Today

I. Logistics wrap up: in-person meetings, first Hw posted, recording
II. Theme of the Course
III. Macroscopic observables
IV. Extensivity and the Fundamental Equation of Thermodynamics

All classes will be recorded and posted publicly to our course website.

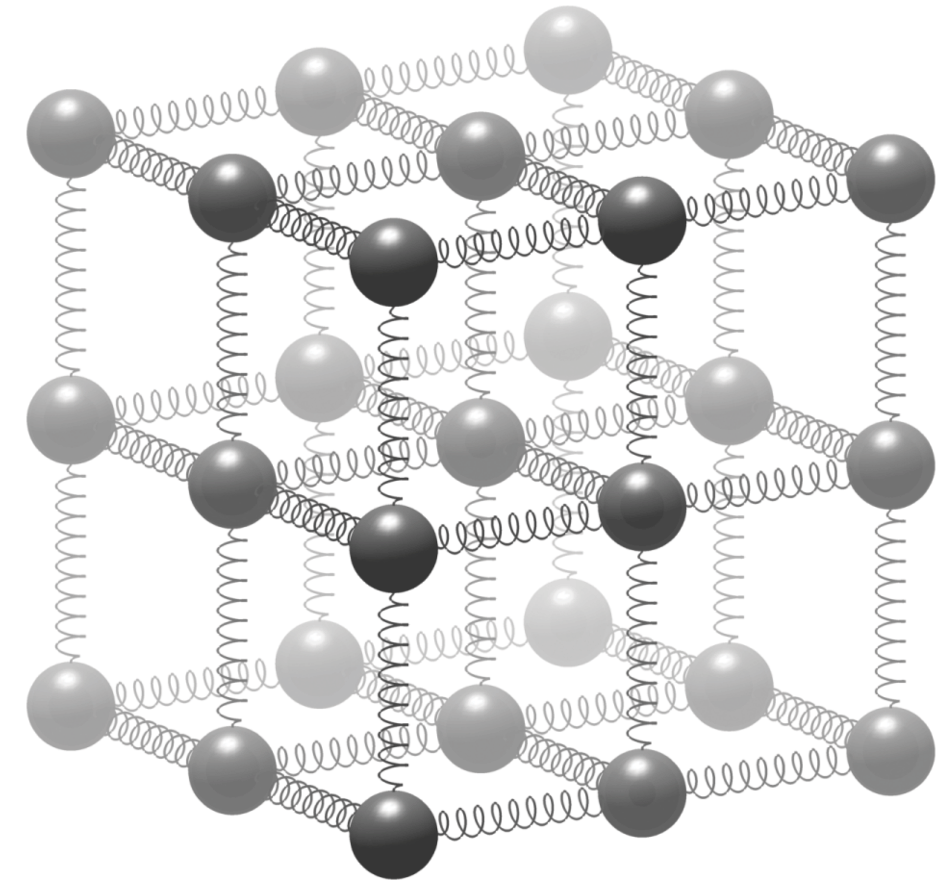
The main theme of our course is going to be connecting the microscopic world to the macroscopic world we see around us.

When we're focused on macroscopic observables we call the theory Thermodynamics. When we’re focused on the statistical properties of the large collections atoms or molecules that make up a macroscopic body we call theory Statistical Mechanics.

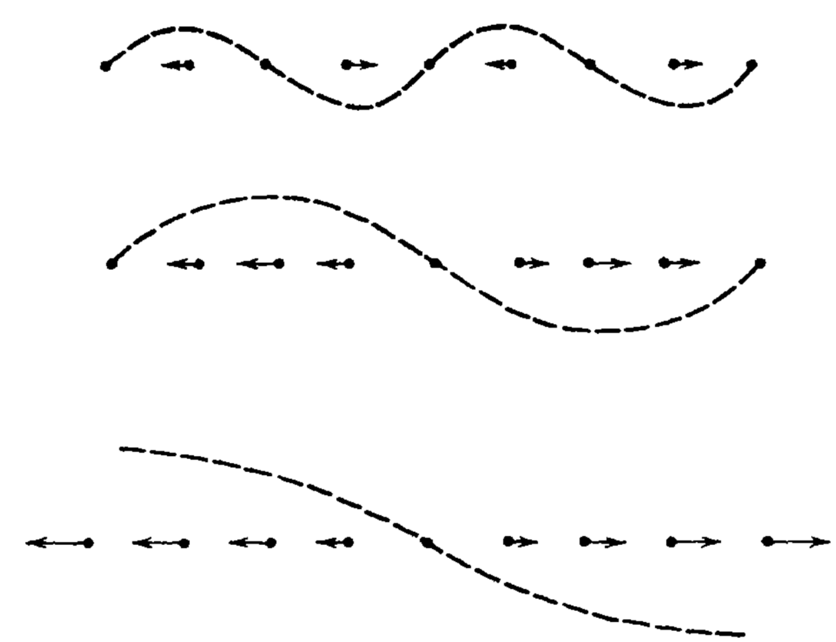
II. Macroscopic Observables

If we drop some cream into a cup of coffee and mix it. After the cream has mixed in and the coffee-cream mixture is no longer rotating, we say that the cup of coffee is in (approximate) thermal equilibrium. In fact, the coffee-cream is hotter than the room it's in and will give up energy to the room (via evaporation). Only after it has come to the same temperature as the room will it be in thermal equilibrium.

An Einstein Solid



The Nature of macroscopic observables



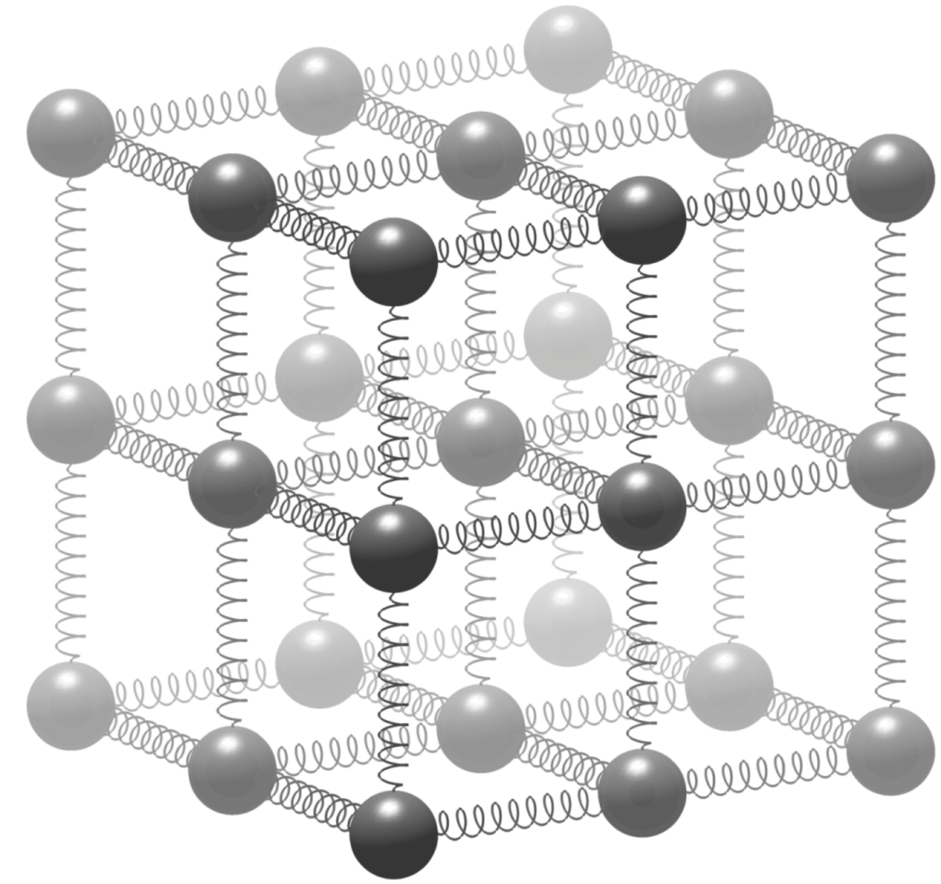
II. Macroscopic Observables

Temperature is what you measure with a thermometer.

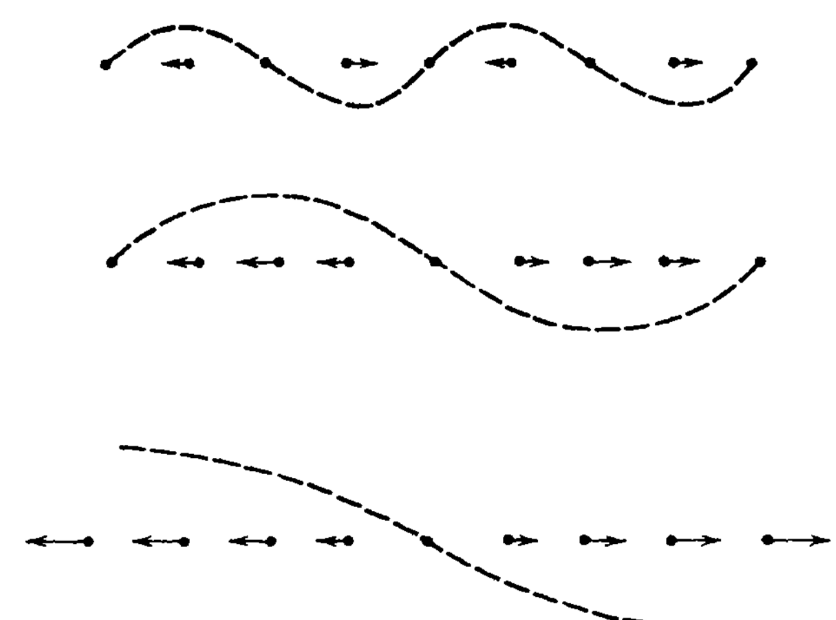
To describe equilibrium we have to decide on two things: (1) the system that we are describing=the molecules or atoms that we are averaging over a spatial region; (2) a time scale=the amount of time we are averaging over.

The macroscopic observables emerge out of these two averaging procedures.

An Einstein Solid



The Nature of macroscopic observables

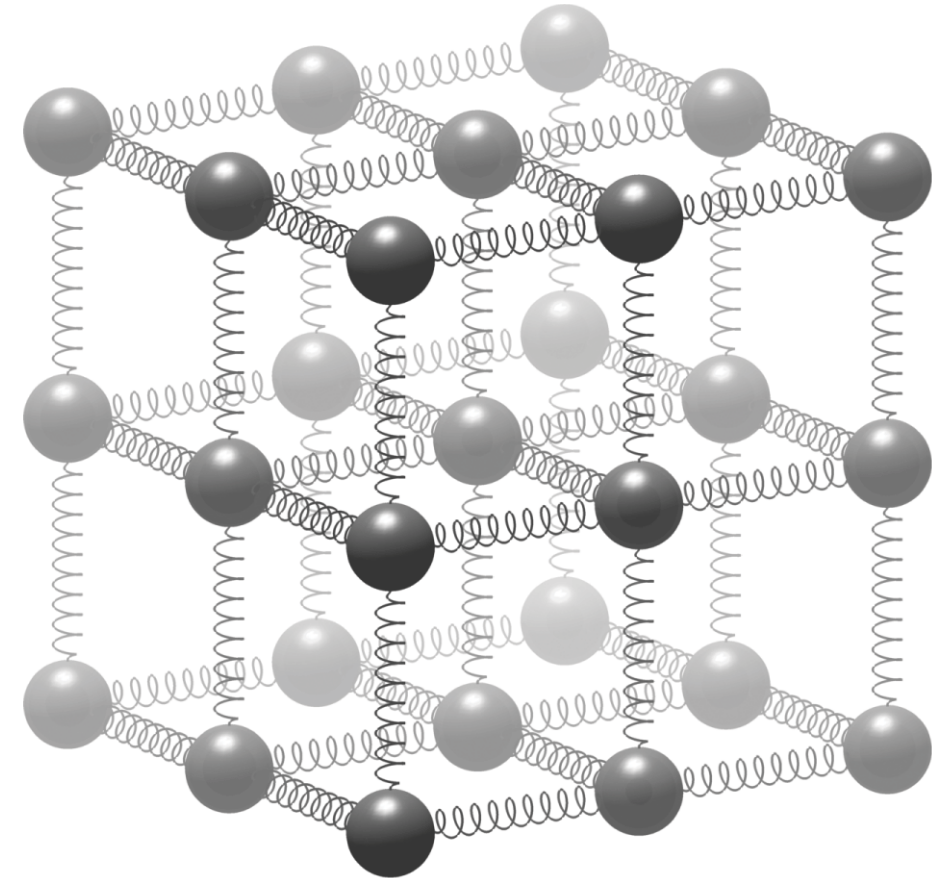


II. Macroscopic Observables

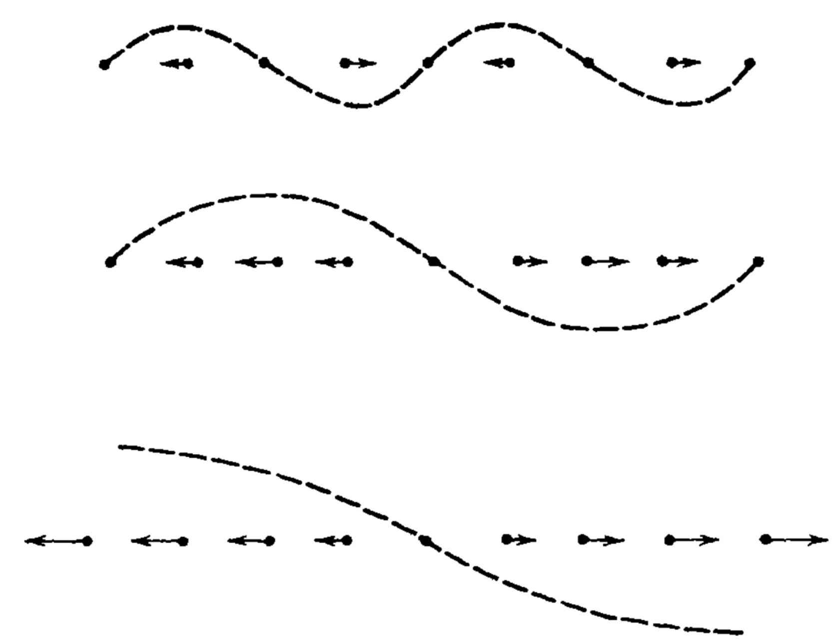
Notice that the normal mode motions that have greater spatial variation are also the same modes that have higher frequency motion. This means that when we average over space and time, we find that the most complex motions are averaged away.

On the other hand, the macroscopic volume is related to the global translation of all the atoms together, and this will survive the averaging! So, we have our first macroscopic observable *V*. What else survives?

An Einstein Solid



The Nature of macroscopic observables



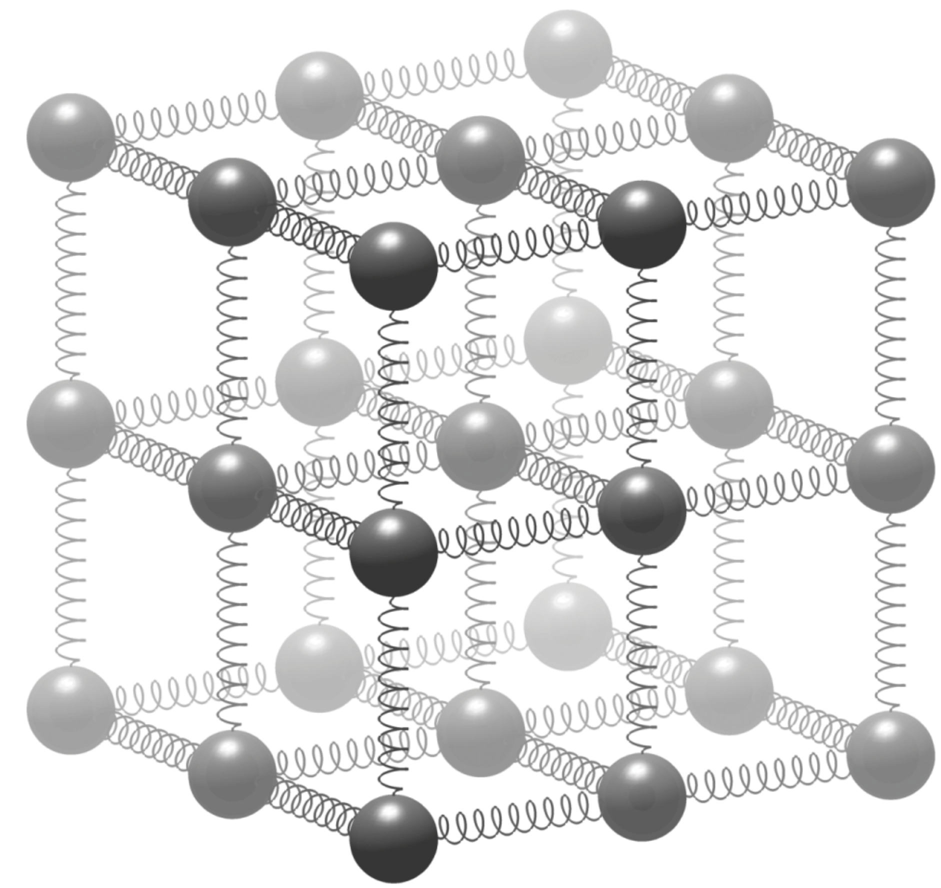
II. Macroscopic Observables

What else survives? If I measure the mass of a chunk of material and I know the mass of a single constituent, I can extract the number of atoms or molecules *N*.

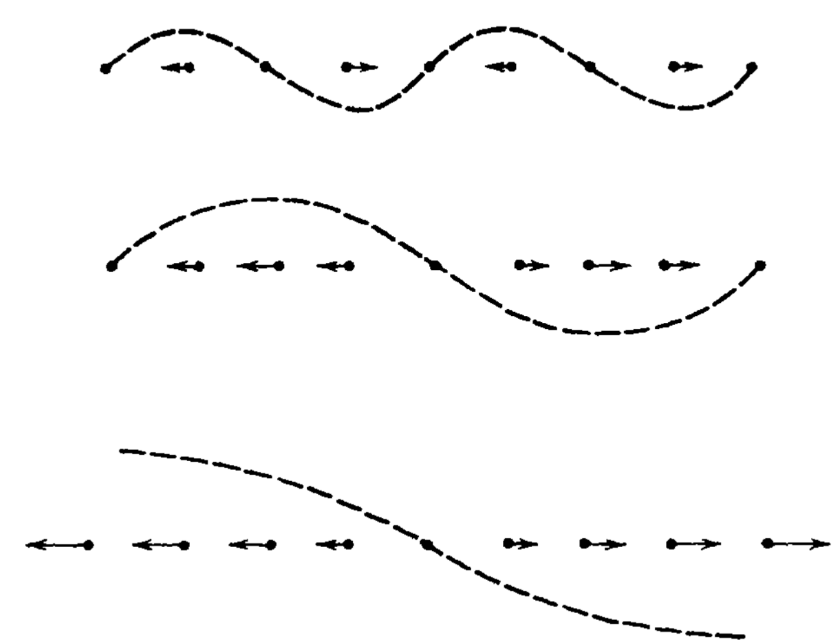
One more is the "internal energy", *U*.

An <u>extensive variable</u> is one that directly scales with the size of the system (e.g. if you make two identical copies of the system and put them together the variable doubles).

An Einstein Solid



The Nature of macroscopic observables

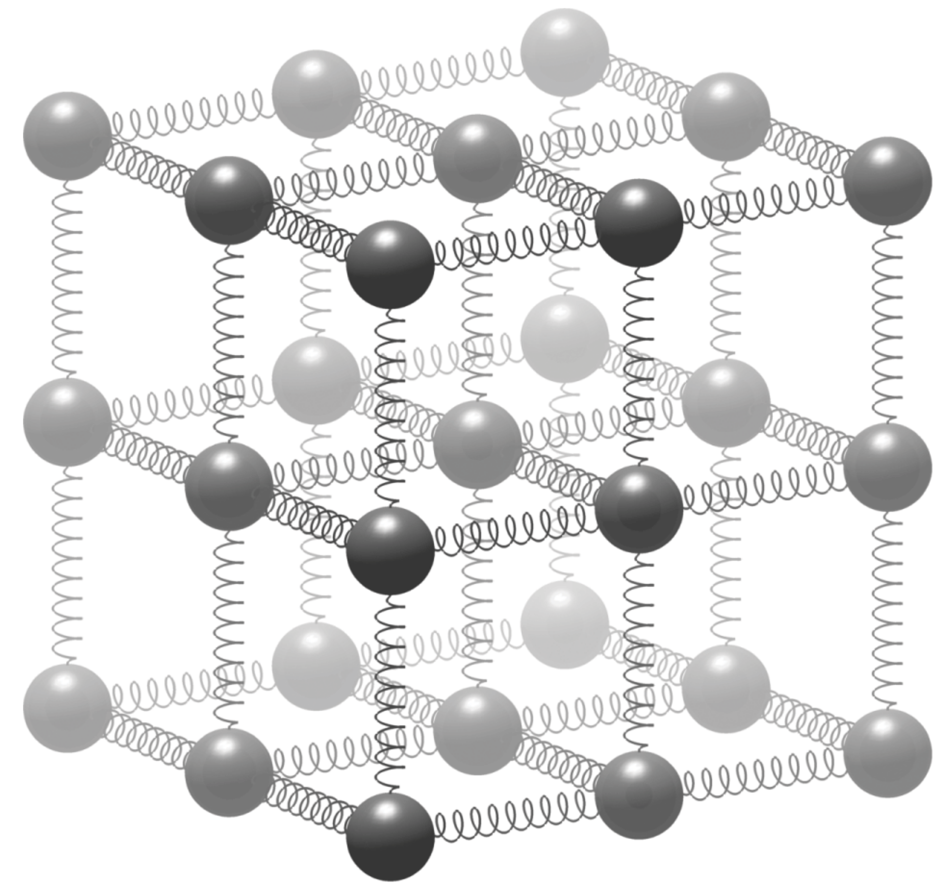


II. Macroscopic Observables

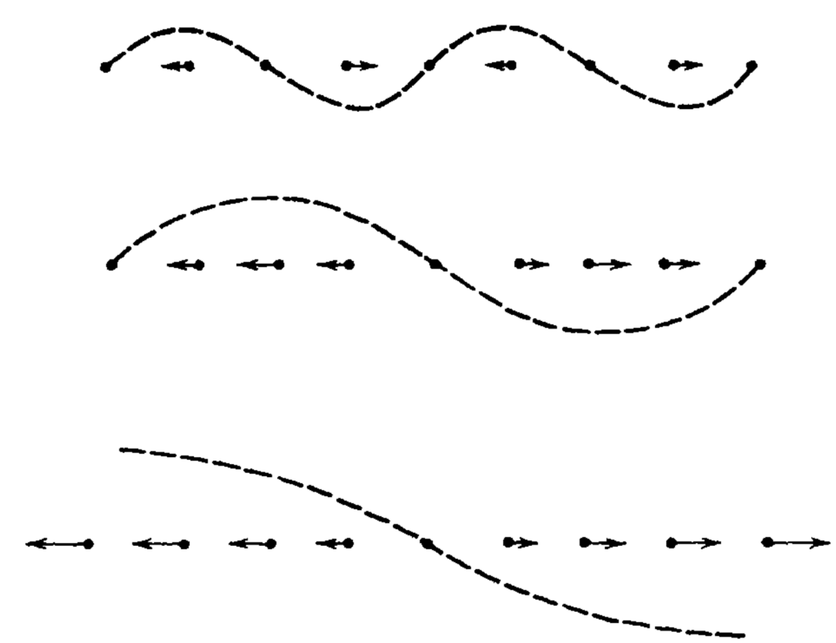
An <u>intensive variable</u> is one that does not scale with the system size at all. E.g. it remains exactly the same when you double the system. Examples: P pressure, T temperature. There is a myriad of ways to make intensive variables, e.g. by taking a ratio:

$\rho = \frac{M}{V}$ density.

An Einstein Solid



The Nature of macroscopic observables



IV. Extensivity and The Fundamental Equation of Thermodynamics

On more interesting (fascinating, cool, amazing) extensive variable is entropy S.

A fundamental postulate of Thermodynamics is that the extensive variables are not all independent. Mathematically it means that Thermodynamics is a constrained system:

$$f(S, U, V, N) = 0.$$

This function expresses the relationship between the various macroscopic parameters of the system.

Sometimes we can solve this constraint for one of the variables

$$S = S(U, V, N)\ .$$