As we have already seen the average kinetic energy of a gas sample can be directly related to temperature by the equation \( E_k(\text{bar}) = \frac{1}{2} m v(\text{bar})^2 = \frac{3}{2} kT \) where \( v(\text{bar}) \) is the average velocity and \( k \) is a constant, known as the Boltzmann constant. So, you might reasonably conclude that when the temperature is 0 K, all movement stops. However, if a molecule stops moving we should be able to tell exactly where it is, right? Oh no! That would violate the uncertainty principle, which means there will need be some uncertainty in its energy! At 0 K (a temperature that cannot be reached, even in theory) the system will have what is called zero point energy: the energy that remains when all the other energy is removed from a system (a quantum mechanical concept completely irrelevant to normal life).

https://www.youtube.com/watch?v=FnUGeYkFCCw

For monoatomic gases, temperature is a measure of the average kinetic energy of molecules. But for systems made up of more complex molecules composed of multiple atoms, there are other ways to store energy besides translation (that is, moving through space). In these situations energy added to a system can not only speed up the movement of molecules but also make them vibrate, bend, and rotate (recall we discussed this briefly in Chapter 4). These vibrations, bends, and rotations are distinct for each type of molecule; they depend upon molecular shape and composition. Perhaps not surprisingly, they are quantized. This means that only certain packets of energy can be absorbed or released depending on which vibrations or rotations are involved. Because of that, we can use these molecule-specific energy states to identify molecules and determine their structure at the atomic level. Just as we can identify atoms of elements by their electronic spectra (how their electrons absorb and emit photons as they move from one quantum level to another), we can identify molecules by the way they absorb or emit photons as the molecule moves from one vibrational or rotational state to another. Because it takes less energy to move between vibrational states, photons of infrared or microwave frequencies are typically involved in this analysis. This is the basis for infrared spectroscopy, a topic that we will return to in a separate work.

As materials become more complex in structure, more energy is needed to increase their temperature because there are more ways for a complex molecule to vibrate, bend, and rotate; some of the added energy is used up in vibrations and rotations as well as translations. The amount of energy required to raise the temperature of a particular amount of substance is determined by the molecular-level structure of the material. We can do experiments to determine how adding energy to a substance affects its temperature. Although the word heat is sometimes used to describe thermal energy, in the world of physics it is specifically used to describe the transfer of thermal energy from one thing to another. So, we will stick with thermal energy here.

The units of thermal energy are joules (J). Thermal energy is the sum of the kinetic and other potential energies of the particles in a system. There are two commonly used measures of how much energy it takes to change the temperature of a substance and, conversely, how much energy a substance can store at a given temperature: specific heat capacity (J/g °C) and molar heat capacity (J/mol °C). The specific heat of a substance tells you how much energy is required to raise the temperature of a mass (1 g) of material by 1 °C; the molar heat capacity tells you how much energy is required to raise the temperature of a mole of particles by 1 °C. The specific heats and molar heat capacity of a substance depend on both the molecular structure and intermolecular interactions (for solids and liquids, but not gases). Usually, more complex substances have a higher molar heat capacity because larger molecules have more possible ways to vibrate, bend, and rotate. Substances with strong IMFs tend to have higher heat capacities than those with weaker IMFs because energy must be used to overcome the interactions between molecules, rather than make the substance move faster - which increases the temperature.
References

92 Translational energies are also quantized but the quanta are so small that in practice we do not need to worry about that.

93 There are a number of different energy units, including calories, but they are all measures of the same thing, so we will stick to joules here.