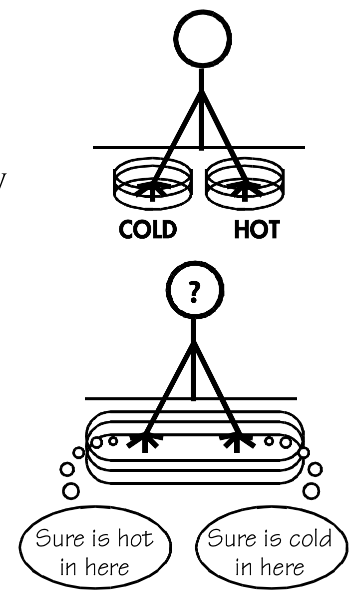
PhyzGuide: What *is* Temperature?

We often think of temperature as a measure of “hotness” or “coldness.” But what’s the difference between hot and cold? Temperature, of course. We might call that uniform circular logic (UCL). Like electricity, temperature is something everyone understands until they try to define it. How about “temperature is what a thermometer measures,” followed by a definition of thermometer as “a device that measures temperature.” I think I’m getting dizzy.

HUMAN TOUCH

Touch is one method by which we determine hot and cold. Temperature-sensitive nerve endings in the skin send electrical signals to your brain when you touch something hot or cold. But these nerves and electrical signals work on a relative, immediate basis—not an absolute basis—and can sometimes be tricked. Try this experiment: put your left hand in hot water and your right hand in cold water, then place both hands in room temperature water. The left hand “thinks” the water is cold while the right hand “thinks” the water is hot. All of which should alert you to the fact that human sense of temperature cannot be relied upon for great accuracy.



The human thermometer can be tricked!

Still, humans are pretty clever animals, and have developed thermoscopes, thermometers, and thermocouples to accurately measure temperature. Yet the question remains: What do these devices actually measure?

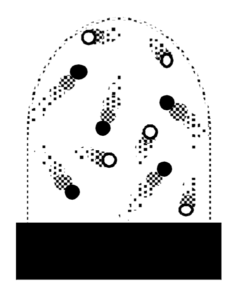
DISSECTING THE PHYSICS DEFINITION

Physicists typically use the following definition:

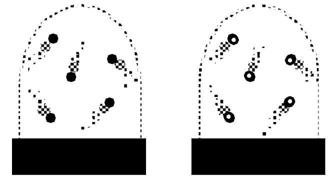
Temperature is a measure of the average kinetic energy of the random translational motion of the particles in a sample.

I count about five phrases or words in that definition worthy of further examination, so let’s make like biologists and dissect.

1. **kinetic energy**: Temperature is associated with kinetic energy, not speed. You might have heard someone say that one object is hotter than another because its particles (atoms or molecules) are moving faster. This is incomplete and may be incorrect. If the two objects are made of the same substance, the statement is true and nobody goes to phyzjail. But the atoms in a lead (Pb) ball can move more slowly than those in an aluminum ball while having a higher temperature. And if a volume of gas


In a mixture of gases, the lighter particles (•) move more rapidly than the heavier ones (◦).

includes light particles (such as helium atoms) and heavier particles (such as nitrogen molecules), the light particles will be moving with a considerably higher average speed to compensate for their lower mass.

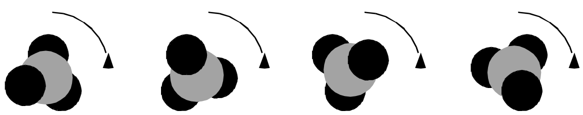


If separate containers hold lighter particles and heavier particles moving at the same speed, the collection of heavier particles has a higher temperature.

2. **average**: A population of particles will have a wide variety of individual kinetic energy values. Temperature is an indication of the average. It is not a measure of the *total* kinetic energy represented by the motion of the particles, either. So a cupful of water taken from a filled bathtub will have the same temperature as the water remaining in the bathtub without having as much total energy. That total energy, by the way, is associated with **internal energy**. More on that later.

3. **random... motion of the particles**: Consider a bucket of water at rest on the floor. The *collection* of water molecules is at rest and thus has no kinetic energy as an object. The water molecules *themselves* are moving around each other in a frenzied dance rich with kinetic energy.

4. **translational motion**: Temperature is not a measure of the average kinetic energy of the particles, just the average kinetic energy associated with the *translational* motion of the particles. It "misses" the kinetic energy associated with molecular rotation and molecular vibration. These energies are taken into account in internal energy.



Molecules in liquids and gases can rotate. Rotational kinetic energy is **not** accounted for in temperature.

Molecules can expand and contract. The energy associated with molecular vibration is **not** accounted for in temperature.

5. **a measure of**: Think of this phrase as a way of saying the definition is not complete or exact; some physicists don't like it at all. It serves our purpose as an introduction to the concept of temperature. But in the future, you may find it limiting or misleading: you may outgrow it! Physicists who delve deeply into the meaning of temperature prefer definitions that appear more nebulous: **Temperature is the tendency of a collection of particles to transfer energy** or **Temperature is hotness measured on some definite scale**.

BASE OR DERIVED?

Temperature is a useful and important concept. We think of it as associated with energy, but we don't measure it in energy units. Remember that physicists seek unification of concepts wherever possible (the moon and an apple accelerate under the same influence, electricity and magnetism are two sides of the same coin, likewise for mass and energy). Still, temperature is left with its stature as a fundamental quantity; the SI unit for temperature, the kelvin, is a base unit. The thrust of what temperature means varies with the context of its use. As a student in your first encounter with a technical definition of temperature, what's important to you is that it is a measure of the average kinetic energy of the random translational motion of the particles in a sample.