Conceptual Physics
Matter
Solids
Liquids

Lana Sheridan

De Anza College

July 24, 2017

Last time

- atoms
- charge
- subatomic particles
- elements

Overview

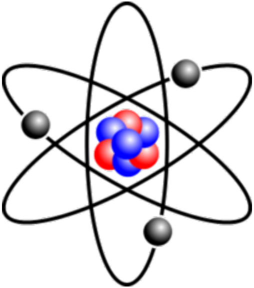
- matter
- atoms
- molecules
- solids
- density
- elasticity
- liquids
- pressure

Atomic Structure

Atoms have a compact nucleus composed of **protons** and **neutrons**.

The nucleus therefore has an overall positive charge.

A cloud of electrons surrounds the nucleus, attracted by the electrostatic force.



[1] Figure from Wikipedia.

Isotopes

Isotopes of an element are different versions of the element's atom.

For two atoms to be of the same element they must have the same number of protons.

But, they can have different number of neutrons.

An example: Carbon-13.

Most carbon atoms have 6 protons and 6 neutrons for an atomic mass of 12.

A few (about 1%) have 7 neutrons for an atomic mass of 13.

Electron cloud structure in atoms

Electrons near nuclei can be in various states with different energies.

Analogy: rooms on different floors in a hotel.

A guest in a floor further from the ground has a greater potential energy.

Electron cloud structure in atoms

Electrons near nuclei can be in various states with different energies.

Analogy: rooms on different floors in a hotel.

A guest in a floor further from the ground has a greater potential energy.

Guests are lazy, so they will take a room in the lowest available floor. However, when low floor rooms are taken, they will climb the stairs to a room on the next floor.

Only one guest can occupy each room, and different floors have different numbers of rooms.

1st floor: 2 rooms; 2nd floor; 8 rooms, and so on.

Electron cloud structure in atoms

Electrons really do operate in a similar fashion.

No two electrons in a single atom can be in exactly the same state.

Very bizarrely, this comes from a symmetry argument: fundamental particles have certain kinds of symmetry they must obey. (Pauli Exclusion Principle)

The number of rooms on a floor is determined by the intrinsic properties of electrons.

We call the different "hotel floors" for electrons **energy levels**.

Example: Carbon

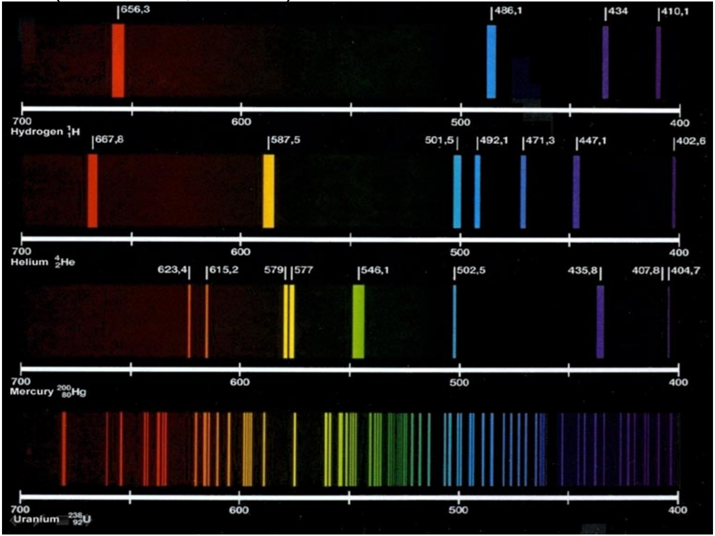
Carbon has 6 electrons.

The two rooms (states) on the ground floor and 4 of the 8 rooms (states) on the next floor are filled.

The states that are occupied determine a lot of properties about how the atom (and hence the element) behaves.

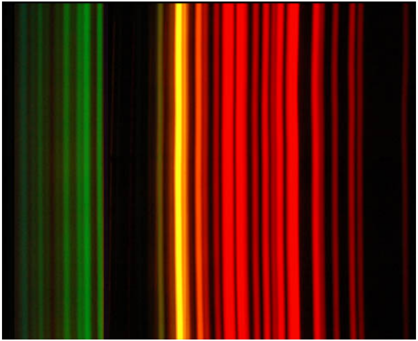
Atomic Spectra

Each kind of element has its own characteristic colors of light that it emits (emission spectrum).



[1] Image from http://www.chemistryland.com.

Atomic Spectrum of Neon



spectrum of Neon

Neon sign

[1]Images from http://hyperphysics.phy-astr.gsu.edu.

Ions

Ions are atoms that have lost or gained some electrons.

How many atoms are lost or gained typically depends on the electron cloud structure.

Ions

Ions are atoms that have lost or gained some electrons.

How many atoms are lost or gained typically depends on the electron cloud structure.

Sodium, Na, tends to lose one electron. The ion is: Na^+.

Chlorine, Cl, tends to gain one electron. The ion is: Cl^-

Magnesium, Mg, loses two electrons to form Mg^{2+}

Elements

Group→ ↓Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo
		*	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
		**	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

Compounds vs. Mixtures

compound

a substance formed when atoms or ions of different elements react and bond together. A compound may have quite different properties that the starting elements.

eg. water, table salt (sodium chloride)

This is different from a mixture

mixture

two or more different elements or molecules put together that do not react to form a new substance

eg. air, soil, seawater

Molecules

One way that atoms react to form compounds is through covalent bonds.

Example: water

Hydrogen - Oxygen - Hydrogen

which we write as H_2O.

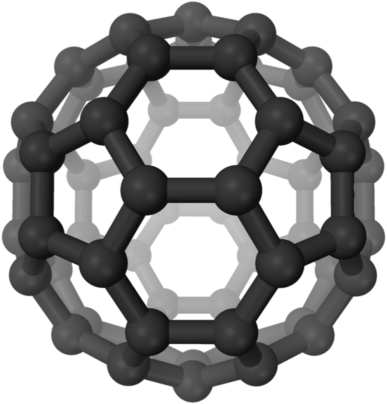
covalent bond

the sharing of electrons between atoms, causing them to stick together

Atoms of the same element can also bond this way, for example oxygen: O_2, and nitrogen: N_2.

Molecules

Molecules can be quite large.



C_{60}, Buckminsterfullerene.

Macromolecules (such as proteins) can be composed of thousands of atoms.

[1]Figure by Benjah-bmm27, Wikipedia.

Exotic Matter: Antimatter

Particles exist that have the same mass as the basic constituent particles of atoms we discussed earlier, but are sort of mirror-image particles.

They have the same mass, but opposite charge and other particle properties.

The electron's antiparticle is the positron (e^+).

The positron was seen as a valid solution to Dirac's equation and thus predicted before it was observed in 1932.

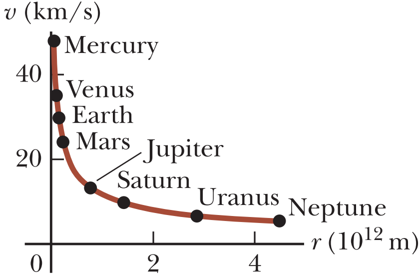
Exotic Matter: Dark Matter

?

Exotic Matter: Dark Matter

?

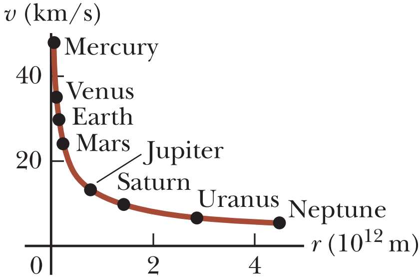
We know that there is matter out in the universe (stuff with mass) that we can't see.

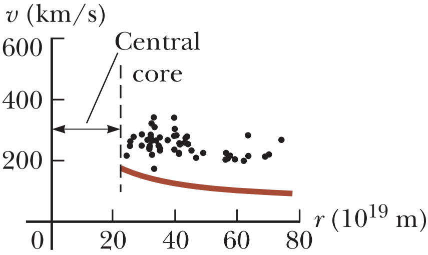


Exotic Matter: Dark Matter

?

We know that there is matter out in the universe (stuff with mass) that we can't see.





$$v \propto \sqrt{\frac{m}{r}}$$

We know that it accounts for perhaps 23% of the mass in the universe, but we don't know what it is.

Phases of Matter

The rest of the chapters in section 2 of the textbook deal with phases of matter:

- solids
- liquids
- gases
- plasmas

and some physics relevant to describing matter in each phase.

Solids

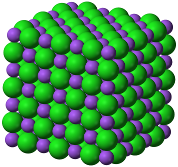
In solid matter, the atoms or molecules making up the matter are not free to move around.

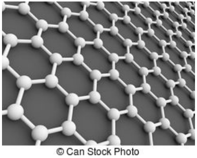
They are *frozen* in place.

Examples:

- rocks
- crystals
- ice
- most metals at room temperature
- most everything at extremely low temperatures (but not quite everything)

Crystal Structure





crystal

a material whose constituent atoms are arranged in a regular array (lattice)

Examples:

- metals that are solid - iron, copper, gold, etc.
- salts - sodium chloride (table salt)
- minerals - quartz, topaz, diamond

Glass is *not* a crystal. It is an *amorphous solid*.

Crystal Structure

The properties of those different crystaline materials are different because the types of chemical bonds in each:

- metals - metallic bonds. The outer electrons of each atom overlap with the electrons of the neighboring atoms.
  Properties: flexible, malleable, conductive
- salts - ionic bonds. The atoms in these substances are ionized and held together in a lattice by opposite-charge attraction
  Properties: hard, but brittle
- minerals - ionic and/or covalent bonds. In covalent bonds, electrons are shared between an atom and one of its neighbors.
  Properties: very hard if covalently bonded, sometimes transparent

Crystal Structure

The properties of those different crystaline materials are different because the types of chemical bonds in each:

- metals - metallic bonds. The outer electrons of each atom overlap with the electrons of the neighboring atoms.
  Properties: flexible, malleable, conductive
- salts - ionic bonds. The atoms in these substances are ionized and held together in a lattice by opposite-charge attraction
  Properties: hard, but brittle
- minerals - ionic and/or covalent bonds. In covalent bonds, electrons are shared between an atom and one of its neighbors.
  Properties: very hard if covalently bonded, sometimes transparent

Diamond for example, is one giant carbon molecule.

Crystal Structure

[1]Metals, http://www.luckysci.com
[2]Salt, Potassium dichromate, Wikipedia user Benjah-bmm27
[3]Mineral, Quartz, Wikipedia user, Archaeodontosaurus

Density

density

the amount of mass per unit volume

$$\text{density}, \ \rho = \frac{m}{V}$$

Density is a quantity we can use for solids, liquids, and gases.

Density

density

the amount of mass per unit volume

$$\text{density, } \rho = \frac{m}{V}$$

Density is a quantity we can use for solids, liquids, and gases.

A gold brick is incredibly heavy because gold is so dense.

A clay brick of the same size is much lighter by comparison.

Density

density

the amount of mass per unit volume

$$\text{density}, \ \rho = \frac{m}{V}$$

Density is a quantity we can use for solids, liquids, and gases.

A gold brick is incredibly heavy because gold is so dense.

A clay brick of the same size is much lighter by comparison.

Iridium is the densest material found on Earth at 2.265×10^4 kg/m^3.

The density of water is $1 \ g/cm^3 = 1000 \ kg/m^3$.

Density Question

American red oak has a density of 7.4×10^2 kg/m^3.

You are told by a new supplier that a sample of wood is American red oak. You measure its dimensions:

length: 1 m
width: 20 cm
depth: 6 cm

and you find its mass is 8.9 kg. Is the supplier giving you the correct kind of wood?

(A) Yes
(B) No

Density Question

American red oak has a density of 7.4×10^2 kg/m^3.

You are told by a new supplier that a sample of wood is American red oak. You measure its dimensions:

length: 1 m
width: 20 cm
depth: 6 cm

and you find its mass is 8.9 kg. Is the supplier giving you the correct kind of wood?

(A) Yes $\longleftarrow$
(B) No

Elasticity

Elasticity is a property of some solids: they can be deformed and return on their own to their original shape.

A spring is a device that makes use of this effect: it is a coil of metal.

It can be stretched to a longer length or compressed to a shorter one, but when released will return to its original length.

Elasticity

The force that the spring exerts to restore itself to its original length is proportional to how much it is compressed or stretched.

This is called Hooke's Law:

$$F = -kx$$

where x is the distance that the spring is stretched or compressed by and k is a constant that depends on the spring itself. (The "spring constant").

If a very large force is put on the spring eventually it will break: it will not return to its original shape. The *elastic limit* is the maximum distance the spring can be stretched so that it still returns to its original shape.

Spring example

If a 2 kg painting is hung from a spring, the spring stretches 10 cm. What if instead a 4 kg painting is hung from the spring? How far will it stretch?

Spring example

If a 2 kg painting is hung from a spring, the spring stretches 10 cm. What if instead a 4 kg painting is hung from the spring? How far will it stretch?

We don't know the spring constant, but we can work it out from the information about the first 2 kg painting. The force on the spring is just the weight of the painting.

$$k = \frac{F_g}{x} = \frac{(2\text{ kg})g}{0.1\text{ m}} \approx 200\text{ N/m}$$

$$x = \frac{F}{k} = \frac{40}{200} = 0.2\text{ m}$$

Spring example

If a 2 kg painting is hung from a spring, the spring stretches 10 cm. What if instead a 4 kg painting is hung from the spring? How far will it stretch?

We don't know the spring constant, but we can work it out from the information about the first 2 kg painting. The force on the spring is just the weight of the painting.

$$k = \frac{F_g}{x} = \frac{(2 \text{ kg})g}{0.1 \text{ m}} \approx 200 \text{ N/m}$$

$$x = \frac{F}{k} = \frac{40}{200} = 0.2 \text{ m}$$

If you put on twice the force, you stretch the spring twice as far!

Spring example

If a 2 kg painting is hung from a spring, the spring stretches 10 cm.

Now suppose a 6 kg painting is hung from the same spring. How far does it stretch?

Spring example

If a 2 kg painting is hung from a spring, the spring stretches 10 cm.

Now suppose a 6 kg painting is hung from the same spring. How far does it stretch?

$x = 0.3$ m.

Another spring example

Prob. 4 from the textbook.

Consider a spring that stretches 4 cm when a load of 10 N is suspended from it. How much will the springs stretch if an identical spring also supports the load (a) in parallel and (b) in series? (Neglect the weight of the springs.)

Another spring example

Prob. 4 from the textbook.

Consider a spring that stretches 4 cm when a load of 10 N is suspended from it. How much will the springs stretch if an identical spring also supports the load (a) in parallel and (b) in series? (Neglect the weight of the springs.)

(a) 2 cm
(b) 8 cm in total (4 cm each)

Liquids

liquid

a state of matter where the constituent particles are free to move around relative to one another, but the substance is nearly incompressible. Volume is fixed, but shape is not.

A solid that is heated will *melt* to form a liquid.

If that liquid is further heated it will *boil* to form a gas.

Both liquids and gases can flow, but the density of a substance in its liquid state is close to that in its solid state. For gases the density can vary.

Liquids

Liquids require a fairly narrow range of temperatures and pressures to exist.

Earth has the right temperature and pressure on its surface for water to be liquid.

Examples of liquids at room temperature:

- water
- oil
- alcohol
- mercury

Pressure

Most liquids maintain nearly constant volume whatever the pressure.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

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

An illustration: a hammer and a nail pounded by the same hammer exert the same force on a board. The pressure at the tip of the nail is much higher.

Pressure

Pressure is measured in Pascals, Pa.

1 Pa $= 1$ N/m^2.

Atmospheric pressure is 101.3 kPa, or 1.013×10^5 Pa.

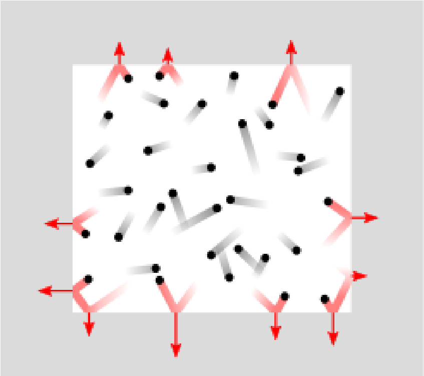
Since the Pascal is a small unit (even 1 atmosphere is $\sim 10^5$) sometimes *atmospheres* are also used as a unit of pressure.

1 atmosphere $= 1.013 \times 10^5$ Pa

Fluid Pressure

Pressure is a scalar quantity.

We understand that its underlying cause is molecular collisions:



[1]Diagram by Brant Carlson, on Wikipedia.

Liquid Pressure

Liquids also apply pressure onto submerged objects.

Liquid pressure depends on depth.

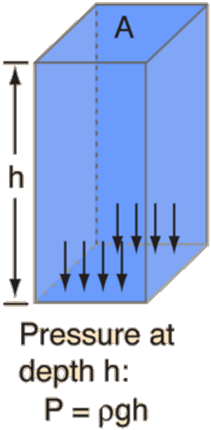
$$\text{liquid pressure} = \begin{array}{c}\text{weight density}\\ \text{of fluid}\end{array} \times \text{depth}$$

$$P_{\text{liq}} = \rho g h$$

where $\rho = m/V$ is the mass density of the fluid and h is the depth.

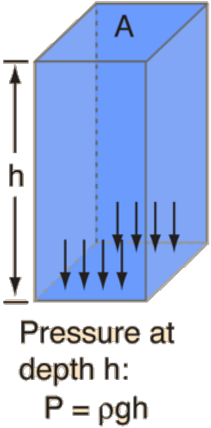
It does not depend on the total amount of water involved, just the depth of water.

Liquid Pressure



The force exerted downward by the column of water is
$F = mg = \rho V g$.

Liquid Pressure



The force exerted downward by the column of water is
$F = mg = \rho V g$.

Pressure, $P_{\text{liq}} = \rho V g / A = \rho g h$.

Total Pressure

The liquid pressure only expresses the pressure due to the weight of the fluid above.

However, this is not the total pressure in most circumstances, *eg.* diving on earth.

Total Pressure

The liquid pressure only expresses the pressure due to the weight of the fluid above.

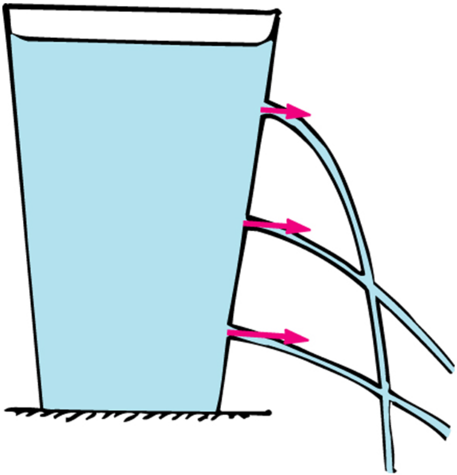
However, this is not the total pressure in most circumstances, *eg.* diving on earth.

The total pressure is the sum of the pressure due to the liquid *and* the pressure due to the atmosphere.

$$P_{\text{total}} = \rho g h + P_{\text{atm}}$$

where $P_{\text{atm}} = 1.013 \times 10^5$ Pa.

Pressure varies with Depth



Pascal's Barrel

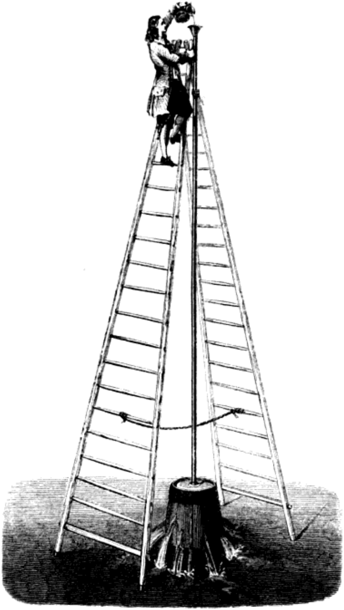


Fig. 45.—Hydrostatic paradox. Pascal's experiment.

Question

Plug and Chug # 2, page 243.

Calculate the total pressure at the base of the Hoover Dam. The depth of water behind the dam is 220 m.

Question

Plug and Chug # 2, page 243.

Calculate the total pressure at the base of the Hoover Dam. The depth of water behind the dam is 220 m.

Density of water: $\rho_w = 1000\ \mathrm{kg/m^3}$

Question

Plug and Chug # 2, page 243.

Calculate the total pressure at the base of the Hoover Dam. The depth of water behind the dam is 220 m.

Density of water: $\rho_w = 1000\ \text{kg/m}^3$

$$P_{\text{total}} \approx 2.3 \times 10^6\ \text{Pa}$$

Summary

- atomic structure
- molecules
- solids, density, elasticity
- liquids, pressure

Talks! Aug 8-9.

Homework Hewitt,

- PREVIOUS: Ch 11, onward from page 211. Ranking: 1; Exercises: 1, 13, 9, 11, 15, 17, 21, 27
- Ch 12, onward from page 225. Ranking: 1; Exercises: 7, 9, 11, 13, 21; Problems: 1, 3, 5;
- Ch 13, onward from page 243. Plug and Chug: 1, 3, 4; Exercises: 11, 19; Problems: 1