# Announcements

- I didn't make it through all the tests, sorry. You'll get them back and we'll talk about them on Friday!
- Homework:
  - WebWorK 5 due tonight!
    - Coding requires you to track *both* balls
    - Will ask for more questions in a moment
  - WebWorK 6 will be due Friday
- Starting Chapter 4 today!
- Polling: `rembold-class.ddns.net`

# Review Question

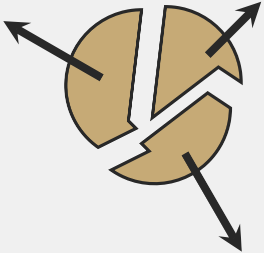
A firework initially has a mass of 500 g and is motionless. It then explodes into 3 pieces. One 100 g piece leaves with a velocity of $\langle 0, 4, 0 \rangle$ m/s, while another 250 g piece leaves at $\langle -2, 0, 3 \rangle$ m/s. How fast is the last 150 g piece initially traveling?

A) 5.2 m/s

B) 6.6 m/s

C) 13.1 m/s

D) None of the above



**Solution:** 6.6 m/s

# Momentum of the System

- If we take a change in the position of the center of mass:

$$\Delta\vec{\mathbf{r}}_{CM} = \frac{m_1\Delta\vec{\mathbf{r}}_1 + m_2\Delta\vec{\mathbf{r}}_2 + m_3\Delta\vec{\mathbf{r}}_3 + \cdots}{M_{total}}$$

  assuming that the mass isn't changing.

- Dividing by $\Delta t$ then gives us:

$$\begin{aligned}
\frac{\Delta\vec{\mathbf{r}}_{CM}}{\Delta t} &= \frac{m_1\frac{\Delta\vec{\mathbf{r}}_1}{\Delta t} + m_2\frac{\Delta\vec{\mathbf{r}}_2}{\Delta t} + m_3\frac{\Delta\vec{\mathbf{r}}_3}{\Delta t} + \cdots}{M_{total}} \\
\vec{\mathbf{v}}_{CM} &= \frac{m_1\vec{\mathbf{v}}_1 + m_2\vec{\mathbf{v}}_2 + m_3\vec{\mathbf{v}}_3}{M_{total}} \\
M_{total}\vec{\mathbf{v}}_{CM} &= \vec{\mathbf{p}}_1 + \vec{\mathbf{p}}_2 + \vec{\mathbf{p}}_3 + \cdots \\
M_{total}\vec{\mathbf{v}}_{CM} &= \vec{\mathbf{p}}_{total}
\end{aligned}$$

Upcoming:

# Contact Forces: Understanding the Big from the Little

# When Incompressable Objects Meet

- Have been approximating things to point masses
  - Useful for many times of long-range forces like gravity or the electrostatic force
- Consider collisions:
  - We originally found $\Delta t$ from the compression distance and the arithmetic average velocity
  - But point masses don't compress, by definition!

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  - But point masses don't compress, by definition!
- We need a new way of looking at solids to understand how they interact when touching

# Starting Small

- To understand large solids, we'll start with their building blocks: atoms.
- Groups of atoms follow general rules:
  - Always moving based on temperature
  - Generally attracted to one another
  - Unless they get too close, then they are repulsed

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- To understand large solids, we'll start with their building blocks: atoms.
- Groups of atoms follow general rules:
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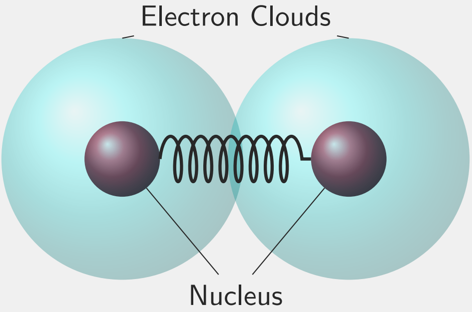
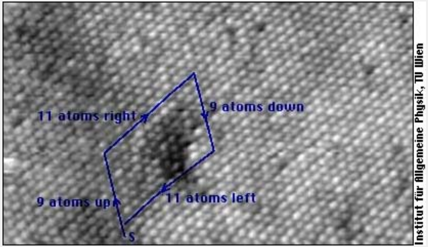
  - Unless they get too close, then they are repulsed
- The last two lead to an obvious analog: springs!



# Making Solids from Springs




- Many solids form crystalline structures
- Can visualize (and model) as packed grids of atoms, each with little springs connecting it to its neighbors
- This model will let us reason and explain such things as:
  - Tension
  - Friction
  - The normal force

# Properties of Atomic Springs

- Our goal is to understand macroscale behavior originating from an atomic spring model
- Would be useful to understand some properties of atomic springs
- Given that

$$\vec{\mathbf{F}}_{spring} = -k_s s \hat{\mathbf{L}}$$

  some useful things to know would be:
    - Spring constants of atomic springs
    - Relaxed lengths of atomic springs
    - Typical stretched distances of atomic springs

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# Spring Lengths

- Operating on the assumption that atoms are usually spaced at their relaxed length
- The relaxed length is going to depend on a few properties:
  - How the atoms are arrayed in the crystal structure
    - We'll generally assume nice cubic lattices
  - How tightly the atoms are packed
    - Related to the density of a material
- Note that the relaxed spring length is akin to the approximate diameter of the atom!

**Important!**

Relaxed spring lengths will depend on the material of the object involved! An object made of copper will have a different relaxed length than an object made of lead!

# Full of Lead

Looking at a periodic table, lead has a molar mass of about 207 g. Since a mole is $6.02 \times 10^{23}$, that is 207 g per $6.02 \times 10^{23}$ atoms. The density of lead is about $11.34\,\mathrm{g/cm^3}$. Estimate the relaxed spring length of lead.

**Solution:** $3.11 \times 10^{-8}$ cm

# Stacking Springs

- Now want to know about the molecular spring constants
- Impossible to measure directly, so we base it off macroscopic observations
- Doing so requires us understanding how multiple springs work together

## End-to-End

- Each spring stretches the same
- Total string stretches $N$ times
- Reduces effective spring constant by $N$ times

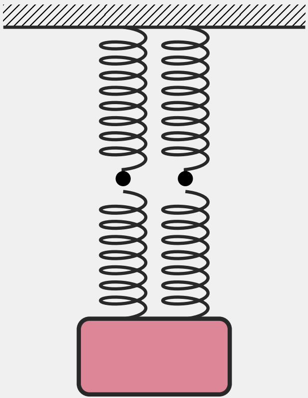
## Side-by-Side

- Springs split the load by $N$
- Reduced load implies reduced displacement
- Increases effective spring constant by $N$

# Understanding Check

We've determined that the springs in the front of the room are displaced by about 6 cm when a 250 g mass is hung from them individually. If I hang the mass from the spring configuration shown to the right, how far from equilibrium will the springs be displaced?

A) 3 cm
B) 6 cm
C) 12 cm
D) 24 cm



**Solution:** 6 cm

# Counting the Strings of Springs

- We can consider a solid wire to be made up of many of these strings of springs
- How many depends on the thickness of the wire
- Cross-sectional area is the area shown by slicing through a solid
  - A circle for cylinders
  - A rectangle for blocks, etc
- Knowing the density of atoms and the cross-sectional area will set us calculate the number of strings of springs
- Can then use that to work backwards to get the spring constant

# Spring Loaded Lead

A thin lead rectangular wire with side length of 2 mm is 3 m long. A 10 kg weight is hung from the end and the new length of the wire is carefully measured to be 4.6 mm longer. What is the intermolecular spring constant between lead atoms?

**Solution:** 4.98 N/m

# Practice Time!

You have a thin gold wire with a radius of 1 mm which is 2 m long. Gold has an atomic weight of 196.966 g/mol, a density of 19.30 $g/cm^3$, and an intermolecular spring constant of 20.29 N/m. How far will the gold wire stretch when a 10 kg mass is hung from the end?