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| *4* | Mon. 9/23<br>Tues 9/24<br>Wed. 9/25<br><br>Lab<br>Fri., 9/27 | **4.1-.5** Atomic nature of matter / springs<br><br>**4.6-.7, .9-.10** Stress, Strain, Young's Modulus, Compression, Sound<br>***Science Poster Session****: Hedco7pm~9pm*<br>**L4:** Young's Modulus & Speed of Sound (Read **4.11-.12**)<br>**4.11-.12; .14-.15** Sound in Solids, Analytical Solutions **Quiz 3** | **RE 4.a**<br>**EP 3, HW3:** Ch 3 Pr's 42, 46, 58, 65, 72 & CP<br>**RE 4.b**<br><br><br>**RE 4.c bring laptop, smartphone, pad,…** |
| *5* | Mon. 9/30<br>Tues 10/1<br>Wed. 10/2<br>Lab<br>Fri. 10/4 | **4.8, .13** Friction and Buoyancy & Suction<br><br>**5.1-.5** Rate of Change & Components **Quiz 4**<br>**Review for Exam 1**(Ch 1-4)<br>Exam 1 (Ch 1-4) | **RE 4.d**<br>**EP 4, HW4:** Ch 4 Pr's 46, 50, 81, 88 & CP<br>**RE 5.a bring laptop, smartphone, pad,…**<br>**Practice Exam 1 (due beginning of lab)** |

**Set-up**

- Clicker program loaded with participants

**Equipment**

- Clickers
- Look over WebAssign questions
- Ball & Spring model of a solid, a wire
- Masses hanging from springs
- ball-spring movie on it

**Announcements**

***Wed. night: Science Poster Session****: Hedco7pm~9pm*

**Chapter 4: The Atomic Nature of Matter**

In chapter's 2 and 3, we studied how externally applied forces impacted the motions of objects. In chapter 4, we apply our knowledge that macroscopic objects are themselves systems of much smaller objects – atoms. Fortunately, to get a *sufficiently* good understanding of the microscopic origin and consequences of everyday pulls and pushes, we don't need to work them out in gory quantum mechanical details; we only need the basic atomic picture to understand the macroscopic ramifications of this underlying structure.

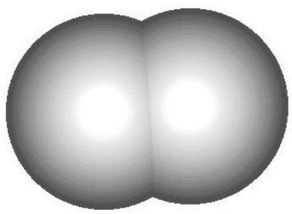
There are of course three 'states' of matter – solid, liquid, gas. We first look at solids.

- This time we tackle the Tension force, (every-day pulls) and the Normal force (every-day pushes). We'll zoom in, look at the internal structure, and think a little about what holds objects together and therefore how objects can themselves be distorted. In the end, we'll be able to see how a distortion waves, i.e. sound waves, travel through solid matter.
- In our life times, we take for granted that all objects around us are composed of atoms, but it was only relatively recently that we could directly image them.

**ppt. Show STM Pictures from down the hall**. Here's a close up of a Pt (001) surface. Each little stitch in this tapestry is the electron cloud of an individual atom. This dropped stitch here is where an atom is 'missing' from the surface.

**4.2 A model of a solid: Balls connected by springs**

- **Simple Atomic Picture.** While quantum mechanics represents our most fundamental understanding of atomic behavior, we can get pretty far with a very rudimentary model. The mere existence of solids, like this table top, implies that
  - **Equilibrium separation.** Atoms bond to each other (to make the solid) but have a preferred separation – it's very hard to stretch or compress most solids.
  - **Like springs.** Hm… an interaction that has an equilibrium separation – compress too much and it pushes back, stretch too much and it pulls back. Sounds a heck of a lot like a *spring.*
  - **Ball-Spring model.** It turns out that modeling the interatomic interaction like a spring is very, very good as long as we're not stretching/compressing the bond much beyond the equilibrium length.
    - **Taylor Series.** We'll get a little more into this later, essentially, if you could draw a plot of how the inter-atomic force *really* depends on separation, and zoomed way the heck in to the little stretch right near equilibrium, it would look like a sloped line in that region; the force would depend linearly on the stretch – that's hook's law.
  - **Molecule.**
    - For example, the hydrogen molecule is *really* held together by two atom's covalent sharing of their electrons to form one shared electron orbital.



    - But if we don't stretch/compress too much, the force is like that of a spring.

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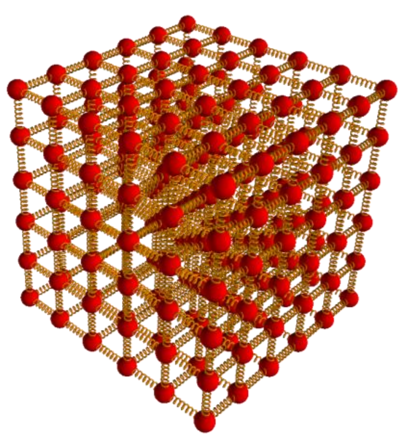
  - **A Solid**
    - A solid is like an uber-molecule; each atom is bound to its neighbors just like in a molecule, except the molecule goes on and on.



**Show ball – spring movie**

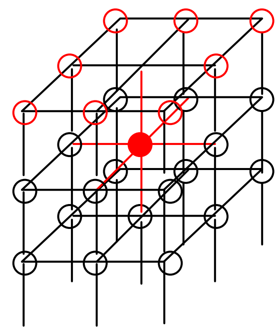
## 4.4 Length of Atomic Bonds & Atomic Masses

The first obvious question is – how small is that? How far apart are the atoms? In general, it's around $3\times10^{-10}$m (3Å), but, from a few commonly tabulated and measurable values, you can figure out the typical separation of atoms in most solids. The two pieces of information you start with are the "atomic mass" of the element and its mass density (or, alternatively, the mass and volume of a chunk of the stuff).

One the one hand, the mass density is the total mass of a chunk of the material divided by its total volume. On the other hand, it's the mass of one atom divided by that atom's personal space.

$$\frac{M_{total}}{Vol_{total}} = density = \frac{m_{atom}}{Vol_{atom}}$$

Assuming that the atoms bond in a simple cubic geometry,



then there's one atom per cube of width, height, and length equal to one bond length, $d$ (assuming simple cubic.) So $Vol_{atom} = d^3$

$$\frac{M_{total}}{Vol_{total}} = density = \frac{m_{atom}}{d^3} \Rightarrow d = \left(\frac{m_{atom}}{density}\right)^{1/3}$$

As for finding the atomic mass, the periodic table at the front of the book gives the "atomic mass" of each element. There are two equivalent ways of interpreting that number – the chemists' way and the physicists' way.

**The Physicists' interpretation**. The 'atomic mass number' is the number of nucleons (neutrons + protons) in the average atom of that type (there are different isotopes in different abundances, so this usually isn't an integer). Multiply that number by the mass of a nucleon, $1.7\times10^{-27}$kg (from the back of the book), and you've got the mass of the typical atom.

$$m_{atom} = a.m.u.* m_{nucleon}$$

Ex. Carbon's atomic mass number is 12.011, so the mass of a Carbon atom is $12.011 * 1.7\times10^{-27}$kg = $2.0\times10^{-26}$kg.

**The Chemists' interpretation.** The 'atomic mass number' is the mass in grams of one "mole" of the atoms. A mole, like a "baker's dozen" is a specific convenient number of items: $6.02\times10^{23}$atom. So divide by the number of atoms in a mole to get one atom's mass (in grams) and then divide by 1000 to get it in kg.

Ex. Carbon's atomic mass number is 12.011, so the mass of a Carbon atom is

(12.011g/ mole)(moles / $6.02\times10^{23}$atoms)(1kg/1000g) = $2.0\times10^{-26}$kg.

Ex. **Like 3.1/3.2 using the idea of a mole. One mole of silicon ($6\times10^{23}$ atoms) has a mass of 28 grams. The density of silicon is 2.33 grams/cm$^3$. What is the typical separation of a silicon atoms (i.e., ~ their diameters) assuming their arranged cubically?**

$$\rho = \frac{M}{V} = \frac{m_{atom}}{V_{atom}} = \frac{m_{atom}}{(d_{atom})^3}$$

$$M = N_{atoms} m_{atom}$$

$$d_{atom} = \left(\frac{m_{atom}}{\rho}\right)^{1/3} = \left(\frac{M_{mole}}{N_{mole}\rho}\right)^{1/3}$$

$$d_{atom} = \left(\frac{28g}{(6\times10^{23}\,atoms)(2.33g/cm^3)}\right)^{1/3} = 2.7\times10^{-8}\,cm\,\frac{1m}{100cm} = 2.7\times10^{-10}\,m$$

note: was able to delay unit conversion to the end, but could just as well have done it up front (being careful to convert all three factors of cm's to m's)

## 4.5 (Prelude to) Stiffness of an Interatomic bond

- According to our ball-spring model of a solid, when you put a book on this table, it should compress a little just like a bunch of balls on springs in series and in parallel would, or when you hang a weight from a wire, it stretches a little, just like a bunch of balls on springs in series and in parallel. In principle then we should be able to relate the macroscopic / observable behavior of a wire holding a mass and deduce microscopic details like how 'stiff' an individual interatomic bond is! We're going to head down that path; along the way, we'll figure out how to handle combinations of springs in series, combinations of springs in parallel, and finally combinations of springs in series *and* in parallel.

## 4.4 Tension & Stretching a wire: Microscopic

- Last Chapter, we thought a little about balls on springs. For example, we considered how a spring could be used to weigh an object that hung from it:

**System:** Hanging Ball

**Interacting External agents:** Spring, Earth

**Picture (with forces):**

**Principles:** Momentum Principle

$$\sum_{all} \vec{F}_{\to ball} = \frac{\Delta \vec{p}_{ball}}{\Delta t}$$
$$\vec{F}_{spring\to ball} + \vec{F}_{Earth\to ball} = 0$$
$$\vec{F}_{spring\to ball} = -\vec{F}_{Earth\to ball}$$
$$-k_{sp}(\vec{r}_{end} - \vec{r}_{eq}) = -\left(m\vec{g}\right)$$
$$\hat{y}: -k_{sp}(y_{end} - y_{eq}) = -m(-|g|) = mg$$

- Now, with ball-spring model of all solids, we can well imagine that the same thing is happening when a rope or string holds a mass.
    - **System:** Hanging Ball
- **Interacting External agents:** String, Earth
    - **Picture (with forces):**
-
    - **Principles:** Momentum Principle

$$\sum_{all} \vec{F}_{\to ball} = \frac{\Delta \vec{p}_{ball}}{\Delta t}$$
$$\vec{F}_{string\to ball} + \vec{F}_{Earth\to ball} = 0$$
$$\vec{F}_{string\to ball} = -\vec{F}_{Earth\to ball}$$
$$\vec{F}_{string\to ball} = -\left(m\vec{g}\right)$$
$$\vec{F}_{string\to ball} = mg\hat{y}$$

- The force transmitted by any cross-section of wire, rope, etc. is broadly referred to as **tension.**
- We will look at tension and stretching in a wire.

- **Parallel and Series Springs**
    - In terms of 'atomic springs' a wire looks like a bunch of spring side by side and a bunch end to end (see model). First, let's think about the effect of combining two springs end to end and then two springs side by side.
    - **Series Springs**
        - Say you hang a mass, M from one spring, and it stretches according to the force that mass exerts.
        - Force on top spring leads to stretch $F = k_1 \Delta l_1 \Rightarrow \Delta l_1 = \frac{F}{k_1}$
        - Force on bottom spring leads to stretch $F = k_2 \Delta l_2 \Rightarrow \Delta l_2 = \frac{F}{k_2}$
        - Taken together: the whole combo stretches

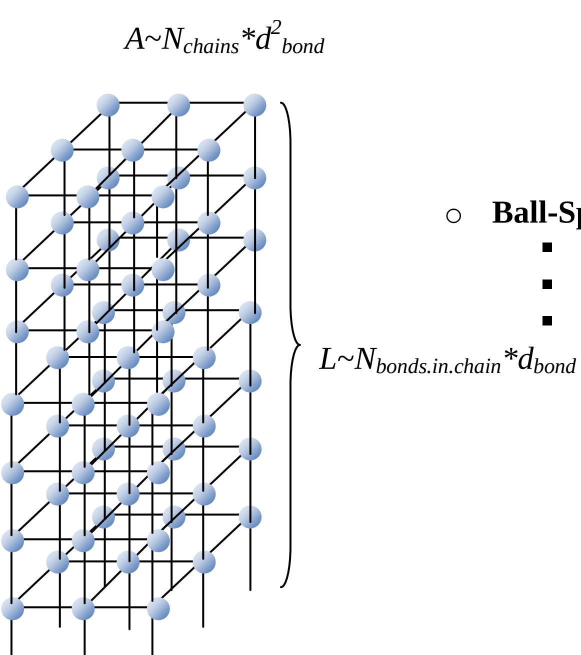
- $$\Delta L = \Delta l_1 + \Delta l_2 = \frac{F}{k_1} + \frac{F}{k_2} = F\left(\frac{1}{k_1} + \frac{1}{k_2}\right)$$
  $$F = \left(\frac{1}{k_1} + \frac{1}{k_2}\right)^{-1} \Delta L$$
- **Special Case – identical springs**
  $$k_1 = k_2$$
  - $$F = \left(\frac{1}{k_1} + \frac{1}{k_1}\right)^{-1} \Delta L = \frac{k_1}{2}\Delta L$$
  - **With $N_{bonds\ in\ chain}$ atoms in a line**
    - $$F = \frac{k_1}{N_{bonds.in.chain}} \Delta L$$
  - The over-all stiffness is then
    - $$k_{series} = \frac{k_1}{N_{bonds.in.chain}}$$

**Ppt. Springs in series**

- **Parallel Springs**
  $$F_1 = k_1 \Delta L$$
  - $$F_2 = k_2 \Delta L$$
  $$F_{tot} = F_1 + F_2 = k_1\Delta L + k_2\Delta L = (k_1 + k_2)\Delta L$$
  - **Special Case – Identical Springs**
    - $$F_{tot} = (2k_1)\Delta L$$
    - **With $N_{chains}$ atoms across**
      - $$F_{tot} = (N_{chains}k_1)\Delta L$$
    - The over-all stiffness is then
      - $$k_{t||} = (N_{chains}k_1)$$

**Ppt. Springs in parallel**

**4.5 Stiffness of an Interatomic bond, Microscopic**




- **Parallel & Series**
  - So, if we had a complicated combination of identical springs in series and in parallel, like this toy here, then
    - $$F = \left(\frac{N_{chains}}{N_{bonds.in.chain}} k_1\right)\Delta L$$
      $$F = k_{tot}\Delta L$$
- **Ball-Spring Model of Wire**
  - A wire is so many atoms long and so many atoms across
  - (draw picture)
  - We can rephrase these numbers ($N_A$ and $N_L$) in terms of macroscopically-measurable quantities: the cross-sectional area of the wire and the length of the wire.
    - L = $N_{bonds.in.chain}$ d (d = typical separation of atoms)
    - A = $N_{chains}$ $d^2$ (not right if atomically narrow wire as illustrated – then most chains are on the surface, but

if a normal wire's size, then most chains run down the bulk.)

$$F = k_{tot} \Delta L$$

$$F = \left( \frac{N_{chains}}{N_{bonds.in.chain}} k_{s.i} \right) \Delta L$$

- $$F = \left( \frac{Ad}{d^2 L} k_{s.i} \right) \Delta L$$

$$F = \left( \frac{A}{dL} k_{s.i} \right) \Delta L$$

$$\frac{F}{A} = \left( \frac{k_{s.i}}{d} \right) \frac{\Delta L}{L}$$

Now, you can imagine (indeed, you will perform) an experiment in which you measure a wire's length and cross-sectional area, then you hang a weight from it (so you know the force it transmits) and measure its slight lengthening then, if you only knew the interatomic distance, you'd know the stiffness of the interatomic bonds!