Demo at the front of the room: two mass-spring systems, with roughly equal periods. Over the span of 10 minutes, one loses most of its motion, the other stays oscillating.

1. Last week, we introduced the concept of *energy*, an attempt to describe motion problems in terms of "stuff" that might change form, but its overall amount is constant.

Physicists find it useful to distinguish three broad classes of energies:

- Potential Energy – energy we can store to use later.
- Kinetic Energy – energy that is evident when something is actually *in motion.*
- Dissipative Energy – energy that spreads out and is "lost" in a certain way.

2. Taking the mass-spring system as an example, potential energy is stored in the spring: when the spring is compressed or stretched a lot (Points A & D), there is a lot of potential energy. As this energy is released, it becomes kinetic energy, which is largest when the mass is moving the fastest (Points C & G).

The system we will use next in lab is electromagnetic, a combination of a capacitor and inductor. The capacitor stores potential energy in its electric field (Points A & D have large charges and strong E-fields); the inductor exhibits kinetic energy in its magnetic field (Points C & G have large currents and strong B-fields).

3. The third type of energy is the one responsible for making the mass-spring system oscillations get smaller over time. As energy is traded back and forth between potential and kinetic, some if it is lost. Mostly, it ends up as heat: the spring stretches, the connections rub, the mass collides with air – all of these turn some of the kinetic energy into heat. As another example, you rub your hands together to warm them up.

The analogous dissipative energy in the electromagnetic case is the system's *resistance*.

4. The study of energy and its transformations is called *Thermodynamics*. The idea that all of the energy in a system is constant, it just changes from one form to another, is called the *First Law of Thermodynamics*.

5. Starting with a study of steam engines, but soon generalizing to many other systems, thermodynamicists realized that one never has a system go through its transitions without generating some dissipative energy. This eventually became codified as the *Second Law of Thermodynamics*. Among its expressions are:

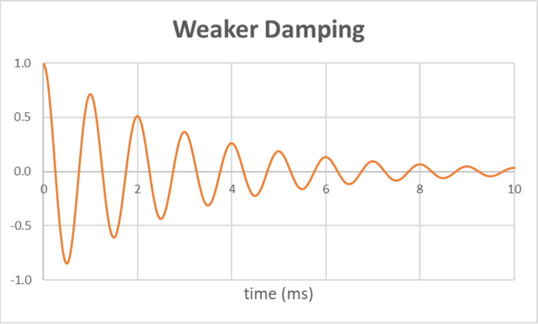
- Heat will only flow spontaneously from a hot to a cold object.
- No perfect engines that convert all of the input heat into useful work.
- No perfect refrigerators that move heat from cold to hot without doing work.
- Over time, systems become more disordered.

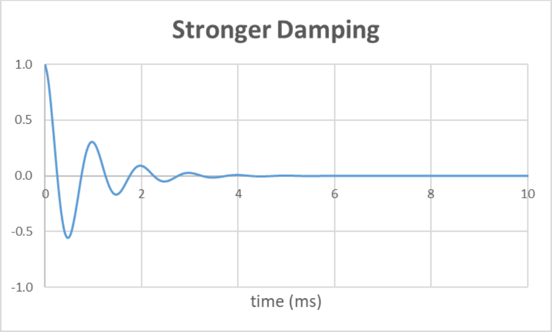
6. One of the reasons this matters so much to us is that out of all of the fundamental laws of physics, the Second Law is the only one that has a direction in time, that observes a difference between past and future. "The Arrow of Time", in some way.

7. Of the two masses we had oscillating at the front of the room, one of them has more friction, losing energy at a faster rate. How do we quantify that energy loss?

8. It is not sensible to talk about "the time when it has lost all of its energy", because it just gradually loses it bit by bit, never fully stopping. But we can distinguish how long it takes to lose a specified fraction of its energy. Putting this in terms of oscillations, we

can define the *Quality Factor*, Q, of the system as "the number of swings a resonator makes until the energy diminishes to a few percent of the energy imparted with the initial push." (J & F-R, p. 41). As shown below, the system on the left has a Q of 10 (weaker damping), while the system on the right has a Q of 3 (stronger damping).





9. We could also consider an oscillating system in terms of how we keep it going. As we will argue, if you stimulate a vibrating system with a driving frequency *near* its natural frequency, you will get a large oscillation. You are familiar with this if you have ever kept a little kid going on a swing. To make that pendulum (the resonator) maintain a large oscillation, you (the energy source) have to push at a frequency that matches the frequency at which the child-pendulum is swinging.

10. We call this process *resonance*. Specifically, this is when,

- You have a system with a natural frequency of oscillation f_0,
- You provide energy with a driving force at frequency f,
- The amplitude of the oscillation depends on frequency, and is only large if $f \approx f_0$.

As we will explain, this is a fundamental process that is at the heart of countless physical phenomena, including the operation of many clocks.

11. You might reasonably ask about the "$f \approx f_0$" condition? How close must f be to f_0? Although it is not obvious at all, the answer to that is related to the Q factor.

If a system has a large Q factor, if the oscillation takes a long time to damp out, then it turns out that only a narrow range of frequencies will excite it. But a system has a small Q factor, if the oscillation takes a short time to damp out, then it turns out that a wide range of frequencies will excite it. The two graphs below correspond to the two damped oscillators shown above. In lab next week, you will see this.