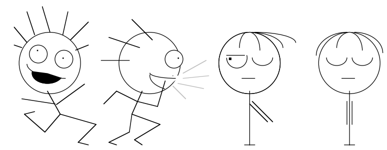
PhyzGuide: Heat Conduction

WHY DOES IT HAPPEN?

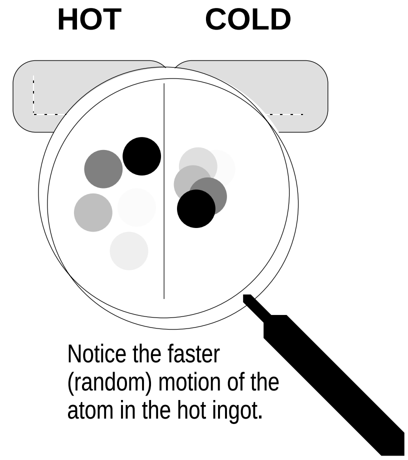


"High temperature, pass it on!"

A collection of anthropomorphized iron atoms in the process of conduction.

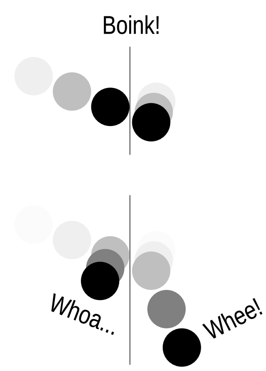
When objects having different temperatures come into contact, heat flows from the object with the high temperature to the object with the low temperature. This mechanism for heat transfer is known as **heat conduction**.

To understand conduction, imagine a hot iron ingot (brick) and a cold iron ingot coming into contact with each other. The atoms in the hot ingot have greater average kinetic energy associated with their random translational motion than do the atoms in the cold ingot. At the interface between the two ingots, high-energy atoms in the hot ingot and low-energy atoms in the cold ingot are colliding *en masse*.

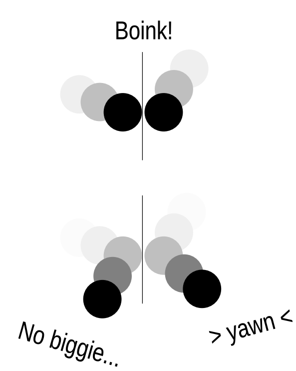


Notice the faster (random) motion of the atom in the hot ingot.

Imagine the results of an individual collision. The low-energy atom is given a "kick" and recoils with increased energy. Where did this energy come from? That's right, it came from the high-energy atom in the hot ingot. How does this leave the atom in the hot ingot? Correct again, young phyzwhiz; it is left with less energy. On a microscopic level, this collision is similar to a head-on collision between billiard balls: the objects "swap" kinetic energy values.



The slowed atom in the hot ingot will soon be kicked from behind by a high-energy molecule farther from the interface. The accelerated atom in the cold ingot will soon be robbed of its energy by a collision with a slow-moving atom farther from the interface. With the atoms returned to their original state, the process of energy transfer can repeat. Each time it happens, a small amount of heat energy is transferred.

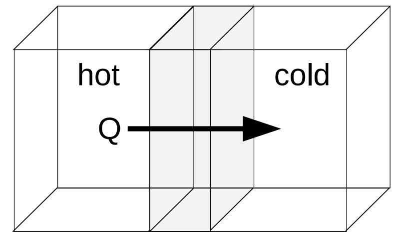


This process continues until the collisions at the interface no longer transfer energy. That is, when atoms on both sides of the interface have equal average kinetic energies associated with their random translational motion. In other words, when the ingots have the same temperature! (I guess I could've said that in the first place, but it wouldn't have been nearly as much fun for me to write or you to read.) This state is referred to as **thermal equilibrium**.

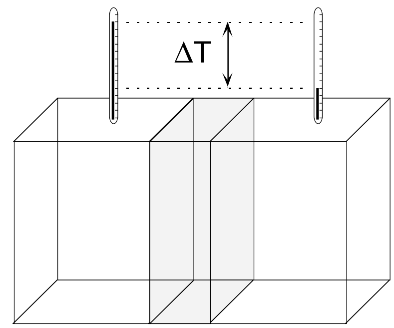
Our understanding of "why it happens" *conducts* us to another question...

HOW FAST DOES IT HAPPEN?

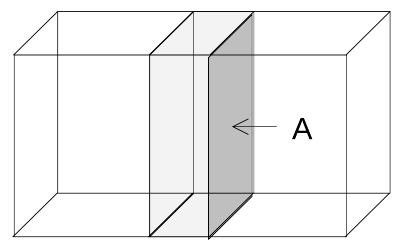
Heat conduction is a process that involves the transfer of energy from a hot place to a cold place. The question of how fast it happens depends on several factors. First, let's make sure we understand what it is we're asking here. "How fast it happens" means how rapidly the energy flows from one place to another: it is the rate of heat flow. Heat is denoted Q, and "rate" implies division by time which is denoted $1/t$. So the rate of heat flow is Q/t.



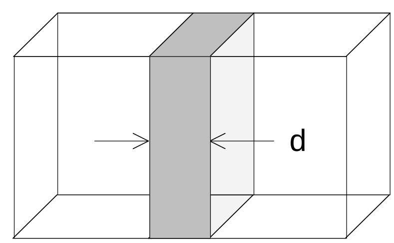
Now, imagine a hot place and a cold place connected by an object. The difference in temperature between the hot place and the cold place is denoted ΔT. The object has a certain length (d) which is—sometimes confusingly—referred to as its thickness. The surfaces of the object that touch the hot place and the cold place have a certain area (A).



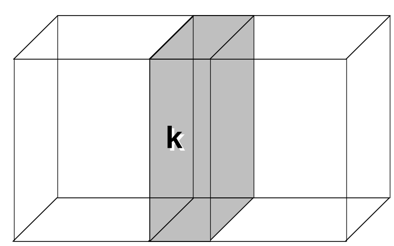
The rate of heat flow (Q/t) by conduction depends on the difference in temperature between which the heat is flowing. The greater the difference in temperature, the greater the rate of heat flow. Since this relationship is a direct proportionality, we can write $Q/t \propto \Delta T$.



Conduction also depends on the area of contact between the hot and cold regions. The greater the area of contact, the greater the rate of heat flow. Since this relationship is a direct proportionality, we can write $Q/t \propto A$.



The farther the heat has to travel, however, the slower it travels. So the rate of heat flow by conduction is inversely proportional to the thickness of the object connecting the hot place to the cold place. Since this relationship is an inverse proportionality, we can write $Q/t \propto 1/d$.



If the object in our diagram was a silver bar, it would conduct more rapidly than a glass bar with the same dimensions. Some materials—like metals—conduct very well. Others do not. This variation in conductive ability is quantified by a factor called **thermal conductivity**, denoted k. The greater the thermal conductivity, the greater the rate of heat flow. Since this relationship is a direct proportionality, we can write $Q/t \propto k$.

Taken together, all of these proportionalities form a single equation.

$$\frac{Q}{t} = \frac{kA\Delta T}{d}$$