you see that is in the river water. Be sure to include any identifiable substances, and any colors.

2. Record the color of the test strip and amount of each ion indicated by the test strip.

Substance Tested	Color	Presence or Absence
Fe^{2+} and Fe^{3}		
NO_3^- and NO_2^-		
Cl^-		
Cu^{2+}		

Gravel Filtration

3. Describe the appearance of the effluent after it was poured through the gravel.

4. Based on your observations, what was removed from the river water after filtering with the gravel?

5. Based on your observations, what remained in the river water after filtering with the gravel?

Gravel and Sand FIltration

6. Describe the appearance of the effluent after it was poured through the gravel and sand.

7. Based on your observations, what was removed from the river water after filtering with the gravel and sand?

8. Based on your observations, what remained in the river water after filtering with the gravel and sand?

Gravel, Sand, and Activated Charcoal Filtration

9. Describe the appearance of the effluent after it was poured through the gravel, sand, and charcoal.

10. Record the color of the test strip and amount of each ion indicated by the test strip.

Substance Tested	**Color**	**Presence or Absence**
Fe^{2+} and Fe^{3}		
NO_3^- and NO_2^-		
Cl^-		
Cu^{2+}		

11. Based on your evidence (observations and strip tests), what was removed from the river water after filtering with the gravel, sand, and charcoal?

12. Based on your evidence (observations and strip tests), what remained in the river water after filtering with the gravel, sand, and charcoal?

Nanofiltration

13. Describe the appearance of the effluent after it was pushed through the NanoCeram® nanofilter.

14. Record the color of the test strip and amount of each ion indicated by the test strip.

Substance Tested	**Color**	**Presence or Absence**
Fe^{2+} and Fe^{3}		
NO_3^- and NO_2^-		
Cl^-		
Cu^{2+}		

15. Based on your evidence (observations and strip tests), what was removed from the river water after filtering through the nanofilter?

16. Based on your evidence (observations and strip tests), what remained in the river water after filtering through the nanofilter?

Part II: Comparing Ultrafiltration with Nanofiltration

After following the lab directions for putting the effluent through the two filters, fill out the following table.

Filter Type	Color of Effluent	Color of Filter	Relative Pressure Required to Push the Solution Through the Filter
Millipore VS ultrafilter			
NanoCeram® nanofilter			

17. Which filter removed the dye the best? How do you know?

18. Which filter required less pressure to push the water through?

19. Based on your results about pressure, which filter would cost less overall?

20. Based on the evidence from your experiments, can you stay and camp another day or do you have to go home to get clean, drinkable water?

21. What do you think might have been the sources of the pollutants in your river water?

Cleaning Jarny's Water:
Student Instructions & Report

There's a Problem with Our Water…

In the Eastern part of France, in the city of Jarny (see Figure 1), the local people have a serious problem with their drinking water. Their main source of drinking water comes from the ground water table located near an old iron mine. (See Figure 2 for an explanation of ground water.)

The water has always been pumped out of the mine and filtered before being used for drinking water. When the mine was active, this system worked fine. But since closing, the water has flooded up into the mine, creating a pool of standing water that seeps into the ground water used for drinking.

Figure 1. Jarny, France (green arrow) [1].

Over time, the water sitting in the mine reacted with the debris left in the abandoned mine, leaving much of the water contaminated. A local water-monitoring agency has watched the rising contamination levels and determined that the current water cleaning system is not good enough to make the water safe to drink. Even before the water flooded up into the mine, a few substances were slightly above safety limits, but now their levels are even higher.

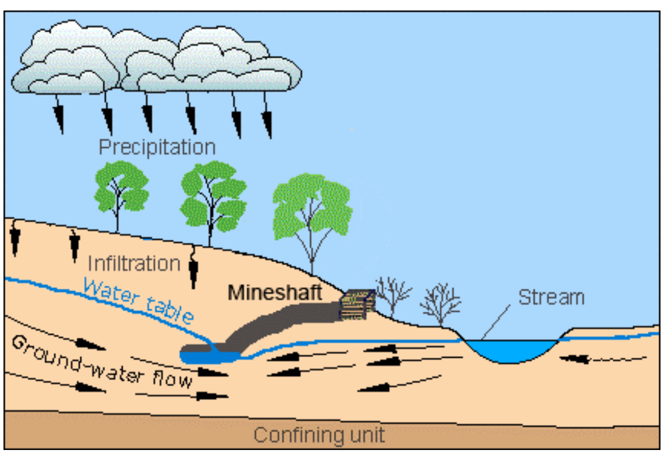

Figure 2. Ground water [2].

Water that comes from rain (precipitation) trickles through the ground (infiltration) until it flows to an area that it can't pass through, such as bedrock. Fresh water accumulates in these places and is referred to as *ground water*. The top of the ground water is the water table. When this underground water is large enough, it is called an aquifer. Aquifers are a commonly used source of fresh drinking water for people all over the world.

Now that you have some background on the water problem facing Jarny, your team's job is to design a system to clean the water to make it drinkable by the local residents. To do this you will need to do the following:

1. Analyze the data in Table 1 to identify what harmful substances are present in the water. This table provides raw water measurements on a set of substances, selected due to their change in concentration before and after the flooding.
2. Complete question 1 in the Student Report. Record the following information for each substance:
   - The name of the substance identified to be filtered out of the water
   - The amount the substance is over the acceptable limit
   - The ranking of substances by size (1 = largest)
   - The least expensive filter needed to filter the substance identified
3. Analyze the data on the current water cleaning system (Table 2), your reading handouts, and relevant charts to help inform your design of a system to clean the water to make it drinkable. Assume that your design will be added on to the system currently in place: a flocculation procedure, a sand filter, and a 1.0 micron microfilter. Remember that the town is poor and your design needs to provide a cost-effective solution. Your design may involve single-step or multiple-step methods.
4. Complete questions 2 and 3 in the Student Report.

Table 1. Water Measurements Before and After Flooding

Substance	Before flooding (mg/L)	After flooding (mg/L)	"Safe" levels (mg/L)	Health hazard or water-taste quality
Ca^{2+}	168	296	160	Contributes to water "hardness"
Mg^{2+}	31	185	15	Contributes to water "hardness"
Na^{+}	50	260	350	Dehydration
CO_3^{2-}	367	500	100	Taste or alkalinity
SO_4^{2-}	192	1794	300	Water taste
Cd^{2+}	.002	.018	.005	Kidney damage
Bacteria (*E. coli*)	0	24	0	Diarrhea, cramps, nausea, or headaches
Asbestos (million fibers/L) from rotting pipes	2	12	7	Increased risk of developing intestinal polyps
Human hair (million hairs/L)	16	48	3	None known, just disgusting

Table 2. Jarny's Current Water Cleaning System

Jarny's current water cleaning system involves treating the water with a flocculent (a material that combines with large-sized particles in the water) and then letting the flocculent (with the large particle combinations) sink to the bottom so it can be removed. The remaining water is filtered through two filters: 1) sand, and then 2) a membrane with 1.0 micrometer diameter holes.

References

[1] http://maps.google.com

[2] Adapted from http://ga.water.usgs.gov/edu/earthgwdecline.html

Student Report

1. Use the water quality information in Table 1 to fill in Table 3 below.

Table 3. Substances Present at Unacceptable Levels

Substance	Amount over acceptable limit	Rank substances by size (1=largest) If there is a range, choose the size at the smallest end of the range Particles of similar size can have the same ranking	Least expensive filter necessary
Ca^{2+}			
Mg^{2+}			
CO_3^{2-}			
SO_4^{2-}			
Cd^{2+}			
Bacteria (*E coli)*			
Asbestos			
Human hair			

.

2. The best filter or combination of filters to add to Jarny's water system are the following, in order:

3. Draw your design showing the water and its contents before and after passing through each filter in your design.

New Nanomembranes: Student Reading

The Desalination Problem

In the early1960's, the United States government challenged the scientific community to discover an inexpensive yet effective method for removing salt from water (**desalination**) on a large scale. Desalination offered the potential to make water from the oceans drinkable, but at the time, desalination methods tended to be expensive and inefficient.

Accepting this challenge, Samuel Yuster and two of his graduate students at the University of California, Los Angeles created a porous material that simulated the movement of water through a living cell's membrane. This material, a type of cellulose **polymer**, was called a **reverse osmosis** (RO) membrane.

Within a living cell, water travels across the cell membrane from an area of higher concentration of **solute** to an area of lower concentration. This natural process, called **osmosis**, continues until the concentration of solute on the inside and outside of the cell are equal. In *reverse* osmosis, water is transported through an artificial membrane from an area of lower concentration to one of higher concentration—the opposite of osmosis. The water goes against the "concentration gradient."

Because this does not happen naturally, pressure (e.g. from a pump) is required to push the water through the membrane. By pushing water through this membrane, which salt and other ions can't pass through, the water is filtered, leaving it pure and safe to drink. Reverse osmosis is the most expensive type of water filtration due to the constant energy required to pump water through the membrane at high pressure. Thus, even though we have a technique to make ocean water drinkable, the cost still prevents wide scale use.

Desalination technology has not changed much over the last fifty years…until now. Currently, there is a considerable amount of active research going into the creation of a variety of nanotechnology membranes, all with the goal of finding an inexpensive, but highly efficient method of removing salt from water.

Meet Eric Hoek

Eric Hoek, a researcher at the University of California, Los Angeles, has been making the news lately. Dr. Hoek is an assistant professor of civil and environmental engineering and is working with a company to patent a nanofiltration membrane that shows promise as an efficient and cost-effective way to remove salt from water.

Dr. Hoek is working to create membranes with pore sizes of one nanometer. Because of the small pore size, the membrane blocks substances that are only a few nanometers in size.

Figure 1. Dr. Eric Hoek, Assistant Professor at the University of California in Los Angeles (UCLA) [1].

However, the membrane not only filters based on *size* but also based on *charge*. In other words, the membrane can stop particles of a particular size and of a particular electrostatic charge while allowing water through. He explains that one-nanometer pores are an optimal size because an electric field is generated that covers the entire pore. This electric field is adjustable in strength so that it can be “tuned” to reject charged items in solutes.

In addition, Dr. Hoek has figured out how to embed noxious substances in his nanomembranes—substances that will kill bacteria on contact! Dr. Hoek explains that at the nanoscale level, you can build substances into the membrane to give it certain properties. For example, by implanting into the membrane substances that are toxic to bacteria, you can effectively kill bacteria in water.

Dr. Hoek’s nanomembranes provide all of these new filtration benefits, but equally importantly, they filter water at much less pressure and cost than traditional reverse osmosis techniques. How does this happen? Dr. Hoek explains that channels can be built into the membranes that are surprisingly hydrophilic (attractive to water molecules). The hydrophilic channels *attract* water to pass it through the membrane, thus reducing the pressure needed to *push* the water through it.

Dr. Hoek plans to continue working on the development of smaller, “adaptive” membranes that can be adjusted through the combination of pressure-driven and electric/charge driven filtration. In other words, the membrane will allow you to have much greater control over the types of particles that can be filtered out. He also envisions creating membranes that are self-cleaning, which would reduce both maintenance and operating expenses. As Dr. Hoek tells his students, “Work on important problems, and your work will be appreciated. You'll do incremental work along the way to the goal, but you need the important problem to steer your work.”

Fred Tepper and His Company Argonide

Fred Tepper, founder of the company Argonide, invented a new type of water filtering membrane with pores containing nano-sized ceramic fibers. What is the advantage of this type of filter?

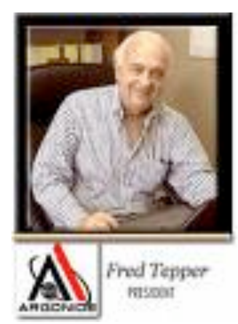

Figure 2. Fred Tepper, founder of Argonide [2]

Because the filter has such a large quantity of **nanofibers**, it contains a tremendous surface area. The larger the surface area in a filter, the greater amount of “dirt” the filter can trap and remove from the water. This type of filter can hold many times more dirt than an **ultrafiltration** (UF) membrane can. And it is highly efficient in capturing very small particles in a water stream. Ultrafilters are often used as **prefilters** for reverse osmosis (RO) membrane systems, taking out particles that can clog, or **foul,** RO membranes.

How Does Argonide’s Nanofiltration Membrane Work?

The **nanoceramic** filter is composed of several different filter materials. In effect, each filter contains multiple layers of pores, which makes it very efficient at trapping a wide variety of particle sizes through a nanoscale adhesion process (**nanoadhesion**). The filter is completely lined with an **alumina**-based material which, when reduced to nano-sized fibers, gives the fiber surfaces a very strong positive charge. Negatively-charged particles, like salts or ions that need to be removed from water, are attracted to the positively-charged fiber surfaces and are effectively removed from the water.

Nanoceramic filters can sustain high water-flow rates, and are very good at capturing small particles. In traditional filtration, to capture smaller particles, you need smaller pores in the filter. However, with the **electroadhesive** properties of nanoceramic filters, particles are attracted to and captured by the positive charges on the filter surfaces. For standard filters to approach the efficiency of nanoceramic filters, they must typically use a smaller pore size. This smaller pore size leads to increased clogging (fouling) of the pores and a lower flow rate of water compared to the nanoceramic filters.

Nanoceramic filters act as prefilters to reverse osmosis membranes since they are able to filter out particles that would typically harm or foul RO membranes. This allows the RO membrane to do what it does best: remove salt ions from water. The RO membrane will last much longer if it doesn't have to trap bigger particles, and it will need fewer maintenance/cleaning cycles, which can extend its lifetime. Thus even though the nanoceramic filter does not perform reverse osmosis, it contributes to a larger technology solution that makes RO less expensive.

References

[1] http://www.cnsi.ucla.edu/institution/personnel?personnel_id=124316

[2] http://www.argonide.com/company.html

Glossary

Term	Definition
alumina	A synthetically produced aluminum oxide (Al_2O_3)
desalination	The process by which salt is removed from salt water (e.g. sea water) to make it drinkable.
electroadhesive	Two substances adhere to each other by the attraction of opposite charges.
electroconductor	A material that conducts electricity.
foul (fouling)	The process in which the substance(s) being filtered out block the pores of a filter, making that filter unable to transport water.
nanoadhesion	A process in which charged particles are (electrostatically) attracted to nanofibers that have been coated with a thin metallic film.
nanoceramic	A ceramic (inorganic, nonmetallic material) that is synthesized from nano-sized powders.

nanofibers	Fibers with diameters less than 100 nanometers.
osmosis	The passage of water through a semi-permeable membrane from a region of low solute concentration to a region of high solute concentration until equilibrium is reached.
polymer	A long molecule that is made up of a chain of many small repeated units.
prefilter	A filter that cleans small particles out of the water, thereby increasing the efficiency of the next, smaller filter.
reverse osmosis	A method of producing pure water by forcing saline or impure water through a semi-permeable (selectively permeable) membrane across which salts or impurities cannot pass.
solute	A substance that is dissolved in another substance (called the solvent) in a homogeneous mixture. For example in salt water the salt ions are the solute and the water is the solvent.
ultrafiltration	Method for removing particles from water via a membrane filter. By applying pressure, water passes through this membrane.

Name___________________________________ Date______________________ Period ______

Reflecting on the Guiding Questions: Student Worksheet

Think about the activities you just completed. What did you learn that will help you answer the guiding questions? Jot down notes in the spaces below.

1. Why are water's unique properties so important for life as we know it?

What I learned in these activities:

What I still want to know:

2. How do we make water safe to drink?

What I learned in these activities:

What I still want to know:

3. How can nanotechnology help provide unique solutions to the water shortage?

What I learned in these activities:

What I still want to know:

4. Can we solve our global water shortage problems? Why or why not?

What I learned in these activities:

What I still want to know: