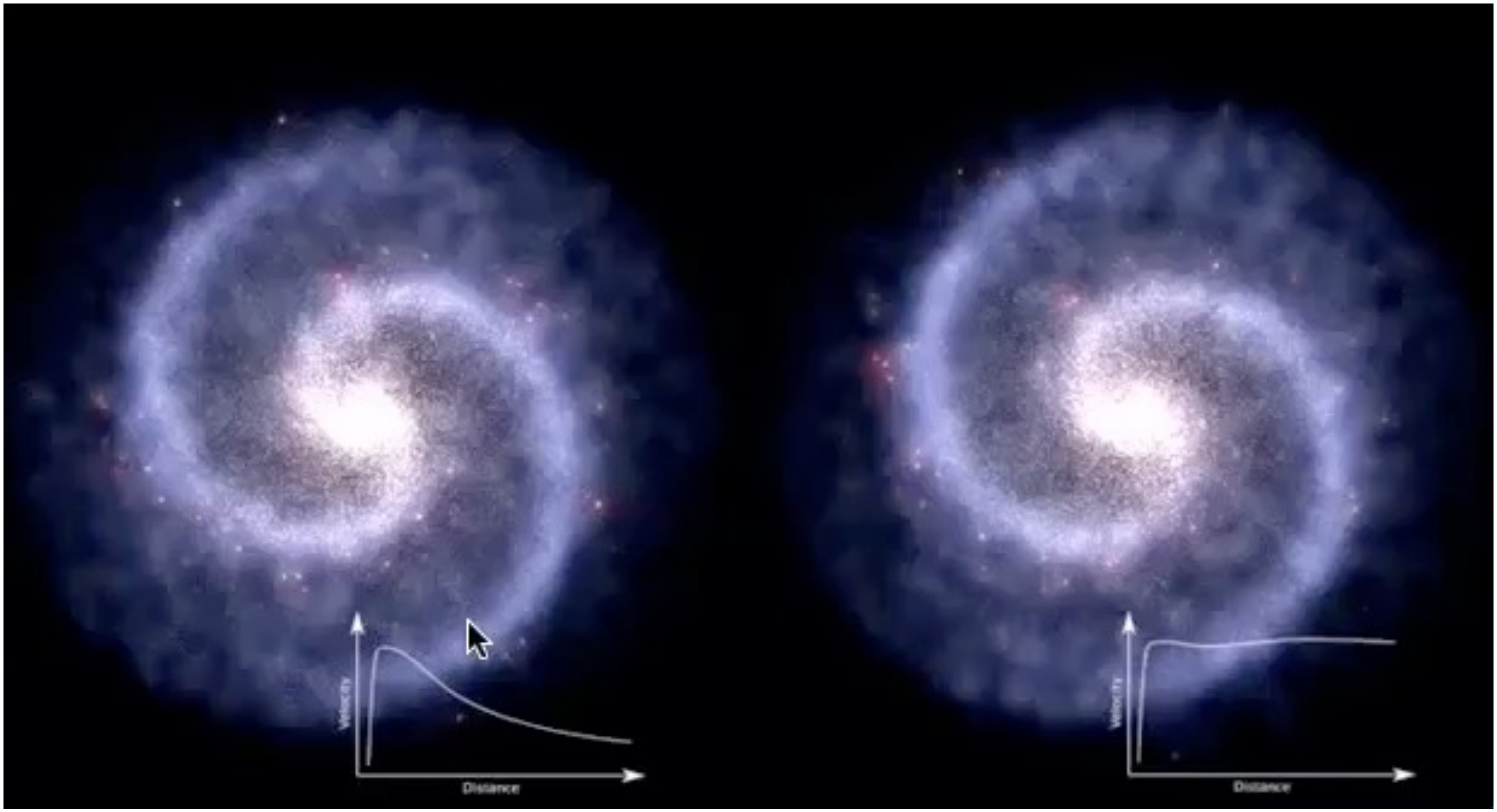
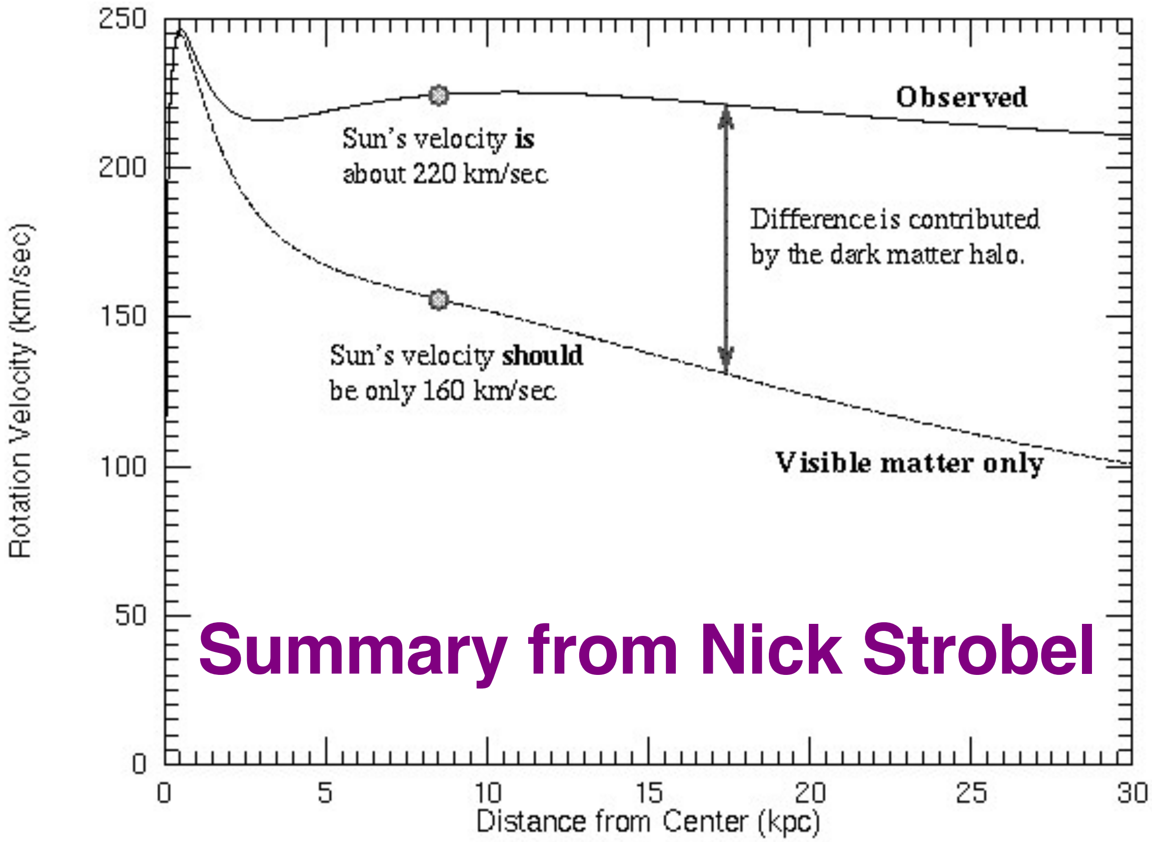
Physics 141.
Lecture 6.

Rotation Curves



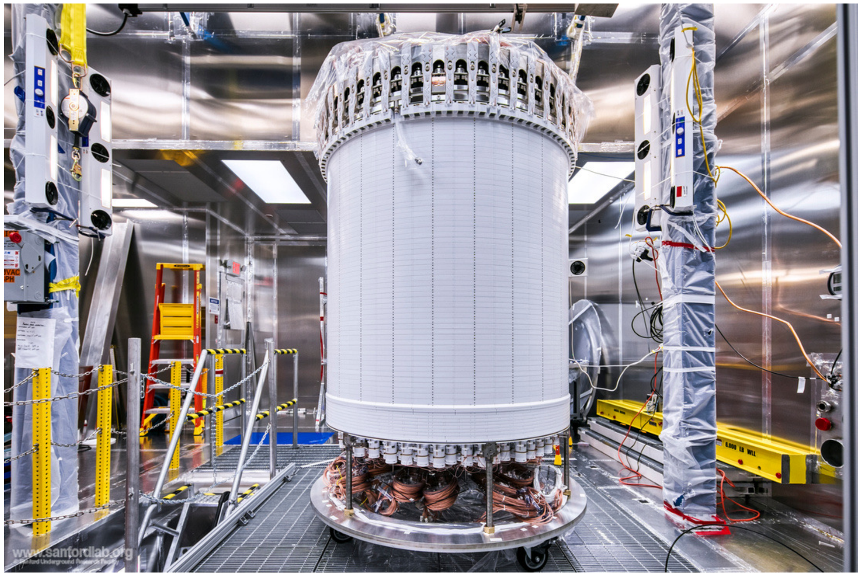
Our sun is moving too fast! We are moving through a sea of dark matter.



The gravity of the visible matter in the Galaxy is not enough to explain the high orbital speeds of stars in the Galaxy. For example, the Sun is moving about 60 km/sec too fast. The part of the rotation curve contributed by the visible matter only is the bottom curve. The discrepancy between the two curves is evidence for a **dark matter halo.**

Building the infrastructure to detect dark matter in South Dakota.

LZ: The most sensitive dark-matter detector in the world.



Back to reality.
Outline.

- Course information:
  - Scientific data analysis – using Igor.
- Quiz
  - Three questions. Every answer is correct!
- Contact forces and the momentum principle (Chapter 4):
  - Properties of the spring-mass system.
  - Equations of motion of the spring-mass system.
  - The speed of sound.

Physics 141.
Laboratory information.

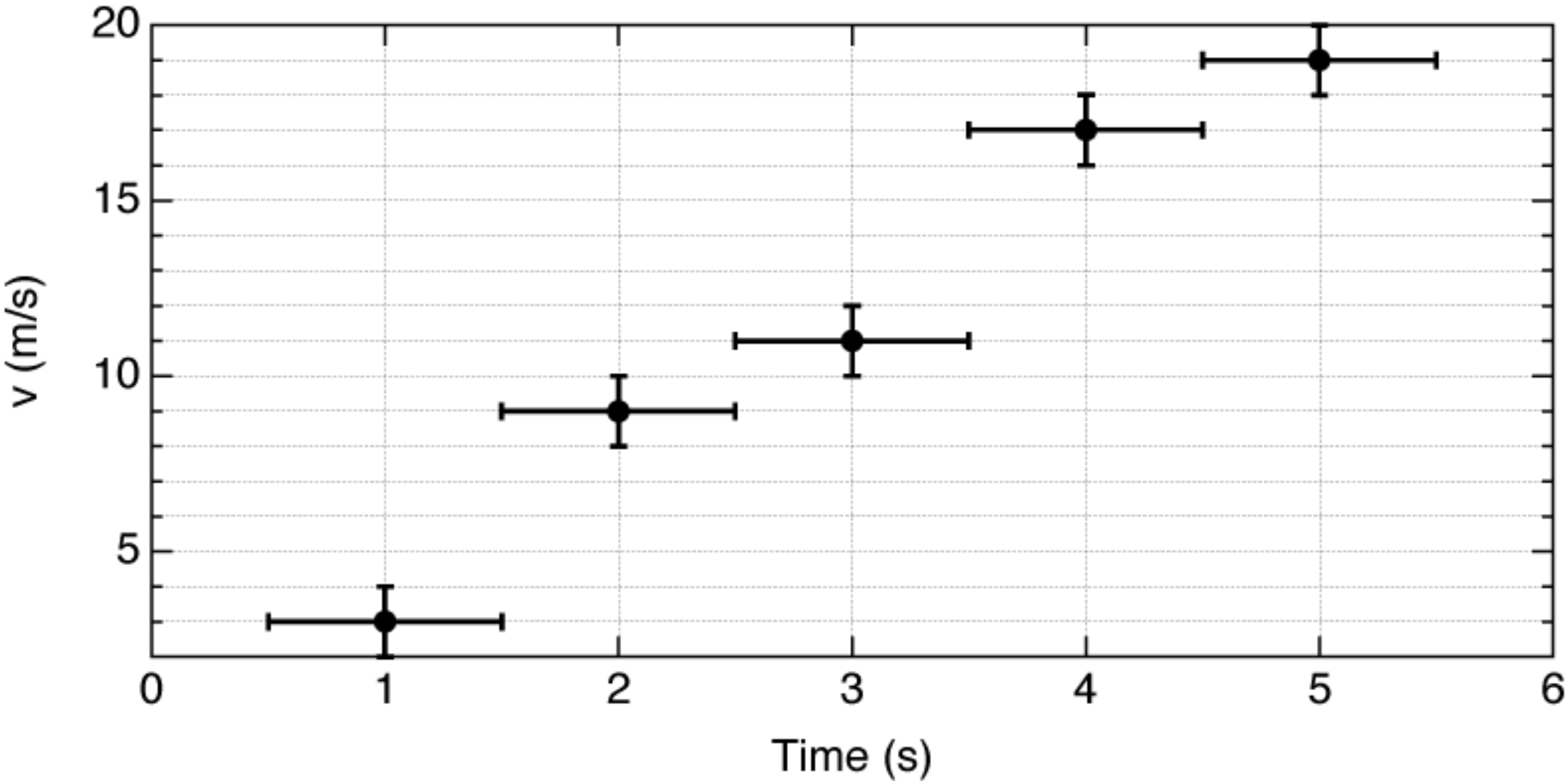
- The first laboratory report is due on Friday 9/22 at noon. It must be uploaded in pdf format to BOX (link is available on the PHY 141 web page). The reports will be checked for plagiarism.

- Laboratory # 2 will take place on Monday 9/25 in B&L 407.

- On the WEB you will find a page with a summary of frequently made mistakes while writing a laboratory report. Please use it as a check list before submitting your report.

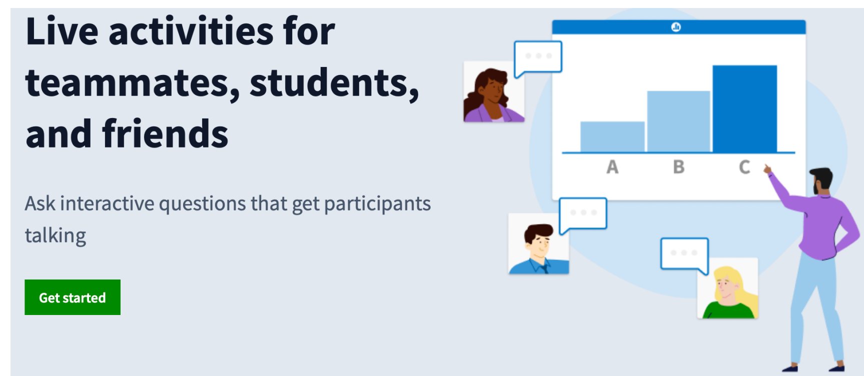
- For the laboratory experiments, you may want to consider using Igor for data analysis. Let's look at a brief introduction to scientific data analysis.

An introduction to scientific data analysis using real scientific tools (not Excel).

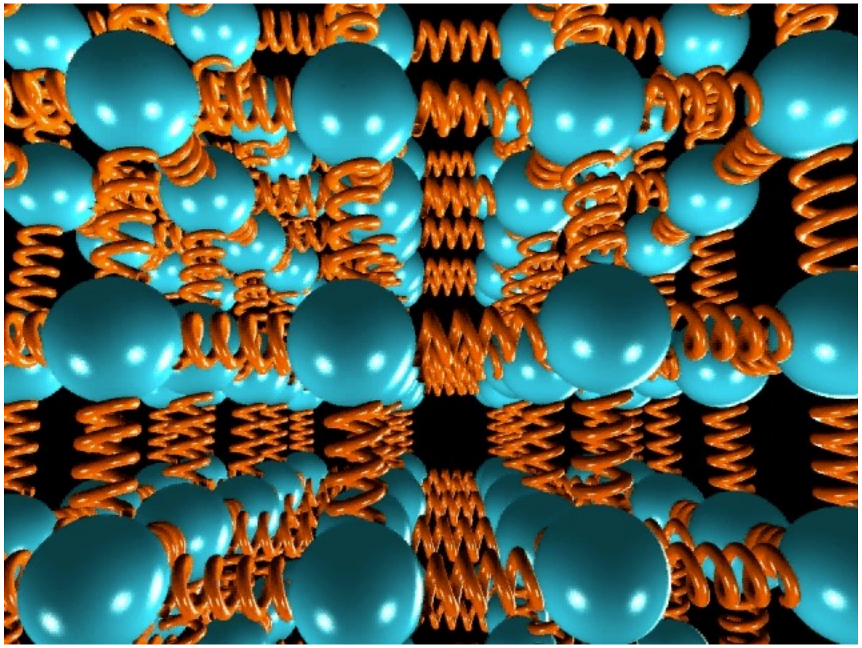


Quiz lecture 06.
PollEv.com/frankwolfs050

- The quiz today will have four questions.
- I will collect your answers electronically using the Poll Everywhere system.
- The answers for each question will be entered in sequence (first 30 s for question 1, followed by 30 s for question 2, etc.).



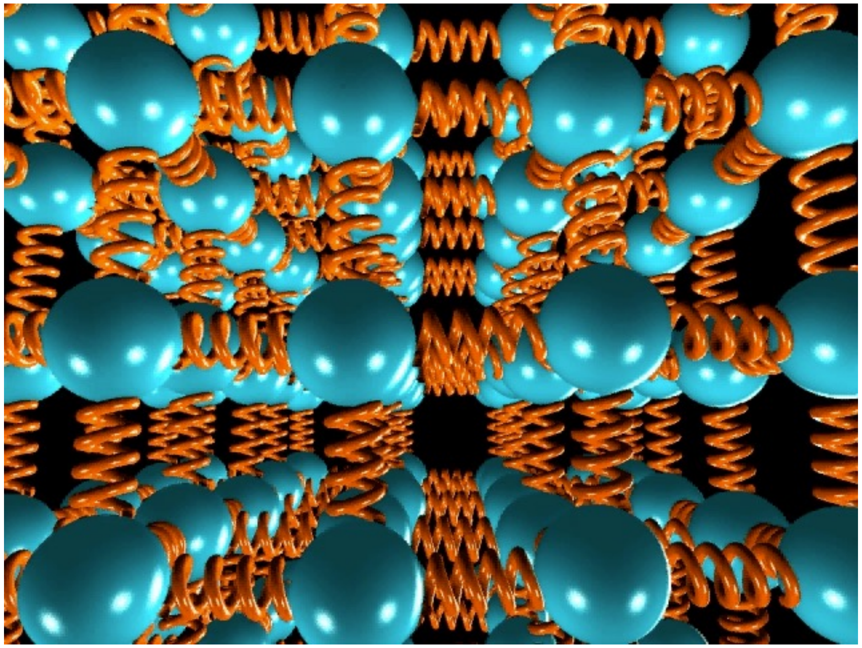
The atomic nature of matter.



- Using a basic model of atoms connected by springs we can understand important properties of matter:
  - The inter-atomic spacing in a wire will increase with height.
  - The tension in a wire is not constant.
  - When an external mass is attached to the wire, significantly heavier than the wire, the assumptions of constant tension and constant inter-atomic spacing become better approximations.

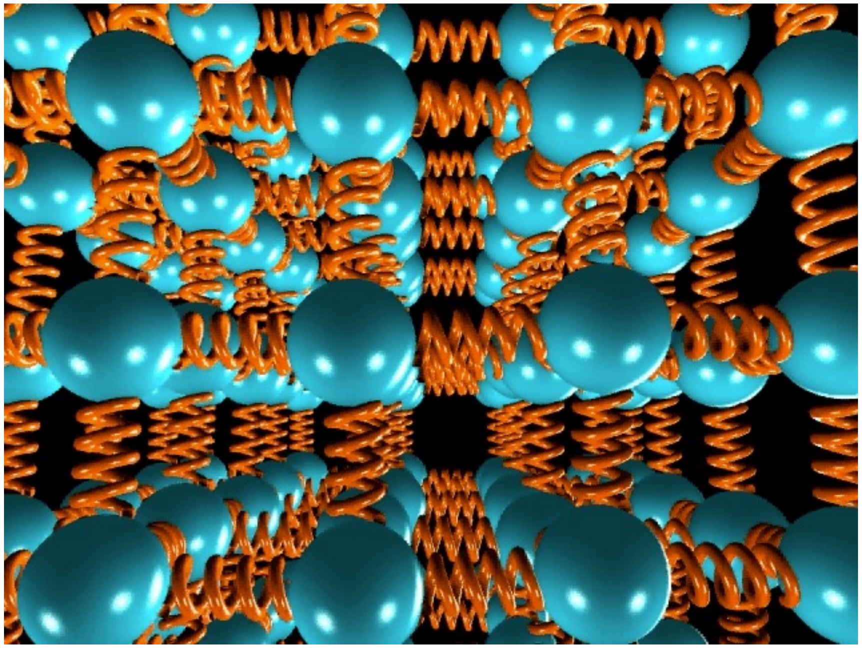
The atomic nature of matter.

- Matter can exist in three states:
  - **The solid state**: a state in which is atoms are highly ordered and strong forces between them is responsible for the preservation of order.
  - **The liquid state**: a state in which the inter-atom separation is larger than in a solid, and the atoms are not tied a specific location.
  - **The gas state**: a state in which the inter-atom separation is very large, and there is virtually no net force acting between the atoms.
- The state of matter will depend on temperature and pressure.

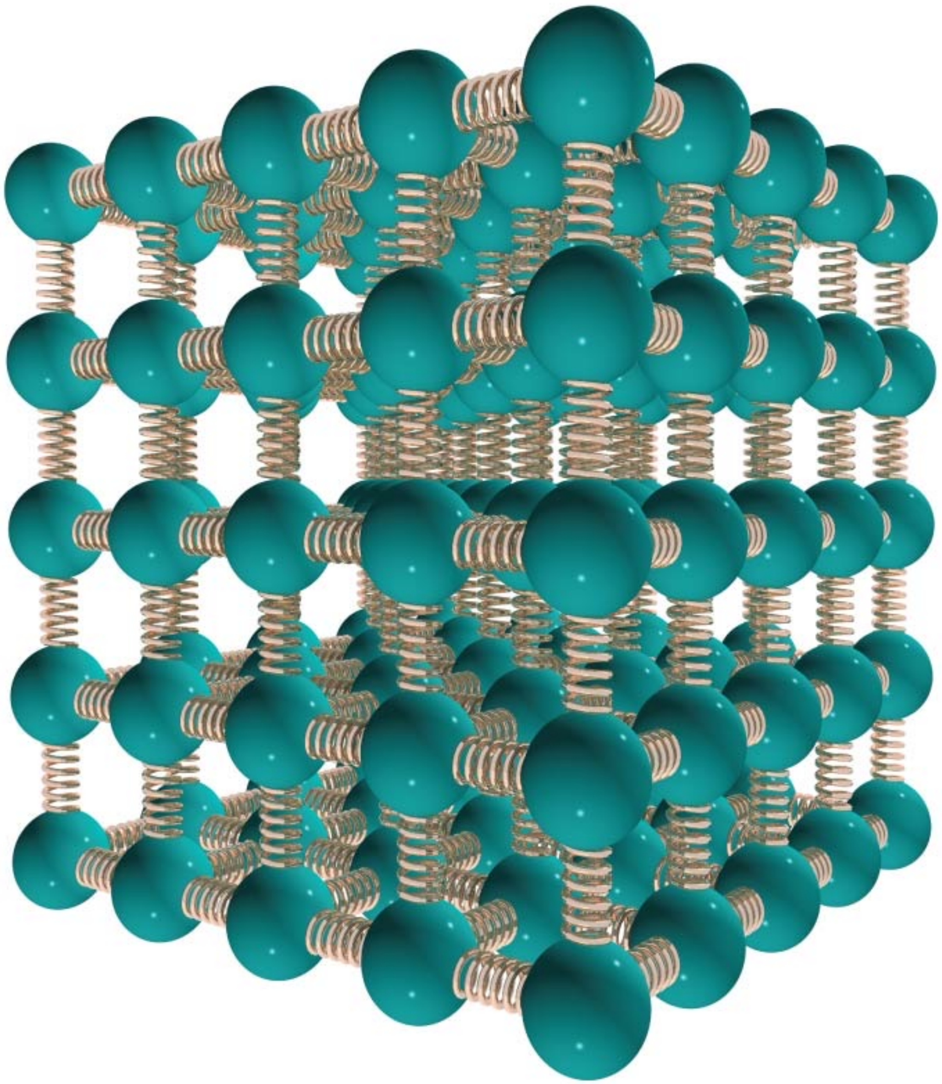


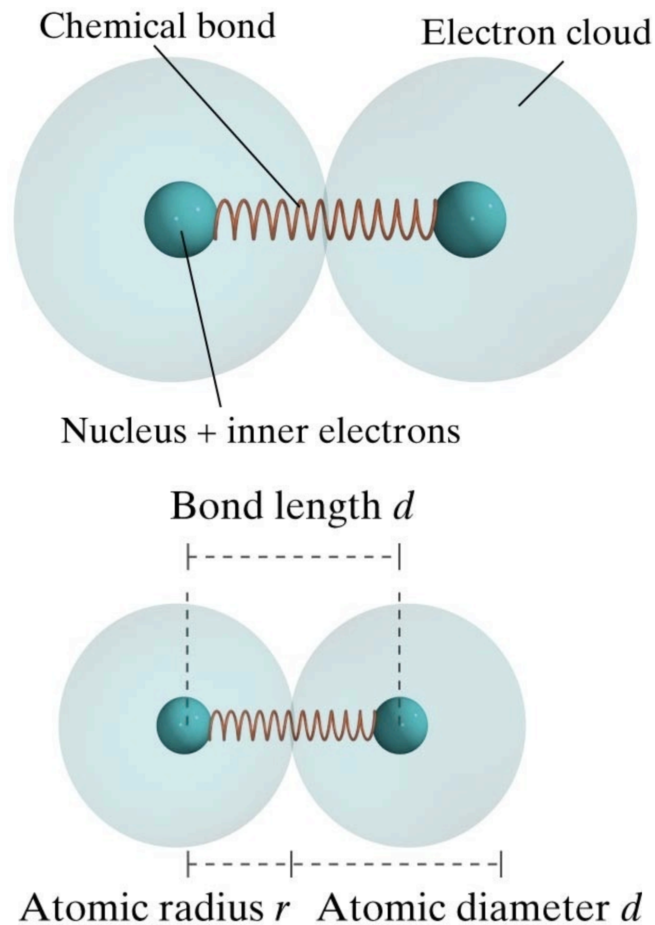
The atomic nature of matter.

- We can visualize a solid as a collection of atoms of mass m, interconnected by springs.
- The atoms are not at rest in a solid, but continuously vibrate around an equilibrium position.
- The temperature of the solid is a measure of the kinetic energy associated with the motion of the atoms.
- This simple model can explain many important properties of matter, but many others can only be explained in terms of quantum mechanics.



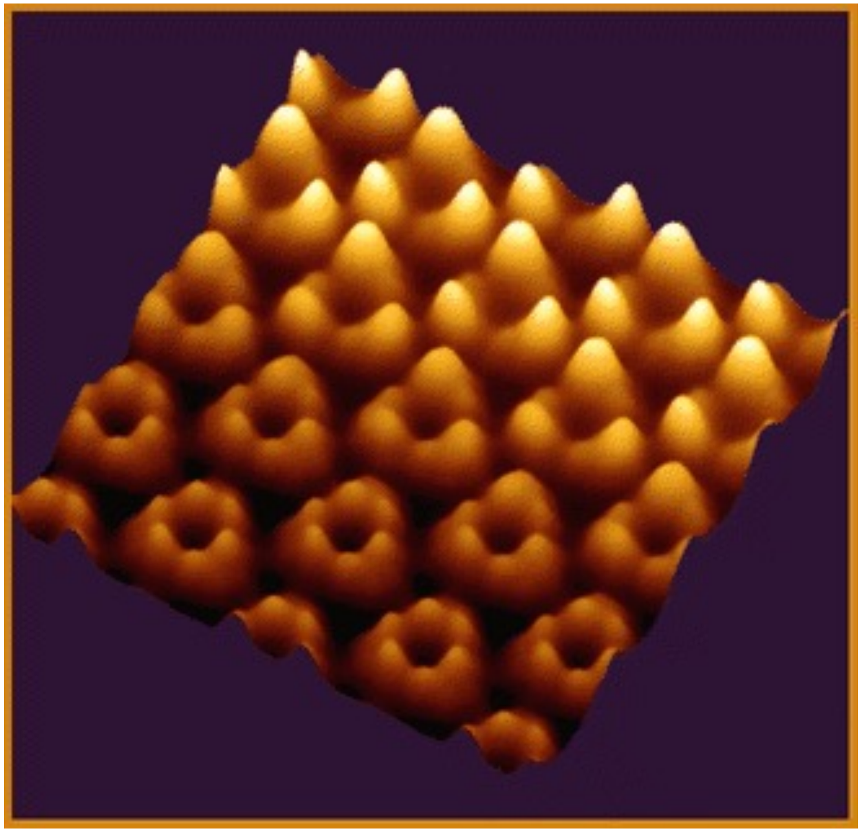
The atomic nature of matter.





The atomic nature of matter.

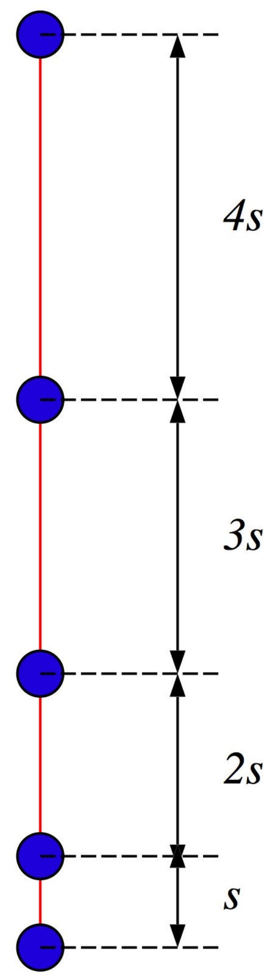
- Our understanding of the atomic nature of matter has greatly benefited from direct measurement of atomic structure using for example Atomic Force Microscopes.
- The models we use to understand the properties of matter usually will try to relate macroscopic properties of matter (such a deformation) with microscopic properties (such as the inter-atomic force).



http://www.mih.unibas.ch/Booklet/Booklet96/Chapter3/Chapter3.html

The atomic model of a wire.

- Consider an atomic model of a wire in which the atoms are connected via springs of spring constant k.
- If the system is in equilibrium, the net force on each atom must be zero.
- Consider the bottom atom: the spring must exert a force of mg in the $+y$ direction. Newton's 3rd law tells us that this spring will exert a force of mg in the $-y$ direction on atom # 2.
- Atom # 2 experiences a total force of $2mg$ in the $-y$ direction which is balanced by a spring force of $2mg$ in the $+y$ direction.
- Etc. etc.

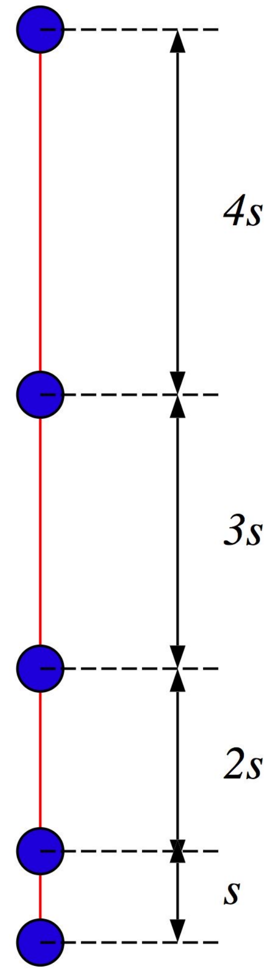


Spring force:

$$F = k\Delta x$$

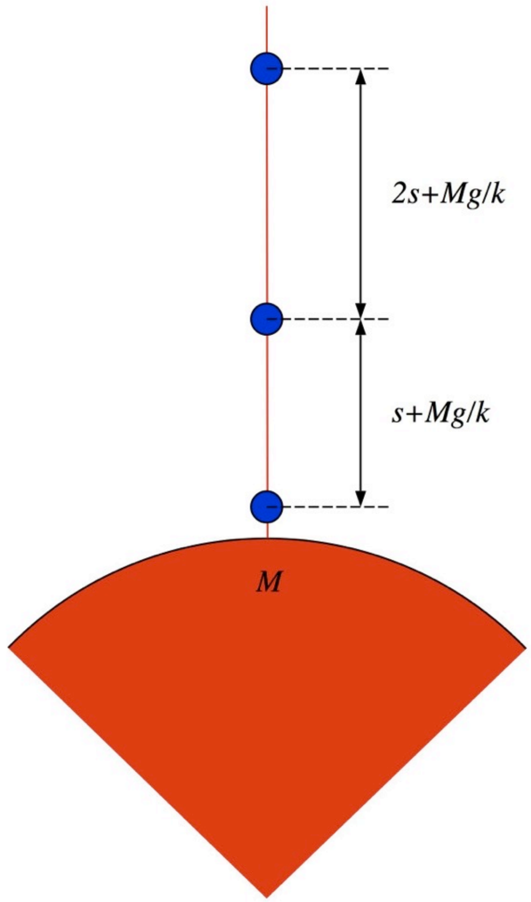
The atomic model of a wire.

- The inter-atomic separation will increase when we move up the wire.
- The assumption that the tension in the wire is constant is thus a poor approximation (in this example there is a strong dependence of the tension on position).
- This model can also explain why you observed a change in turn spacing when you hang a slinky vertically.



The atomic model of a wire.

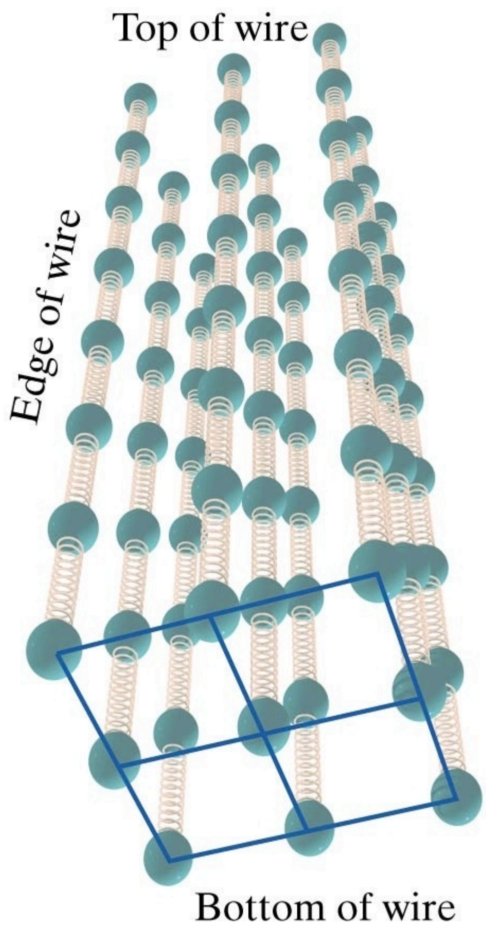
- When we connect a mass to the wire, the force that must be exerted by the springs increases dramatically, assuming that the mass M is much larger than the atomic mass m.
- Although there still will be a dependence of the spring force on position, this dependence will be much smaller than it was before.
- In this case, the assumption that the tension in the wire is constant is a good approximation.

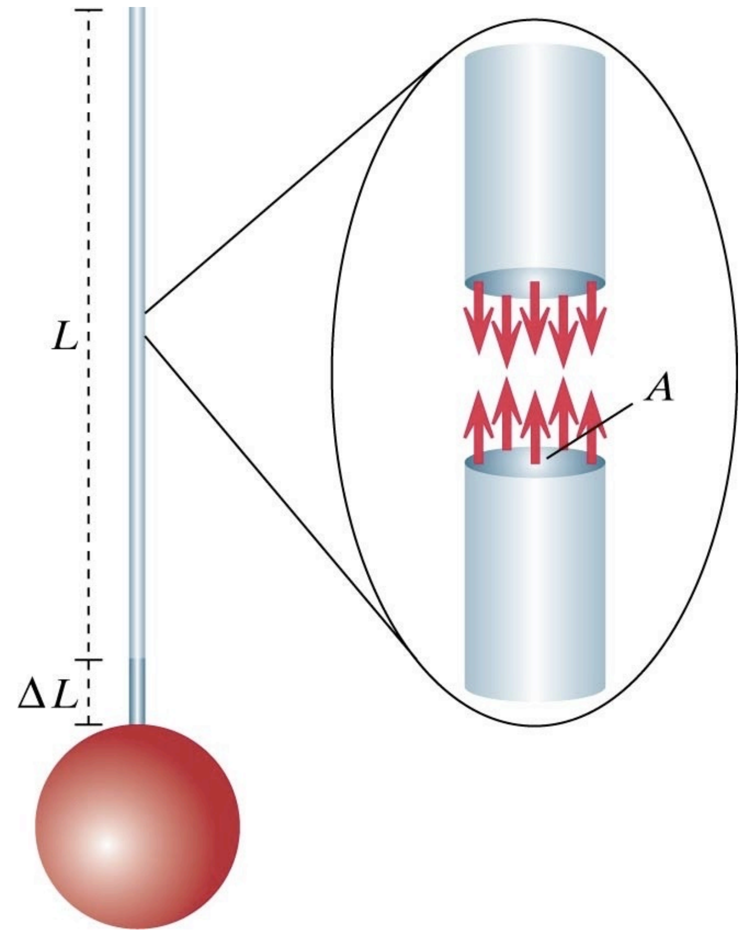


2 Minute 44 Second Intermission

- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let's take a 2 minute 44 second intermission.
- You can:
  - Stretch out.
  - Talk to your neighbors.
  - Ask me a quick question.
  - Enjoy the fantastic music.
  - Go asleep, as long as you wake up in 2 minutes and 44 seconds.

Connecting the microscopic world to the macroscopic world.





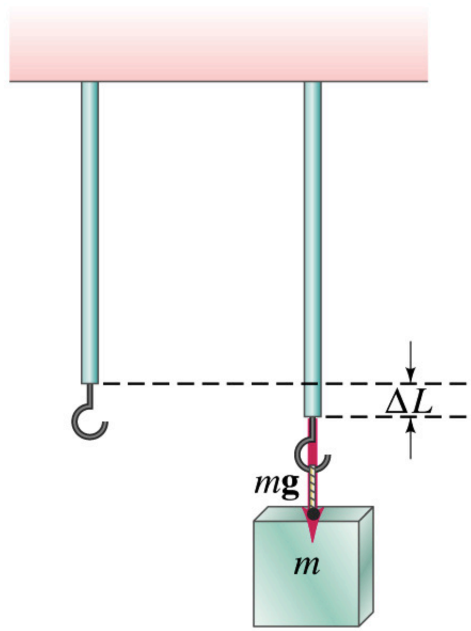
Stress and strain.
The effect of applied forces.

- When we apply a force to an object that is kept fixed at one end, its dimensions can change.

- If the force is below a maximum value, the change in dimension is proportional to the applied force. This is called **Hooke's law**:

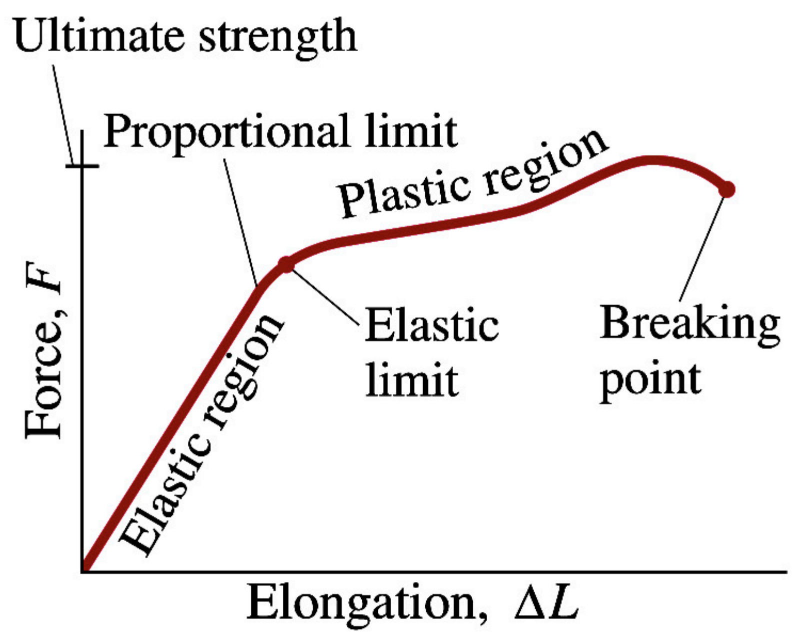
$$F = k\,\Delta L$$

- This force region is called the **elastic region**.



Stress and strain.
The effect of applied forces.

- When the applied force increases beyond the elastic limit, the material enters the **plastic region**.
- The elongation of the material depends not only on the applied force F, but also on the type of material, its length, and its cross-sectional area.
- In the plastic region, the material does not return to its original shape (length) when the applied force is removed.



Stress and strain.
The effect of applied forces.

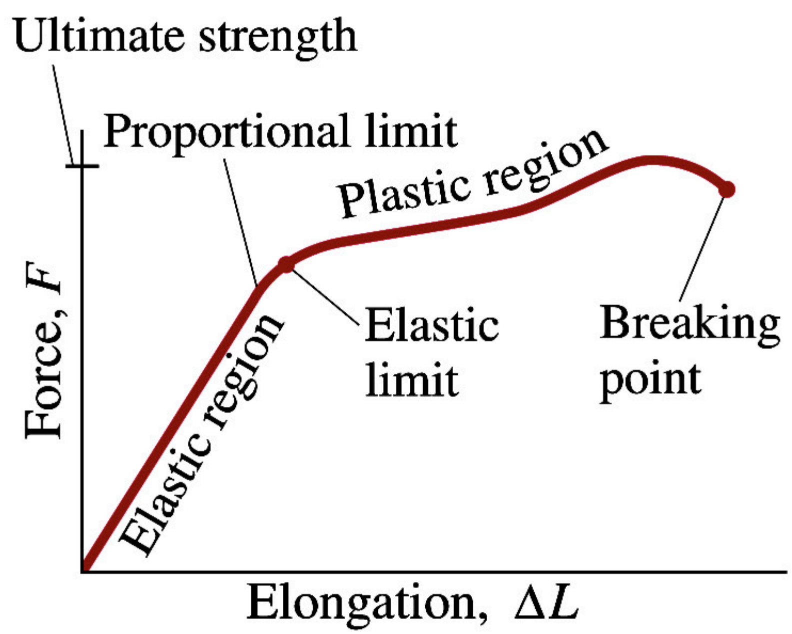
- The elongation ΔL in the elastic region can be specified as follows:

$$\Delta L = \frac{1}{Y}\frac{F}{A}L$$

where

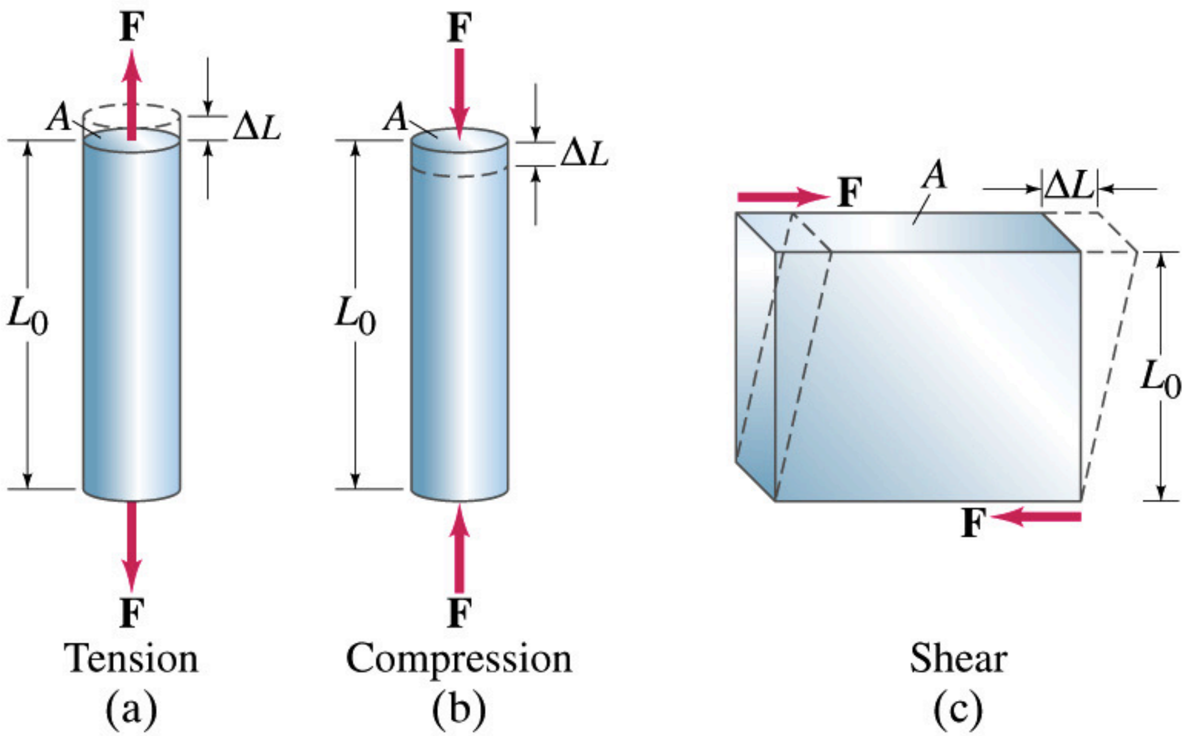
L = original length
A = cross sectional area
Y = Young's modulus

- **Stress** is defined as the force per unit area (= F/A).
- **Strain** is defined as the fractional change in length ($\Delta L/L$).



Note: the ratio of stress to strain is equal to the Young's Modulus.

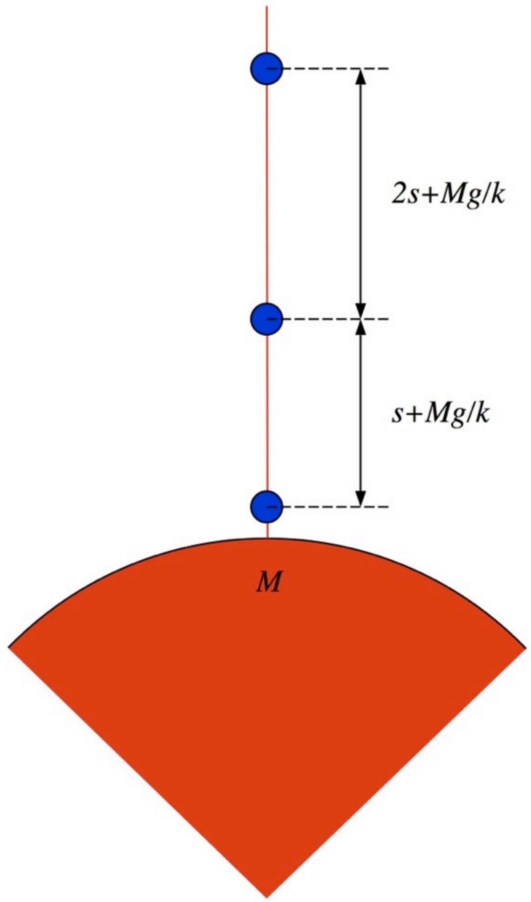
Stress.
Different types.



The response to different types of stress can differ greatly for the same material.

Relating macroscopic properties (e.g. Y) to microscopic properties (e.g. k).

- For a single atom string, adding mass M increases the length of the spring between each atom by Mg/k.
- Even a thin wire will have many parallel atom strings.
- If the volume occupied by an atom when no forces are applied is d^3 and the wire has a cross sectional area A:
  - The stress in the wire is Mg/A.
  - The strain in the wire is $\{\{(Mg/k)/(A/d^2)\}*(L/d)\}/L = (Mgd)/(kA)$.
  - The Young's modulus is thus equal to Y = stress/strain = k/d.



Atomic models.

- Although we can understand many properties of materials, such as expansion, stress, strain, and the velocity of sound, in terms of a simple atomic model with springs, other properties, such as conductivity, require a quantum mechanics model to be understood.

- Using these models we can extract information about the microscopic properties of the materials, such as the effective inter-atomic force, from the macroscopic properties that can easily be measured, such as the Young's modulus.

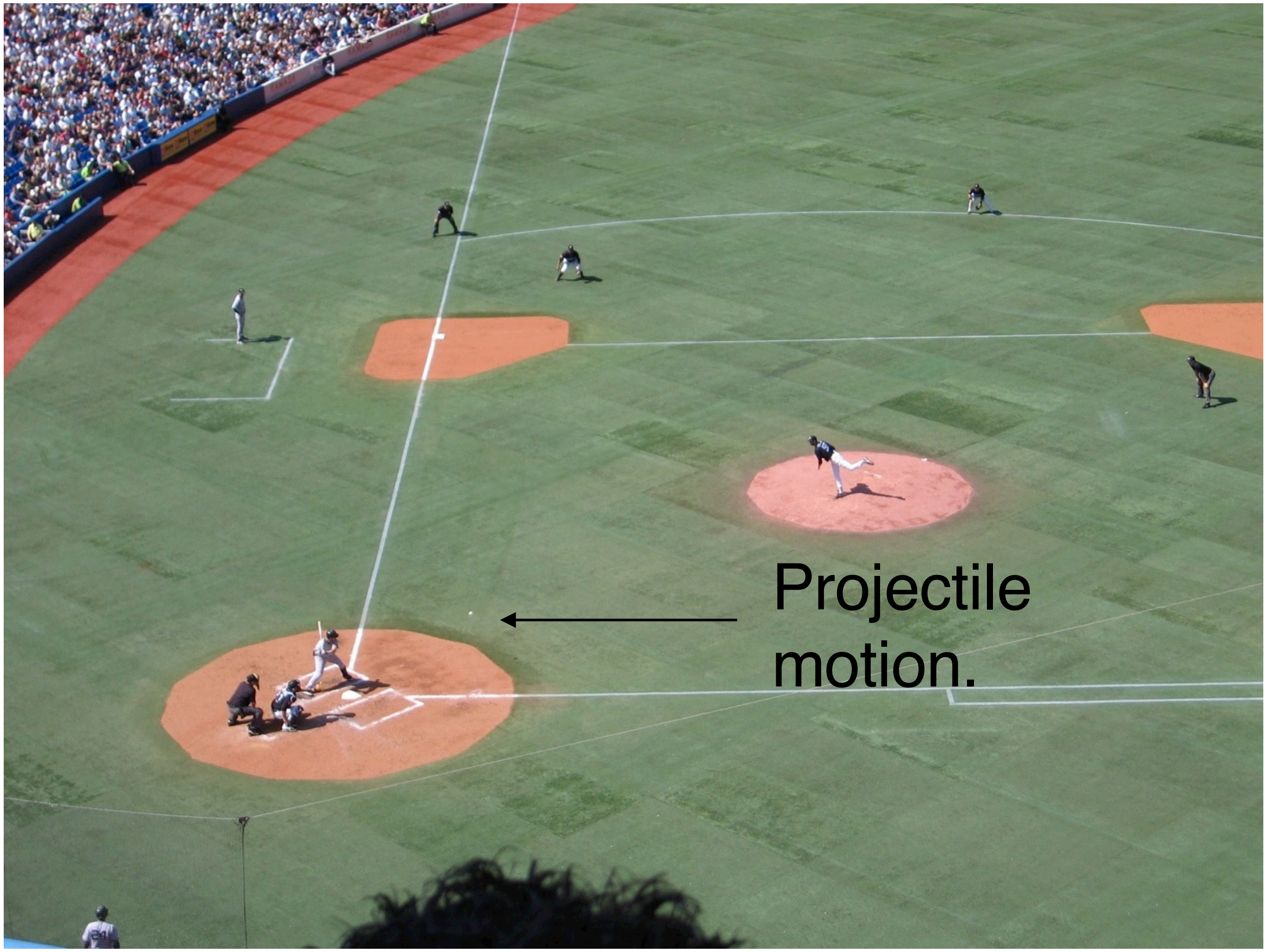
Atomic models.

- The atomic model is also very successful in predicting the speed of sound in solids. Even a simple VPython calculation produces a result that is amazingly close to the measured value. See for example, Speed_of_Sound.py – available on the WEB.
- Note: for a long time, sound and light were both considered to be “waves” that need a medium to travel through. When a sound wave hits a material, it starts a vibration in a material, and the coupling between atoms is responsible for the sound propagation. If there is no material, there is no sound.
- Light on the other hand does not need a medium and travels without a problem in vacuum.

The spring-mass system.

- The key to the understanding of the atomic model of matter is the understanding of the spring-like interaction between the atoms.
- Since matter will never be at the absolute zero temperature, the atoms will have a non-zero average kinetic energy (proportional to the temperature of the matter).
- Since the atoms will move, the "springs" in our model will carry out a dynamic motion which we will need to understand in more detail. This will be the focus of lecture 7.

Done for today!



Yankees in Toronto