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- Extensive and Intensive Variables
- Thermodynamics: Not Just for Gases
- A Statistical Interpretation of Entropy
- Entropy Increase as "Time's Arrow"

Extensive and Intensive Variables: I

- The various variables that we have examined in studying thermal physics neatly separate into two distinct types:
- **Intensive variables** (such as pressure, temperature, and density) are independent of the size of a system.
- **Extensive variables** (such as mass, volume, internal energy, and entropy) are directly proportional of the size of a system.

Extensive and Intensive Variables: II

Some easy rules relating to intensive and extensive variables:

- The product or ratio of two intensive variables is an intensive variable.
- The product of an intensive variable and an extensive variable is an extensive variable.
- The ratio of an extensive variable to an intensive variable is an extensive variable.
- The ratio of two extensive variables is an intensive variable.
- You don't get physically meaningful variables from . . .
  - . . . multiplying extensive variables
  - . . . dividing an intensive variable by an extensive variable

Thermodynamics: Not Just for Ideal Gases

For simplicity, much of our discussion of thermodynamics has dealt with systems consisting of ideal gases. Do not conclude that thermodynamics only or even mainly applies to ideal gases: the concepts and methods apply to all systems possessing a large number of degrees of freedom.

Statistical Interpretation of Entropy: I

- Thermodynamic states are referred to as macrostates.
- Since the work of Ludwig Boltzmann, it has been recognized that it is the microscopic states, or microstates, that are equally probable in a system in thermodynamic equilibrium.
  - Only with the development of quantum mechanics, years after Boltzmann's death, did physicists come to understand that the microstates are the various possible quantum states of the system.
- Typically, different macrostates have differing numbers of microstates associated with them. Thus, different macrostates are NOT equally likely in thermodynamic equilibrium.

Statistical Interpretation of Entropy: II

- The entropy of a given macrostate is defined by $S = k \ln\Omega$, where Ω is the number of microstates associated with the given macrostate. The use of the logarithm is necessary so that the entropy is extensive. For a system consisting of two weakly interacting subsystems, $S_{tot}=S_1 + S_2$.
- With the fundamental assumption that all microstates are equally likely at equilibrium, we see that the most likely macrostate is the one which has the greatest entropy.
- Because even small systems contain many trillions of atoms, it is very often the case that the most likely macrostate is OVERWHELMINGLY more likely than other macrostates. Hence we can talk about THE equilibrium state and THE entropy at equilibrium.
- But, strictly speaking, entropy increase is merely (MUCH) more likely than entropy decrease: the 2nd law is a statistical law.

Entropy Increase as Time's Arrow

- Imagine that a movie is made of a physical system, and that the movie can be played either backward or forward.
  - For a system with just a few degrees of freedom, we cannot judge which way the movie is being played.
  - Even if the system has many degrees of freedom, if the movie is made of a system that is in equilibrium, we cannot judge which way the movie is being played.
  - However, if the system has many degrees of freedom and the system is far from equilibrium when the filming starts, then it is EASY to tell which way the resulting movie is being played.