8.3: Wrap-Up

In this chapter we have learned how to find the details, and particularly, the time dependence of interacting systems: we use Newton's second law. We know how motion is connected to forces. But as we see, things can get pretty "messy" very quickly, when we look at the details.

We previously mentioned some of the limitations of our models. As we go to atomic sized systems Newton's laws totally break down. Energy and momentum become quantized, but still exist and the idea of conservation exists. However, at atomic sizes we have to get a totally new model to replace the Newtonian model. As we get to systems the size of atoms and molecules, a different fundamental law of nature takes over. The various aspects of this very different law of nature are collectively known as quantum mechanics. One way to represent what is going on in quantum mechanics is with what are called wave packets (probability waves). Particles cease to have meaning in terms of what we normally think of as a particle. An electron is modeled not as a particle circling the nucleus, but is represented by a probability wave.

So, should we replace Newton's laws with wave mechanics (or any other representation of quantum mechanics)? No, not for large scale objects. The very peculiar aspects of quantum mechanics become totally insignificant as the size of the objects approach macroscopic size. In the limit of large scale objects, Newtonian mechanics is a particularly useful approximation (model) of how matter interacts with other matter. Is it a correct model? On a macroscopic level, the very weird quantum effects that the individual objects experience are simply not large enough to be observed when we look at the behavior of the macroscopic objects themselves (at least most of the time). Remember when we addressed the issue of models at the beginning of this course. We emphasized that we shouldn't think of models as being right or wrong, but rather as useful or not useful. This is probably a good way to think about Newton's laws. They are a very useful model of the interactions of (most) macroscopic objects as a whole.

Why do we insert the parenthetical "most" in the previous sentence? Because, even on a macroscopic level, sometimes quantum mechanics takes charge. Consider the phenomenon of superconductivity. This is truly a quantum mechanical effect on a macroscopic scale. The electrons going around the thousands of turns of wire in a superconducting magnet act in some ways as if they were one giant electron. And they go around the wire as if there were no electrical resistance! The currents in superconducting magnets can last months or even years. The magnetic field surrounding the space in a MRI machine (magnetic resonance imaging) is created by super currents in the superconducting magnet around the outside. The electrons act sort of like the entire magnet is one giant atom. But this only happens if the thermal energy is sufficiently low. Thermal energy is the "enemy" of macroscopic quantum effects. At the present time, these superconducting magnets must be kept at "helium temperatures", so called, because liquid helium is used as the refrigerant. At atmospheric pressure the boiling point of helium is 4.2 K, and this is the temperature of the magnet coils.

There is another limit to the applicability of Newton's laws that has nothing to do with size, but rather with speed. When objects move relative to each other with speeds that are not significantly less than the speed of light, very strange behavior begins to be observed. Clocks run slow. Distances shrink. We enter the strange world of special relativity. One thing Einstein's theory of special relativity, developed a hundred years ago, is telling us, is that our concepts of space and time are not "correct". That is, there really isn't a three dimensional space and an independent time. Rather, space and time get all tangled up. This, of course, plays havoc with Newton's laws! Every time you watch television, you are a witness to an example of one of the consequences of special relativity: namely, that nature has an ultimate speed limit of the speed of light: $3 \times 10^8 m/s$. The electrons that are "fired" out of the back end of the picture tube travel toward the phosphors on the screen at almost the speed of light. As energy is transferred to the electrons by an electric field, their energy increases, but pretty soon their velocity approaches the speed of light. Does this mean their kinetic energy can't increase further. No, it is as if their velocity tops out at just under the speed of light, but their *mass* increases. Pretty weird and fascinating stuff.