- In chapter 3, we discussed the four fundamental forces

  Every force we draw on a FBD is ultimately one of these 4

- On a macroscopic scale, we can't always exactly find every force, so we lump them together into "normal", "tension" "friction", etc...

  $\boxed{\text{These are all manifestations of the combined EM forces of billions of individual particles}}$

- We will do something similar here
- In chapter 6, we introduced energy and its fundamental forms

  In chapter 7, we deal with energy on a macroscopic scale (if our system is more than a point of mass)

In all of our chapter 6 examples, we assumed every object could be treated as a single point of mass

---

- Ball falling to Earth
- Comet orbiting Sun
- Mass colliding w/ spring

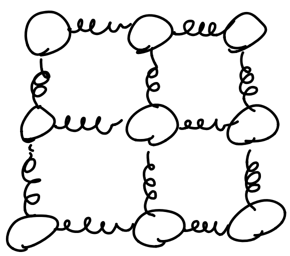
What is the energy of a point mass?

rest + kinetic (no potential)

This model is often useful, but is ultimately incomplete

- For a more descriptive model, let's go back to chapter 4

In chapter 4, we learned that a solid can be thought of as a grid of balls and springs



- contact w/ other objects compresses the springs & exerts a force (friction, normal)

- For a single point system that is at rest the energy is the rest energy $E = mc^2$

- For an extended object at rest, I also have to consider $K + U$ for each ball & ball spring system that makes up the solid

- How can there be kinetic energy if the solid is not moving?

- What do we mean by "moving"

Far beyond the atomic scale of things, the object is not moving

- I can pick any point on it, measure its position $\vec{r}$ @ two different times, + I will find $\Delta\vec{r} = 0$ $(\vec{v} = 0)$

If I zoom in so I can see individual atoms, they are always in motion

- rotating, vibrating, etc
- impossible for them not to!
- motion is random

Show animation

(speed + direction random)

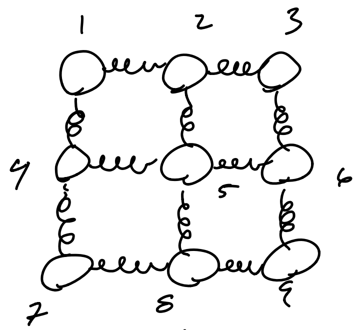
Average position doesn't change

For every $\circ \longrightarrow$

There is a $\longleftarrow \circ$

- If all motions aligned, the object itself would move
  This is unimagenably unlikely, but not impossible

So even if it's not moving or interacting,
the solid has some amount of energy
E_0 due to random motion & spring
potential energy



$$E = \tfrac{1}{2}mv_1^2 + \tfrac{1}{2}mv_2^2 + \ldots + U_{12} + U_{23} + \ldots$$

Now if the box moves w/ speed v

$$E = \tfrac{1}{2}mv_1^2 + \tfrac{1}{2}mv_2^2 + \ldots + U_{12} + U_{23} + \ldots$$
$$+ \tfrac{1}{2}mv^2 + \tfrac{1}{2}mv^2 + \ldots$$

- The random motion of the atoms & the overall motion of the box are separate

$$E = E_{int} + K + U$$

We call the energy associated with this random motion the internal energy

- "Normal" Energy: Kinetic + potential of the macroscopic object (energy it would have if it were just a point mass)

- Internal Energy: energy assoc w/ random motion inside the object (vib, rot, spring compression, etc)

- How do we calculate internal energy?

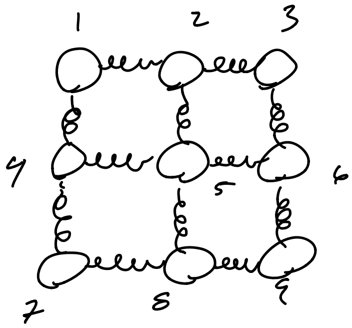
  Add up $\frac{1}{2}mv^2 + U$ for every mass + spring

- What is U_{spring}?

$$F = -ks$$

$$F = -\frac{dU}{dr}$$

$$-\frac{dU}{ds} = -ks \rightarrow dU = ks\,ds \rightarrow U = \frac{1}{2}ks^2$$



So, to find E_{int},

$$E_{int} = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 + \ldots + \frac{1}{2}ks_{12}^2 + \frac{1}{2}ks_{14}^2 + \ldots$$

- Even a small object will have $> 10^{20}$ atoms in it!

$$\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 + \ldots \frac{1}{2}m_{10^{20}}v_{10^{20}}^2$$

- cant even do this w/ a Computer!

(~5 million years with Python)

Instead, we can measure average internal energy

This is what temperature is: a measurement of the avg internal energy

Here's how it works

If I put two objects with different internal energies into physical contact, the moving atoms inside will start to collide.

On average, atoms with higher energies will transfer their kinetic energy to atoms with lower energies.

This results in a net transfer of energy from the object with higher average internal energy to the object with lower average internal energy

At higher internal energy, the average separation between atoms increases, causing the object to expand

So we can use the observed change in volume of one of the objects to infer the internal energy of the object it is in contact with

Example: mercury thermometer

Place a thermometer in contact with a much larger object (say it's a solid)

Both solid and mercury have some random internal energy, their molecules will collide

- Two possibilities
  - Average internal energy of the solid is higher than that of the mercury
    - Atoms in the solid collide with atoms in mercury and transfer some of their energy to the mercury molecules
    - As the mercury molecules gain energy, the average separation between molecules increases, and the mercury expands
    - This continues until the average energy of both objects are the same.

    - Average internal energy of the solid is lower than that of the mercury
        - Now mercury molecules transfer some energy to the solid molecules, so the mercury loses energy
        - As this happens, mercury contracts
    - In either case, the change in volume of the mercury is a measure of the average internal energy of the solid
    - If the solid was much larger than the mercury, then it's energy hardly changed

Changes in Internal energy

- The measurement of temperature relies on a fundamental property of internal energy: if two objects are brought into contact, internal energy will automatically move from the object with higher average energy to the object with lower average energy, until the objects have the same average energy. (Not the same total internal energy, but the same average internal energy)
- Since temperature is a measure of average internal energy we can say this:
    - Energy will move from the object at higher temperature to the object at lower temperature, until the temperatures are equal
- This spontaneous movement of internal energy is called *heat*
- *HEAT: spontaneous energy transfer due to a temperature difference*
- Now we can update our energy principle: DEsys = Q + Wsurr
- DEsys = Ksys + Usys + Eint = Q + Wsurr

Dissipative Forces

- Q only changes Eint
- Wsurr can change all types of energy
- When a force does work that (partially) changes the internal energy of an object, we call it a dissipative force
- Examples:
    - Friction, air resistance
        - *S*ome of the work done on the object raises the temperature of the object and it's surroundings, rather than accelerating it
        - This is why spacecraft need heat shields, and why your hands get hot when you rub them together
- This also plays a role in collisions (when two objects collide, some of the energy is spent raising the temperature, hence kinetic energy is not conserved