Aerogels

Center for Nanotechnology Education

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Aerogels

Abstract

Aerogels are the lightest solid substances known to exist. Silica aerogels have the same chemical structure as silica sand or window glass, but they have structural differences that result in many interesting properties. Aerogels have nanoscale pores and a huge internal surface area, giving them extremely low mass density, very good thermal insulation, transparency to light, and high impact resistance. These properties make aerogels attractive for many products, and they are used in thermal insulation, temperature-resistant windows and the space industry.

In this module, students will learn about aerogels and some of the nanoscale phenomena that give aerogels their remarkable properties.

Outcomes

Students will be able to:

- Define what an aerogel is and list its exceptional physical properties
- Identify several uses of aerogels
- Define what "density" and "thermal conductivity" are and explain how they relate to aerogels
- Cross reference the material an aerogel is made from to the color the gel creates
- Explain how the structure of aerogel is related to its physical properties

Prerequisites

A basic knowledge of chemistry.

Science Concepts

- Mass density
- Thermal conductivity
- Brittleness and elasticity
- Supercritical drying

Nanoscience Concepts

- Surface Area
- Nanoscale structures

Background Information

Aerogels may be defined as "…a diverse class of porous, solid materials that exhibit an uncanny array of extreme materials properties" (from *Aerogel.org*). Aerogels have extremely low mass densities, as low as 0.020 grams per cubic centimeter (g cm^{-3}). This means that water is 50 times more dense than an aerogel.. Aerogels are the lowest density solid materials ever produced and have been made as light as 0.0011 g cm^{-3}. To compare this to more familiar common objects, it would take 150 brick-sized pieces of aerogel to weigh as much as a single gallon of water. Aerogels are 95-99% air (or other gas) by volume, with the lowest-density aerogel ever produced being 99.98% air by volume.

Most of us are familiar with regular gels like gelatin dessert. Such gels are formed of a liquid trapped in the pores within a semi-solid framework. In the case of edible gelatin, water is trapped inside a protein framework, making a soft solid. Aerogels on the other hand are dry gel materials: they have the solid structure of a gel, only with a gas or vacuum in its pores instead of liquid. The technical definition of an aerogel is "an open-celled, mesoporous, solid foam that is composed of a network of interconnected nanostructures"(*Aerogel.org*).The term "mesoporous" generally refers to a material that contains pores ranging from 2 to 50 nm in diameter, making aerogels a nanostructured material. It would take about 2,000 of the largest of these pores, stretched along a line, to equal the diameter of a human hair.

The first aerogel was produced by Samuel S. Kistler in 1931 at the College of the Pacific in Stockton, California. Kistler made aerogel starting with *silica gel*, a material often used in powder form to collect moisture. Small packets of silica gel powder are sometimes placed in boxes of new shoes, electronics, and other items that manufacturers wish to protect from excess humidity. Kistler washed the silica gel with water to remove any salts from the gel and then exchanged the water for alcohol using an organic process. He then used a process known as *supercritical fluid drying*, or SCF, to remove the alcohol while maintaining the gel structure. In SCF drying, a liquid or gel is put into to a sealed chamber which is then highly pressurized. At this high pressure, gases become as dense as liquids, and liquids and gases do not exist as separate phases. After the alcohol was allowed to escape the pressure chamber, the remaining material could be dried to form the extremely light material that Kistler named "aerogel."

Definitions:

Density: Mass per unit volume.

Thermal conductivity: A property of a material that determines how easily or poorly heat will move through that material.

Brittleness: Having a tendency to break when subjected to high stress. Brittle materials undergo very little strain before they reach their elastic limit, and tend to break at that limit.

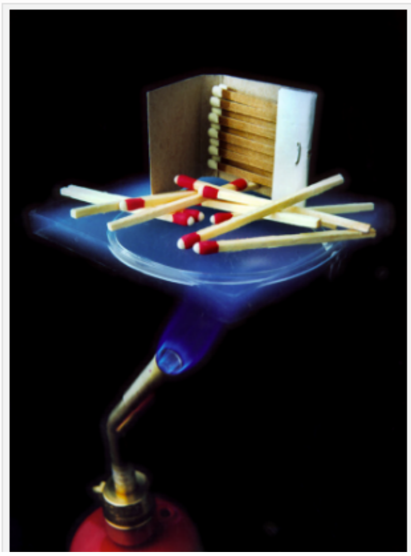


Figure 2. Aerogel is an almost perfect insulator. Here a thin slab of aerogel is able to protect a box of matches from a blowtorch. *Photo: NASA/JPL.*

Elastic: The property of a body or material of returning to its original shape after compression, expansion, stretching, or other deformation

Fiber optics: Technology based on the use of hair-thin, transparent fibers to transmit light or infrared signals.

Index of refraction of a substance is equal to the ratio of the velocity of light in a vacuum to its speed in that substance. Its value determines the extent to which light is refracted (or bent) when entering or leaving the substance.

Critical Point: As the pressure on a gas increases, it becomes more dense; at high enough pressure, the vapor from a substance will get so dense that it will resemble the liquid phase of the substance. The critical point is the temperature and pressure at which there is no difference between a substance's liquid and vapor phases.

Current and Future Applications

Aerogels are found in electronic products such as capacitors; in paints to increase thermal properties and to make safe-to-touch surfaces; in cosmetics as thickening agents; and chemical absorbers for cleaning chemical and oil spills. Since aerogels are also great thermal insulators, they are used to provide insulation in high performance clothing, like firefighting gear and scuba wet suits, in blankets, and in windows. A small piece of aerogel is sufficient heat insulation value to protect matches from a blowtorch, as displayed in the image in Figure 2.

Aerogel is currently being used in scientific research. An aerogel trap was used on the NASA Stardust mission to collect samples from a comet's tail. Another use is in detectors for Cherenkov radiation, which is emitted by very energetic particles passing through dielectric materials.

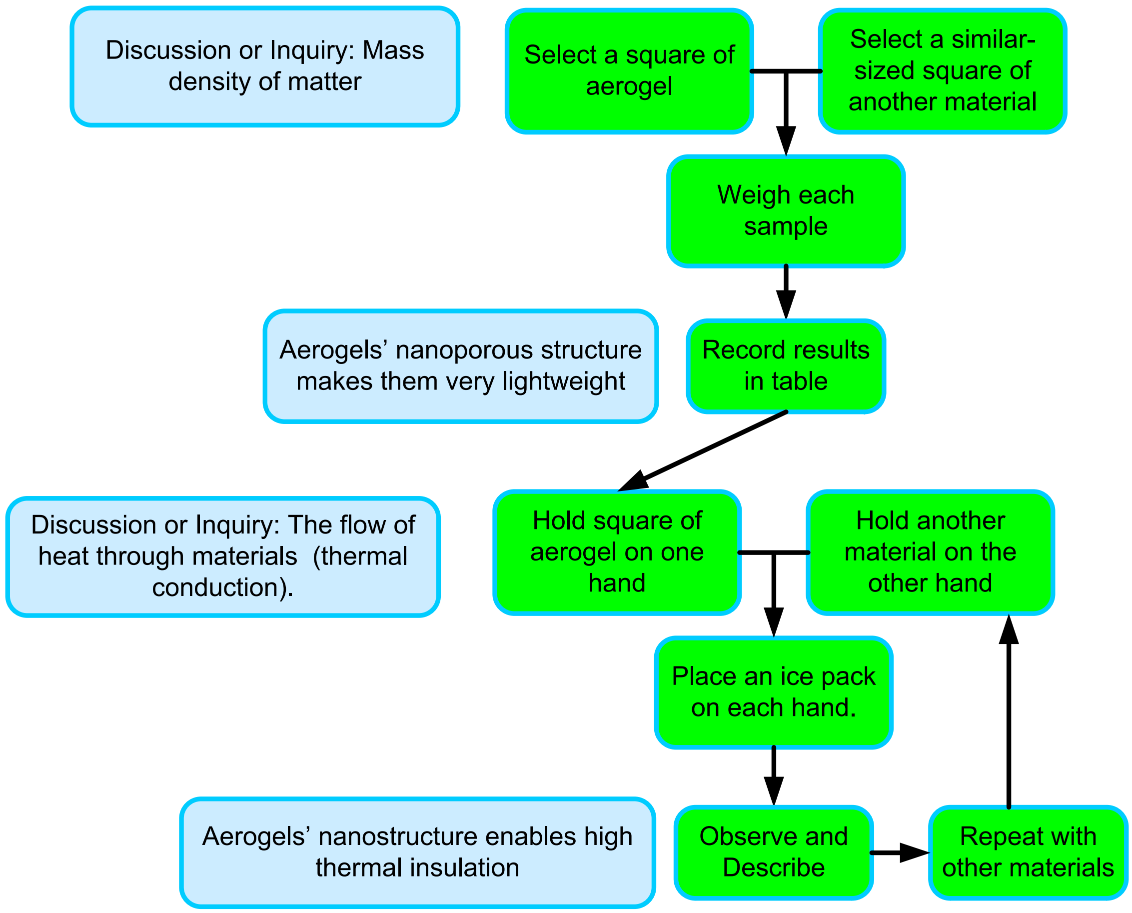
Future Applications

One possible way scientists may use aerogel in the future is in solar energy. Solar collectors need strongly absorbing, nonreflecting materials. Carbon aerogels have a rough surface and multiple areas for internal scattering of photons from sunlight, which meets these requirements and can increase the collection of solar energy.

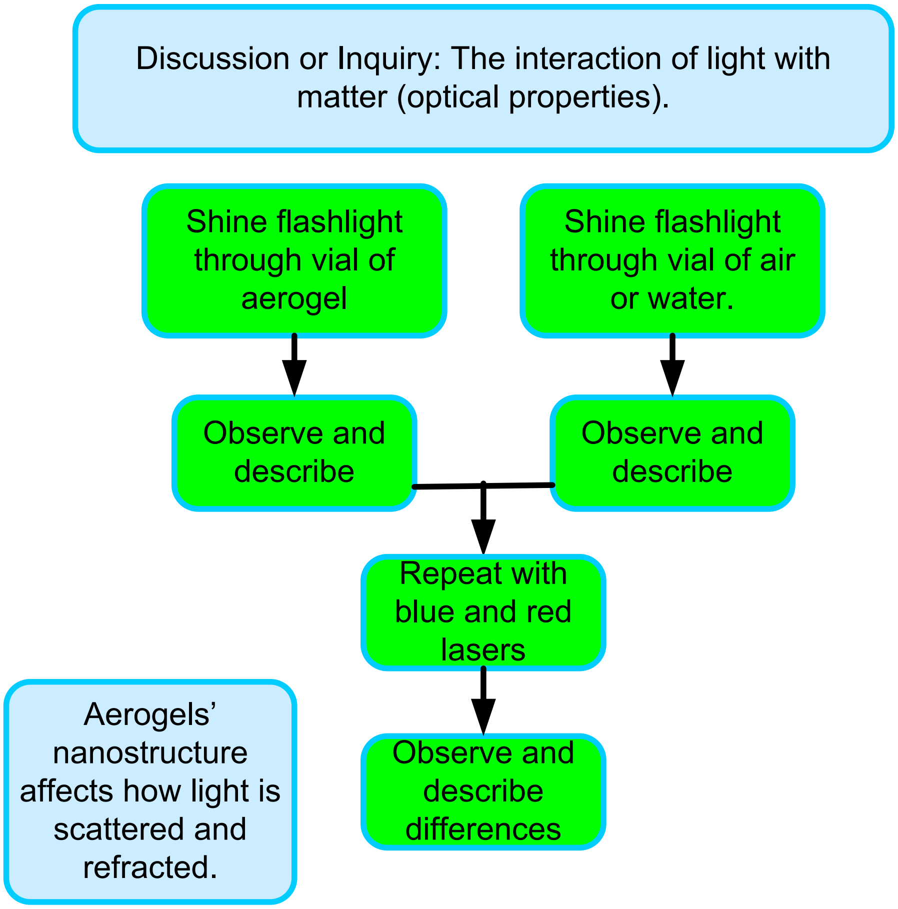
Learning Activity: Aerogels

Activity Flow Charts

Part 1:



Part 2:



Discussion or Inquiry: The interaction of light with matter (optical properties).
Shine flashlight through vial of aerogel
Shine flashlight through vial of air or water.
Observe and describe
Observe and describe
Repeat with blue and red lasers
Aerogels' nanostructure affects how light is scattered and refracted.
Observe and describe differences

Aerogel

Aerogel is a high-performance material which has nanoscale pores. In the following investigation, you will investigate thermal conductivity (ability to conduct heat), density (mass per unit volume), and low index of refraction.

Materials and Equipment

- Pieces of each of the following materials
  - Aerogel insulating blanket https://www.amazon.com/Aerogel-Silica-Block/
  - Felt
  - Cotton
  - Plastic
  - Fleece
  - Wool
  - Aluminum
- Two ice packs
- Vial of aerogel particles https://www.amazon.com/Silica-Aerogel-Frozen-Lightest-Hydrophobic/
- Empty vial
- Vial of water
- Blue laser
- Red laser
- Flashlight
- Lab scale or balance capable of 0.1g resolution

Safety

Aerogel is very drying to the skin and should not be handled without gloves. The aerogel blanket should be kept in a sealed plastic bag and not opened at any time during the experiment. The vials with aerogel should not be opened.

Procedure

Part 1: Density and Thermal Insulation

1. Select a square of aerogel insulating blanket inside a sealed plastic bag.
2. Weigh this piece using a lab scale. Record the weight in the table below.
3. Select a similar sized square of one of the other materials.
4. Weigh this piece using a lab scale. Record the weight in the table below.
5. Place the square of aerogel insulating blanket (left inside the sealed plastic bag) on one hand.
6. Place one of the other materials on the other hand.
7. Place an ice pack on each hand and wait a few minutes.
8. Which hand feels colder? Which material has better insulating properties? Mark results in the table below.
9. Repeat steps 3-8 with other materials.

Data

Record the mass of each material, in grams				Which is the better insulator? Check the box of the better insulator.			
Aerogel blanket		Felt		Aerogel blanket		Felt	
Aerogel blanket		Cotton		Aerogel blanket		Cotton	
Aerogel blanket		Plastic		Aerogel blanket		Plastic	
Aerogel blanket		Fleece		Aerogel blanket		Fleece	
Aerogel blanket		Wool		Aerogel blanket		Wool	
Aerogel blanket		Aluminum		Aerogel blanket		Aluminum	

Discussion questions

1. Describe how the mass of each material differed.
2. Which material(s) seemed to insulate your hand from the cold of the ice pack?
3. Which material(s) seemed to conduct the cold from the ice pack to your hand?
4. Can you think of any uses for an insulating blanket like the aerogel blanket you used in this experiment?

Part 2. Optical properties

1. Shine a flashlight beam through the vial of aerogel particles. Describe the color of the aerogel particles where the white light is shining when viewed from the side.

2. Observe and describe how the light from the flashlight shines through the aerogel particles and emerges from the vial.

3. In a darkened room shine the flashlight through the aerogel-filled vial onto a white background. What color is the light that goes through the aerogel and hits the white background?

4. In the darkened room, shine the blue and red lasers through the vial of aerogel particles. What differences if any do you notice?

5. Look at the spot of laser light that goes through the aerogel and lands on the white background. Which color laser seems to be spread out more and has a less focused beam of light after passing through the aerogel. Red or Blue?

Part 3: Mass density

1. Have a partner close their eyes and hold out their hands. You should place one empty vial in one hand and the vial filled with water in the other. See if they can tell which vial is filled with more than air. Can they tell the difference between the masses of the two vials?

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2. Try the same experiment with the water vial and the vial filled with aerogel. Can they tell the difference between the two?

3. Now compare the air filled vial and the aerogel filled vial. Can they feel the difference between the two?

Discussion Questions

- Describe the composition of aerogel.
- Describe how aerogel is made.
- Aerogel is an extreme material. List at least three properties of aerogel that are extreme.
- Why are aerogels transparent?
- Give examples of applications of aerogels.
- Why can aerogel be considered to involve nanotechnology?
- Which of the materials tested were the best thermal insulators?
- Why does the aerogel look blue?
- List several uses for aerogel.
- How could a brittle material like aerogel be used as a shock-absorbing material?

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Resources

Videos

- QUEST Lab: Aerogel https://www.youtube.com/watch?v=kHnen2nSmDY
- Aerogel Superinsulation Blowtorch Demo: Hershey's Kiss https://www.youtube.com/watch?v=5sw1tNeJ0Rw
- Aerogel Demonstration (Discovery Channel Science) https://www.youtube.com/watch?v=ZsOsWqtrh5M

Articles

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2. DeForrest. "Aerogel Uses: Current and Future." *Untitled*. Western Oregon University, Accessed March 18 2017. www.wou.edu/las/physci/ch350/Projects_2006/DeForrest/Aerogel%20Project/Uses-Current%20and%20Future.html
3. NASA Jet Propulsion Laboratory. *Stardust NASA's Comet Sample Return Mission*. Accessed Mar 19, 2017. **http://stardust.jpl.nasa.gov/photo/aerogel.html**