Introduction to Thermodynamics and Statistical Mechanics

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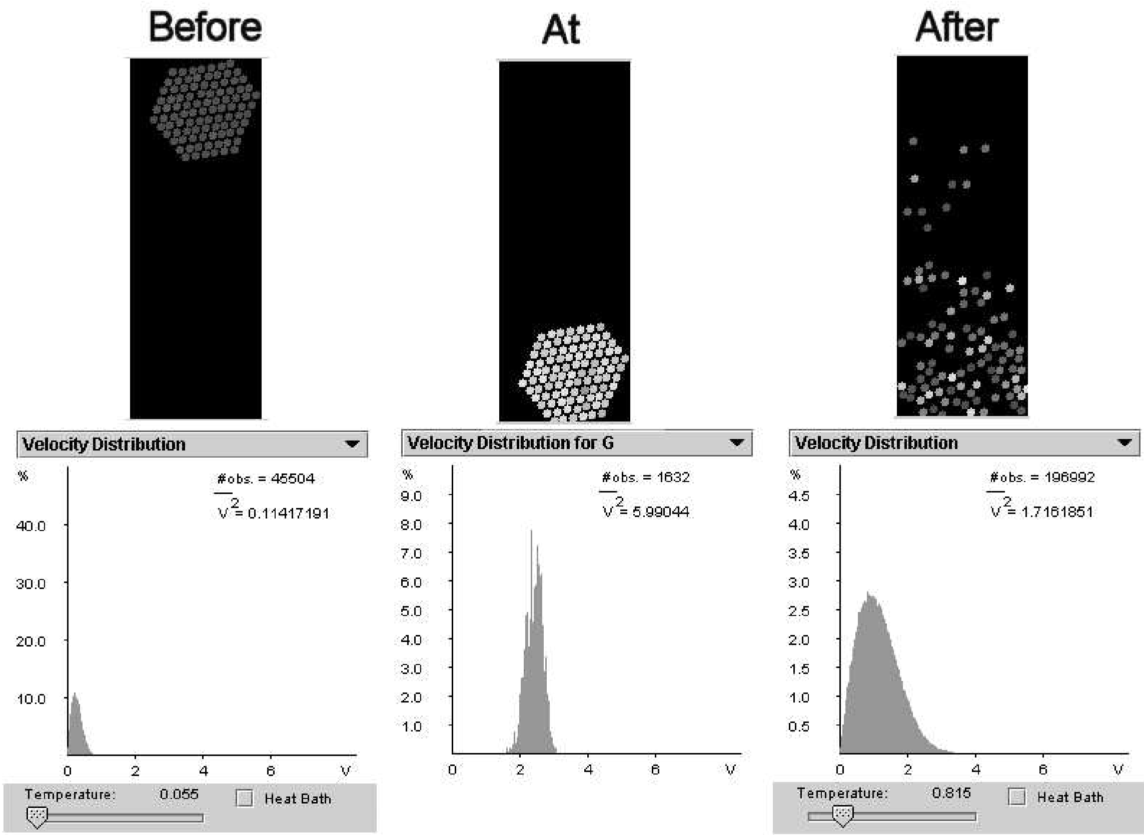
An introductory course for students in the Physical Sciences and Engineering.



Whether physicists, chemists, biologists or engineers, we gain our primary understanding of nature through the study of its macroscopic properties. These are constrained by matter's structure: an enormous number of microscopic particles, interacting with each other in a state of constant motion. The study of this behavior is known as *thermodynamics*.

Thermodynamics is based on two very important laws. The First Law is equivalent to the law of energy conservation. For example, a stone falls from a mountain and comes to rest at the bottom of a valley. According to the First Law, the mechanical energy of this stone does not vanished but is split into very small kinetic energies of the atoms moving in random directions. This energy of random atomic motion is felt by us as heat. Accordingly, the stone and its surroundings get hotter. Conversely, one can imagine a reverse process, like in the movie played backwards: the velocities of all the atoms in this stone due to collisions with surrounding atoms become vertical, so the stone jumps back on top of the mountain and gets colder. This event does not contradict the laws of Newtonian or quantum physics, however it can never happen according to the Second Law of thermodynamics, which states that the degree of disorder in any closed system cannot decrease.

These two laws have great implications across all scientific disciplines: for chemists who use them to predict which reactions will happen and which will not, for engineers who aim to design high-efficiency engines, and for biologists to study the microscopic processes in the human body (at the level of cells and even individual molecules).

We will derive all the predictions of thermodynamics by applying sophisticated mathematical techniques of multivariable calculus to the two Laws of thermodynamics. Our aim, however, is rarely to make particular quantitative predictions, but rather to set general limits of permissible physical processes. The aim of *statistical mechanics* is to derive the macroscopic properties of matter (and, as a consequence, the predictions of thermodynamics) from the microscopic laws of atomic interactions. However, this is possible only in case of a few highly simplified models; even these models require extremely complex mathematical calculations.

These days, fortunately, we have computers to come to our aid. Simulations allow us to visualize molecular motion and thus bridge the gap between the microscopic world of atoms and macroscopic world of thermodynamics. These visualizations make abstract knowledge a part of our everyday experience and clarify many difficult concepts such as entropy and free energy which would otherwise be based solely on mathematical formalism.

In this course, we will use computer simulations as much as possible, but the goal is not to turn the study of thermodynamics into a video game. Instead, the simulations will be there to help us understand and master the fundamental principles of thermodynamics. A rigorous understanding of the underlying mathematical methods will be stressed; grades will be based on your ability to solve theoretical problems.

The primary text for this course will be a classical textbook "Thermodynamics" by one of the greatest physicists of the past century, Enrico Fermi. I will also use textbooks *Introduction to Statistical Physics* by Kersong Huang, *Thermal Physics* by Daniel Schroeder and *Classical an Statistical Thermodynamics* by Ashley Carter.

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