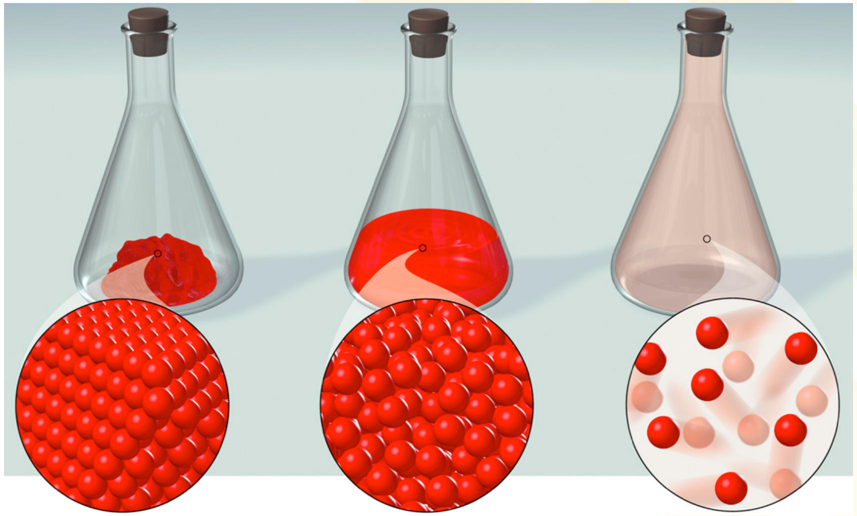
Announcements

- The third midterm exam takes place in White B51 on April 10th, 5 PM - 7 PM.
- The makeup exam takes place in Clark 317 on April 9th, 5 PM - 7 PM.
- The exams covers sections 6.5 (rockets), 7.0 - 7.5 (rotation, gravity), 8.0 - 8.7 (rotational dynamics), 9.0 - 9.7 (states and properties of matter), and 10.0-10.4 (thermodynamics) if we get to it by April 8.
- The formula sheet and an old exam are available on the course webpage.
- Best way to prepare: first, go through all worked examples and clickers from lecture slides, then, if you have time, go through homework and WebAssign "practice tests" (i.e. extra problems). Next, try the old exam without reference materials, and re-review the worked examples from step 1 for any problem areas. Finally (if you still have more time after all that) try additional problems from the text.

Today's lecture

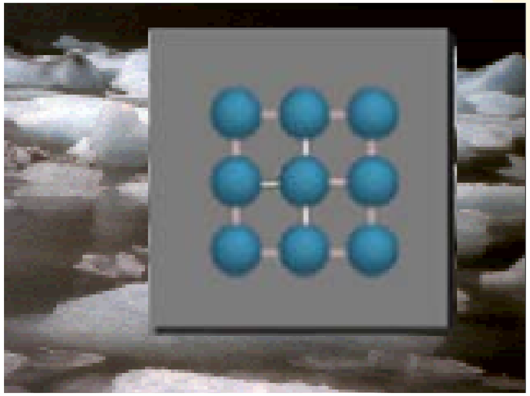
Chapter 9: Solids and Fluids

- States of Matter
- Density and Pressure

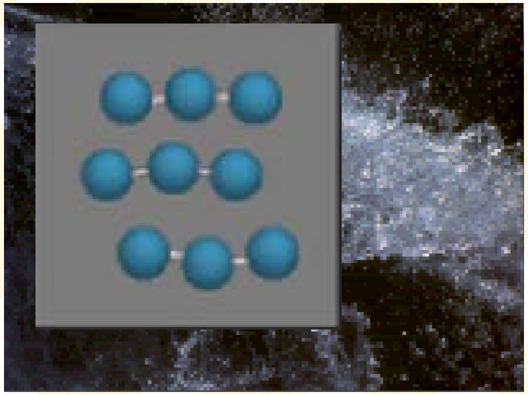


Four Aggregate States of Matter

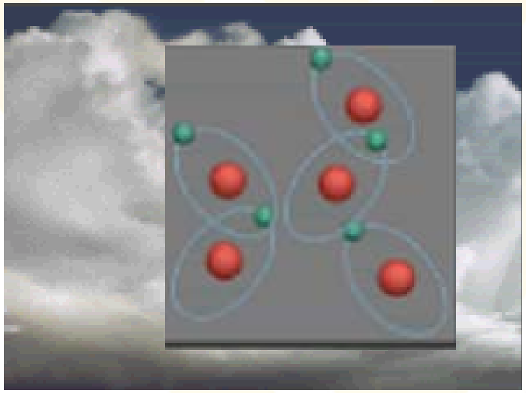
1. Solid:



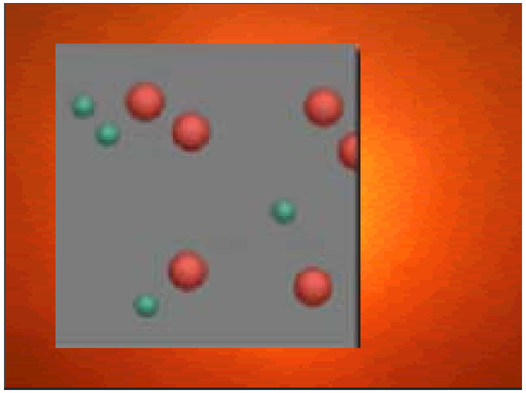
2. Liquid:



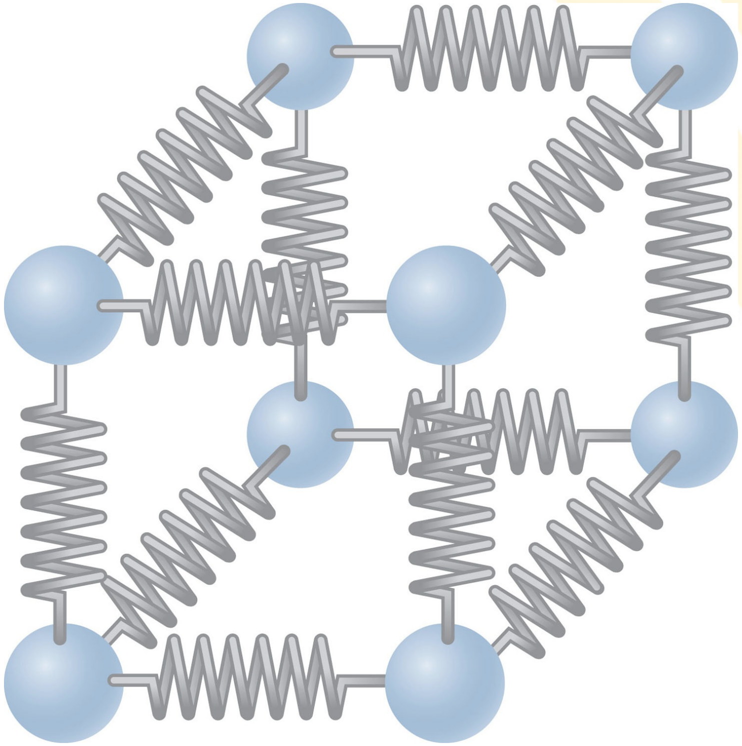
3. Gas:



4. Plasma:

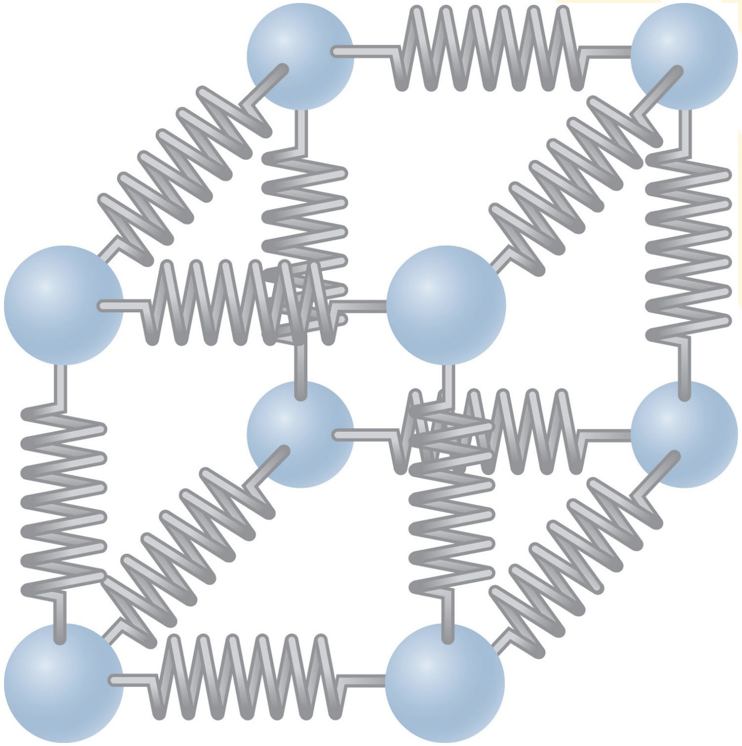


Solids



- Have definite volume.
- Have definite shape.
- Molecules are held in specific locations (by electrical forces).
- Vibrate about equilibrium positions.
- Can be modeled as springs connecting molecules.

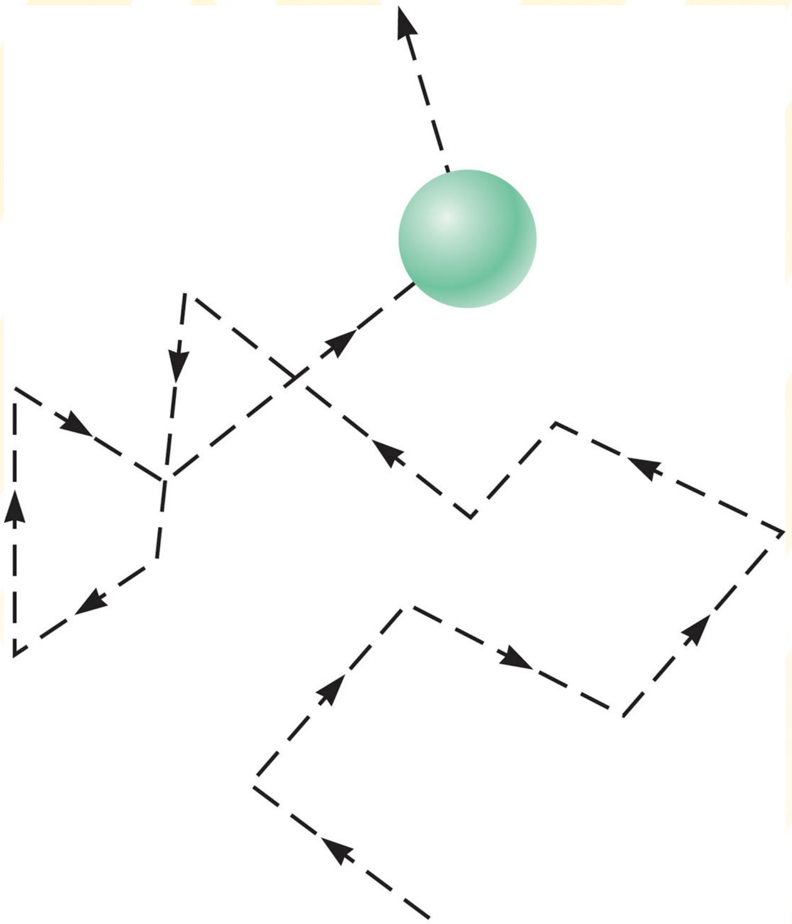
Solids



- External forces can be applied to the solid and compress the material.
  - In the model, the springs would be compressed.
- When the force is removed, the solid returns to its original shape and size.
  - This property is called elasticity.

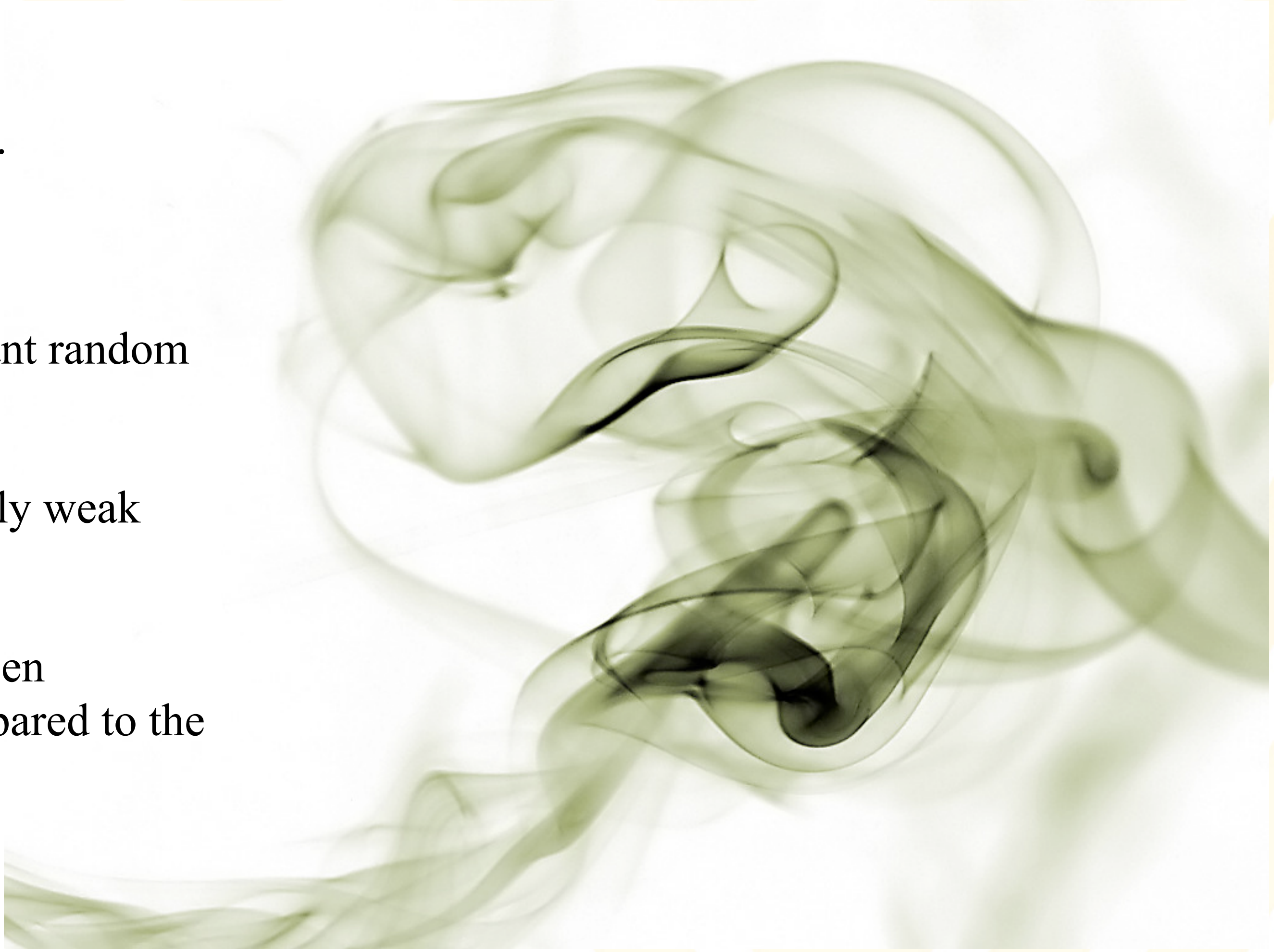
Liquids

- Have a definite volume.
- No definite shape.
- Exist at a higher temperature than solids.
- The molecules "wander" through the liquid in a random fashion.
  - The intermolecular forces are not strong enough to keep the molecules in a fixed position.
- Solids and liquids are both hard to compress, since strong repulsive atomic forces act internally to resist the compression.



Gas

- Has *no* definite volume.
- Has *no* definite shape.
- Molecules are in constant random motion.
- The molecules exert only weak forces on each other.
- Average distance between molecules is large compared to the size of the molecules.



Plasma

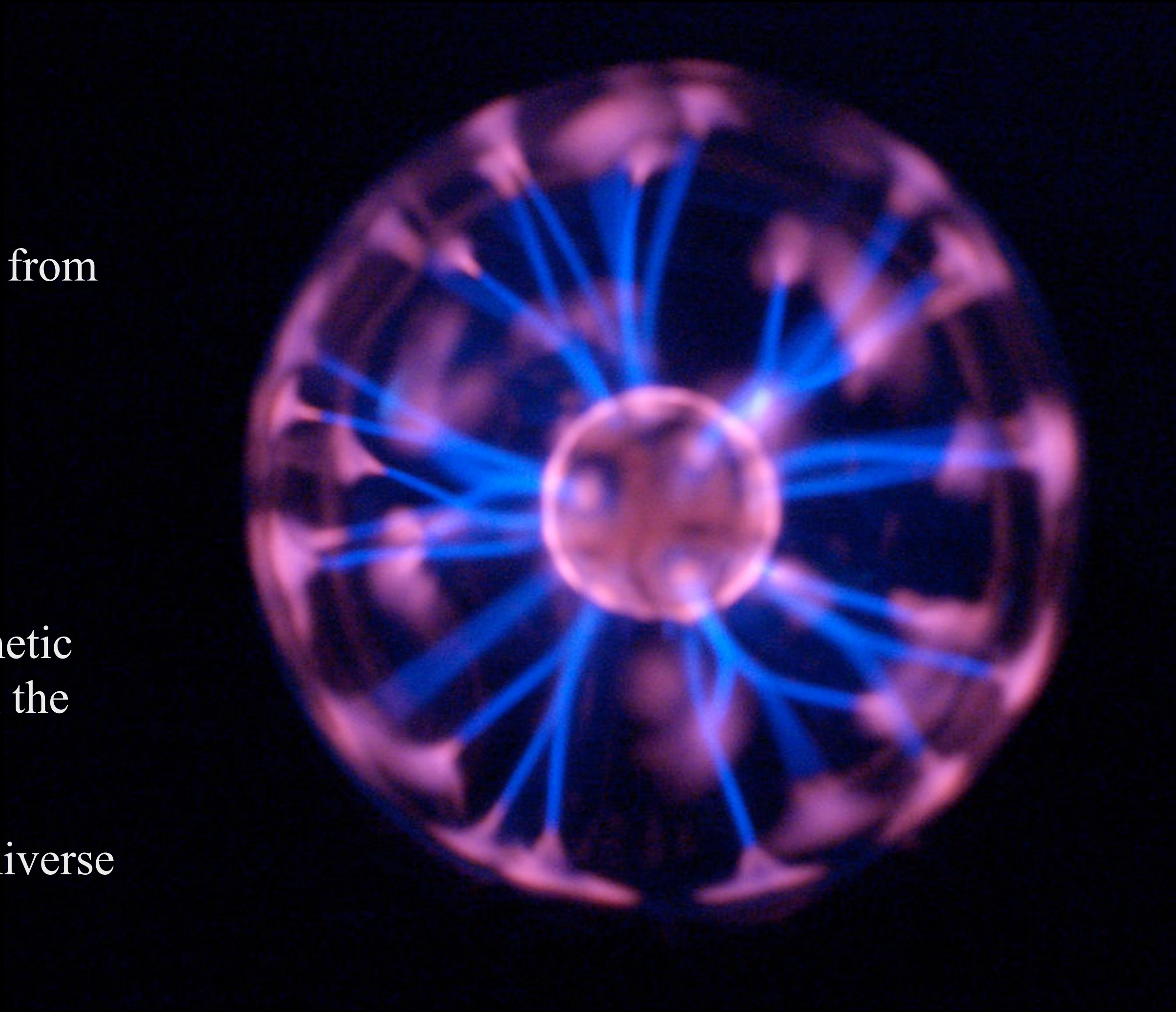
Gas heated to a very high temperature.

Many of the electrons are freed from the nucleus.

Result is a collection of free, electrically charged ions and electrons.

Long-range electrical and magnetic forces allow interactions within the plasma.

95 % of known matter in the universe is in the plasma state.



Density

Equal masses of aluminum and gold have an important physical difference:

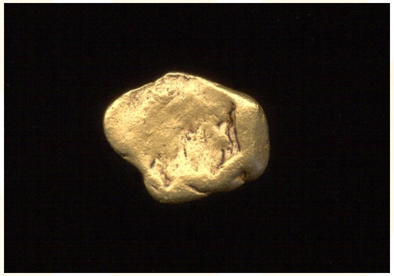
The aluminum takes up over seven times as much space as the gold.

This is caused by the different densities of both materials.

The density of a substance of uniform composition is defined as its mass per unit volume:

$$\rho \equiv \frac{m}{V}$$

Unit: kg m^{-3}



Density and specific gravity

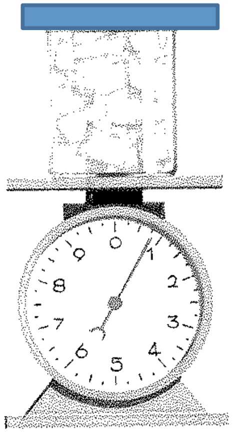
Table 9.1 Densities of Some Common Substances

Substance	ρ (kg/m^3)[a]	Substance	ρ (kg/m^3)[a]
Ice	0.917×10^3	Water	1.00×10^3
Aluminum	2.70×10^3	Glycerin	1.26×10^3
Iron	7.86×10^3	Ethyl alcohol	0.806×10^3
Copper	8.92×10^3	Benzene	0.879×10^3
Silver	10.5×10^3	Mercury	13.6×10^3
Lead	11.3×10^3	Air	1.29
Gold	19.3×10^3	Oxygen	1.43
Platinum	21.4×10^3	Hydrogen	8.99×10^{-2}
Uranium	18.7×10^3	Helium	1.79×10^{-1}

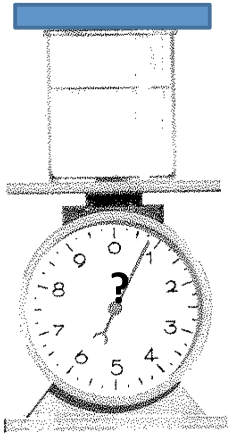
[a]All values are at standard atmospheric temperature and pressure (STP), defined as 0°C (273 K) and 1 atm (1.013×10^5 Pa). To convert to grams per cubic centimeter, multiply by 10^{-3}.

The specific gravity of a substance is the ratio of its density to the density of water at 4° C (=1000 kg/m^3). Specific gravity is a dimensionless quantity.

Clicker questions



lid



If you wait long enough **ice will melt to water**. And if you heat it, **water evaporates to water vapor** (gas).

1.) Will the mass of the different states of water be **different** if the containers are sealed?

2.) Will the mass of the different states of water be different if the containers are **not** sealed?

3.) Will the volume be the same for sealed containers?

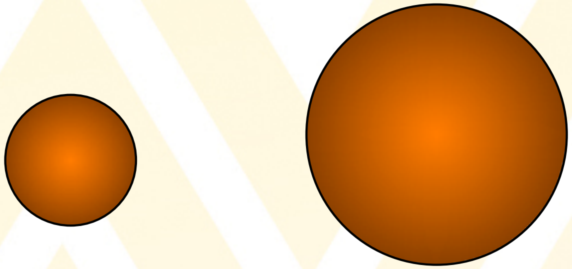
Choices for all 3 questions:

A. No for both
B. Yes for both
C. No for ice, yes for gas
D. Yes for ice, no for gas

Clicker question

The sphere on the right has **twice the mass** and **twice the radius** of the sphere on the left.

Compared to the sphere on the left, the larger sphere on the right has



mass m
radius R

mass $2m$
radius $2R$

A. twice the density.

B. the same density.

C. 1/2 the density.

D. 1/4 the density.

E. 1/8 the density.

$$\rho = \frac{M}{V} = \frac{mass}{volume}$$

$$V_{sphere} = \frac{4}{3}\pi R^3$$

Pressure

- The force exerted by a fluid on a submerged object at any point is *perpendicular to the surface of the object.*

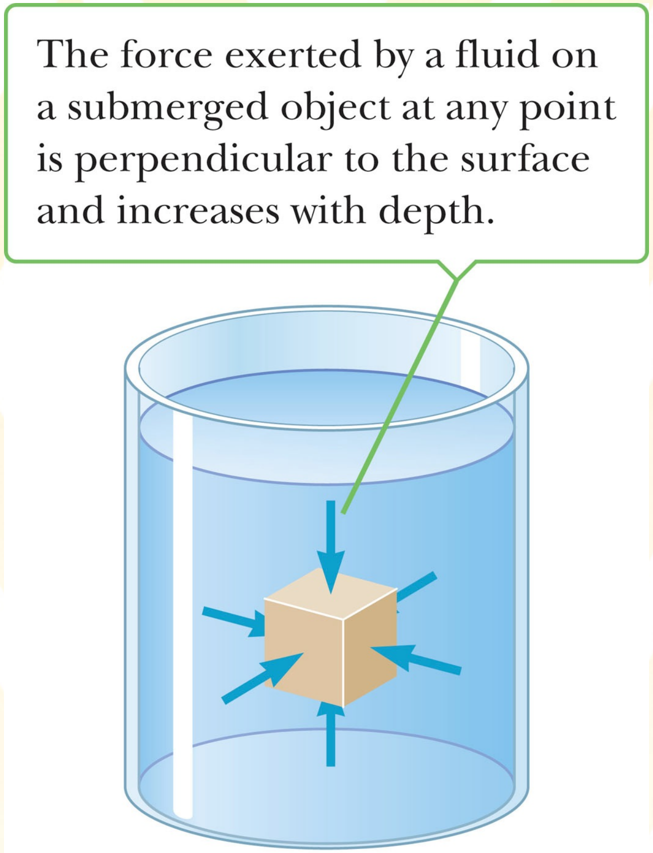
- The average pressure, P, is the force, F, per area, A:

$$P = \frac{F}{A}$$

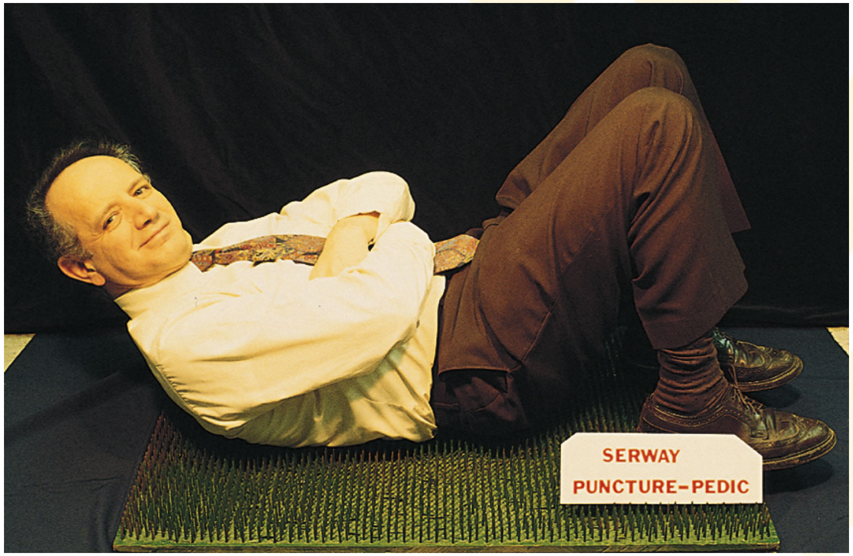
SI-Unit: Pa = N/m^2

English customary unit: pound per square inch.

- Atmospheric pressure: $1.01 \cdot 10^5$ Pa = 1 bar.



Applications



In many situations (walking on snow, lying on needles), you should try to reduce the pressure at a given force. You can do this by increasing the surface area the force acts on.

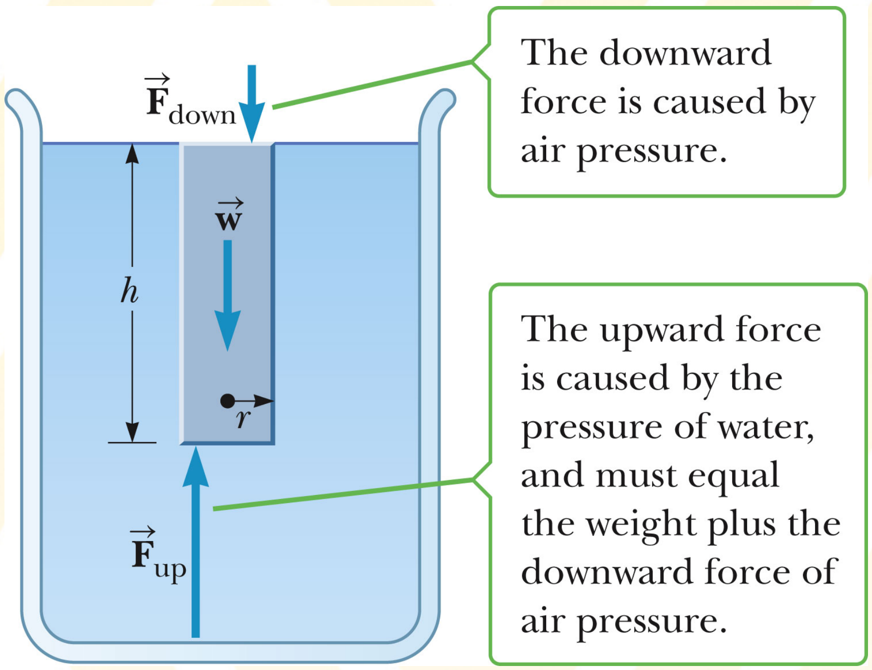
$$P = \frac{F}{A}$$

Example problem: Pressure

(a) Calculate the weight of a cylindrical column of water with height h = 40 m and radius r = 1 m.

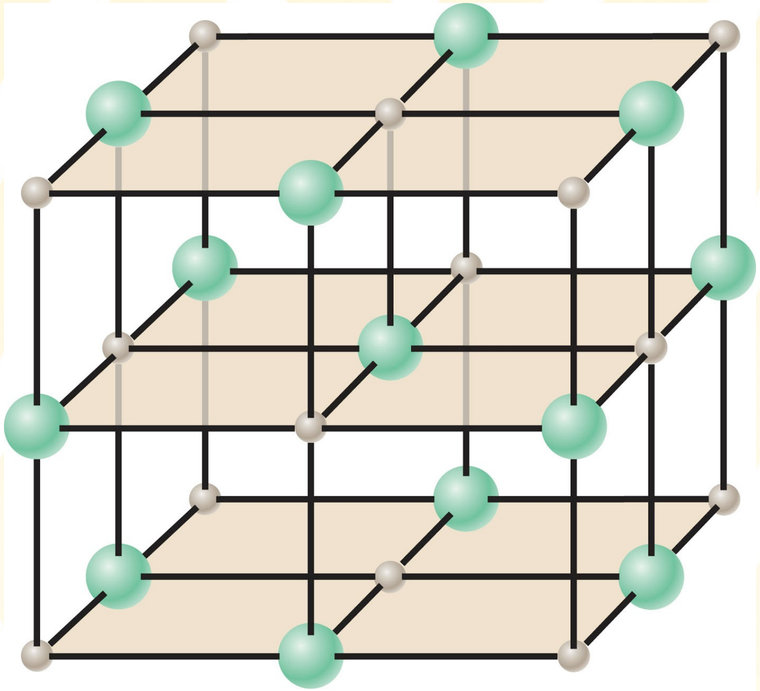
(b) Calculate the force exerted by air on a disk of radius 1 m at the water's surface.

(c) What pressure at a depth of 40 m supports the water column?



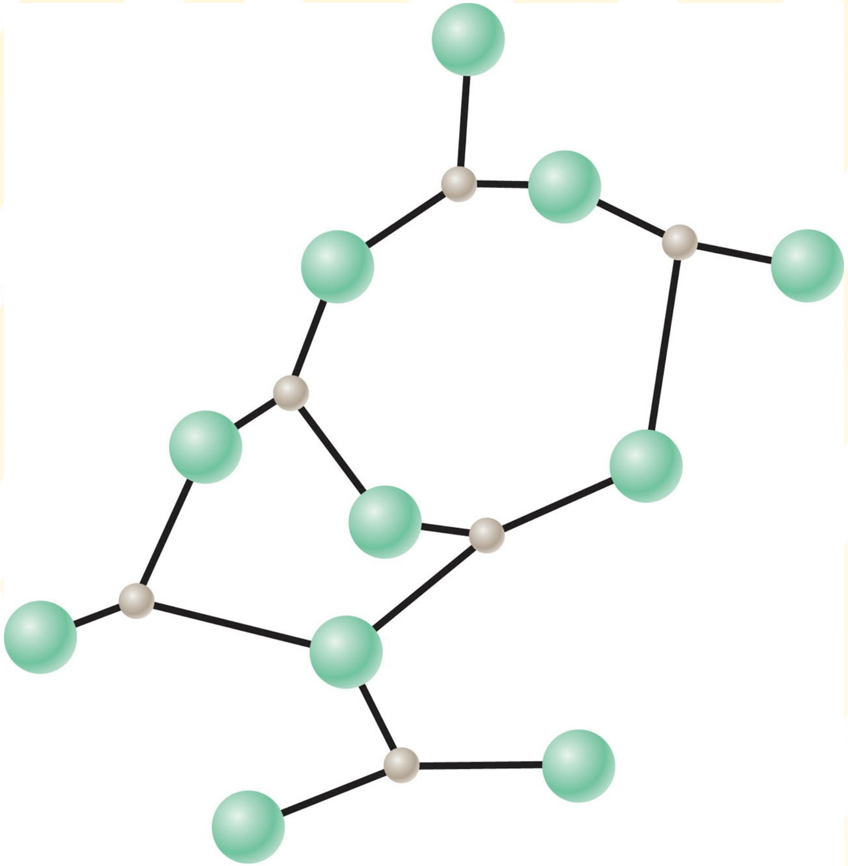
Crystalline Solids

- Atoms have an ordered structure
- This example is salt
  - Gray spheres are Na^+ ions
  - Green spheres are Cl^- ions



Amorphous Solids

- Atoms are arranged almost randomly.
- Examples include glass.



Elasticity, Pressure vs. depth, Pascal's principle

- All objects are deformable. Until a maximum stress (F/A) the object will tend to its original shape, when the force is removed (elasticity).

- There are 3 types of elasticities:

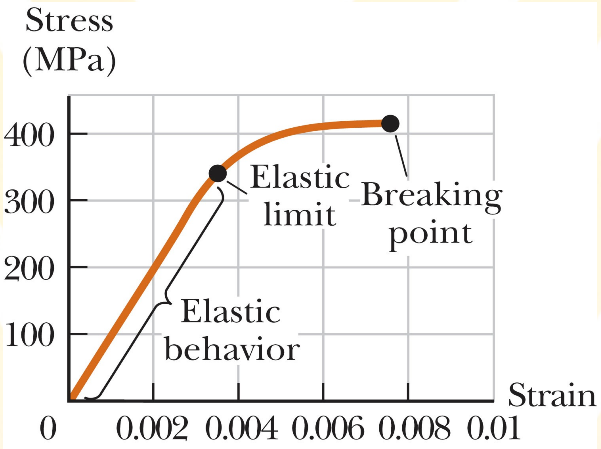
  (i) Elasticity of length: $\frac{F}{A} = Y\frac{\Delta L}{L_0}$

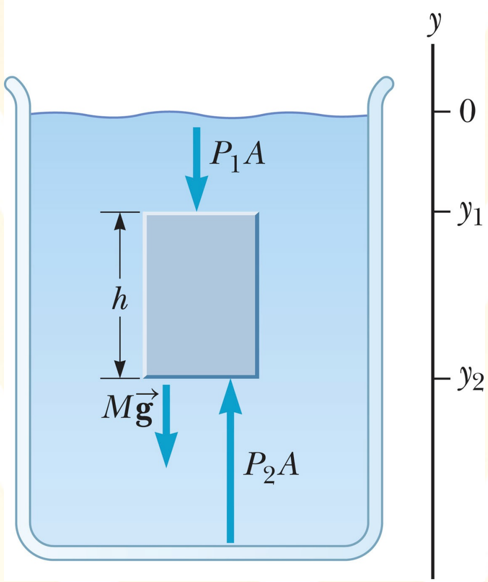
  (ii) Elasticity of shape: $\frac{F}{A} = S\frac{\Delta x}{h}$

  (iii) Elasticity of volume: $\Delta P = -B\frac{\Delta V}{V}$

- Pressure depends on depth: $P = P_0 + \rho g h$

- Pascal's principle: $\frac{F_1}{A_1} = \frac{F_2}{A_2}$ (hydraulic press)

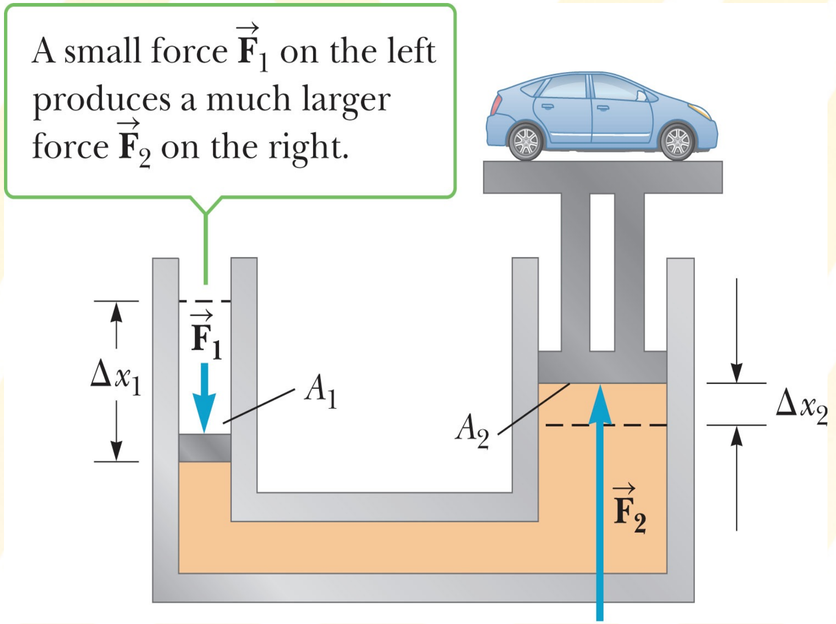




Example problem: Pascal's principle

In a hydraulic press, a force, F_1, is exerted on a small piston of quadratic cross section (side length a = 10 cm). This pressure is transmitted through the fluid to a second larger piston of quadratic cross sectional area (side length b = 30 cm).

What force must be exerted on the smaller piston to lift a 20000 N object via the larger piston?



$$P_1 = P_2 \quad \rightarrow \quad \frac{F_1}{A_1} = \frac{F_2}{A_2}$$