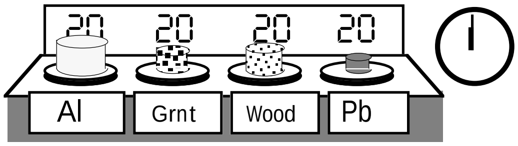
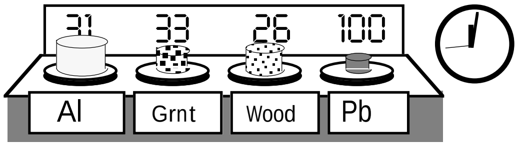
PhyzGuide: Specific Heat

A DAY AT THE (TEMPERATURE) RACES

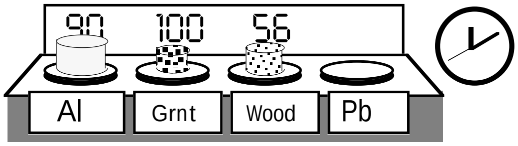
After many hours of tedious research, a group of physics graduate students decided a frivolous competition was in order. They raided the lab supply room and came up with 1kg samples of aluminum, granite, wood, and lead (not to mention 1 bag of Jalapeño-flavor Ruffles™, 4 Twinkies™, 2 Ding Dongs™, and $3^{1}/_{2}$ Ho-Ho's™). Each grad was assigned a (non-edible) substance, and each 1kg sample was attached to a digital temperature display and placed on a heating device. The heater was set to deliver 100J of energy per second to each sample. (Hey! 100J per second... 100J/s... isn't that like 100W?) The stage was set for a temperature race. "Last sample to 100°C is a rotten egg!" yelled one grad, and they were off!



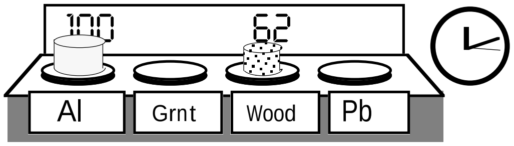
START... All substances have a temperature of 20°C.



1 minute, 44 seconds later: the lead wins by a wide margin!

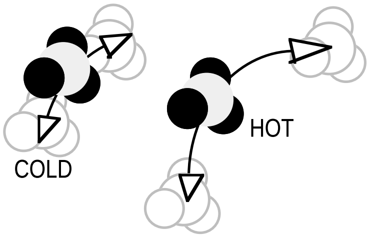


10 minutes, 40 seconds after the start, the granite finishes a distant second.

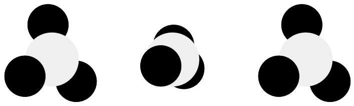


12 minutes, 16 seconds after the start, the aluminum finishes third, wood loses the race.

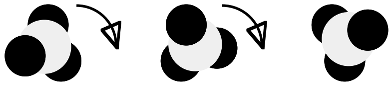
We might think of the lead as having the smallest "thermal inertia" or resistance to temperature increase when energy is added. Wood has the highest "thermal inertia" since its temperature rises most slowly. To understand why the temperatures of different substances increase at different rates when heat is added, we must consider what is happening on the microscopic scale. When heat is added to a substance, the energy is absorbed by the molecules in that substance. The molecules react in the following ways:



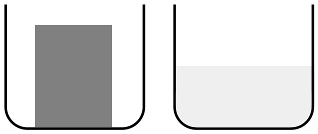
1. The molecules jiggle faster. This represents an increase in the translational kinetic energy of the molecule. This change can be detected by a thermometer: an increase in translational kinetic energy results in increased temperature.



2. The molecules can expand and contract. This is called vibrational energy, and cannot be detected by a thermometer: an increase in vibrational kinetic energy has no effect on temperature.



3. The molecules (if liquid or gas) can rotate. This is called rotational energy, and cannot be detected by a thermometer: an increase in rotational kinetic energy has no effect on temperature.



4. Under the right conditions, a change in phase can occur (we'll discuss this option later). During a change in phase, temperature does not increase.

In some substances, the added energy simply increases the translational kinetic energy of the molecules. These substances heat up relatively rapidly since heat added quickly results in increased temperature. Molecules in other substances, however, absorb the added energy by increased vibration and/or rotation in addition to increased translation. Since temperature is a measure of average translational kinetic energy, the energy stored in vibration and rotation is not detected by a thermometer. These substances do not undergo a rapid increase in temperature.

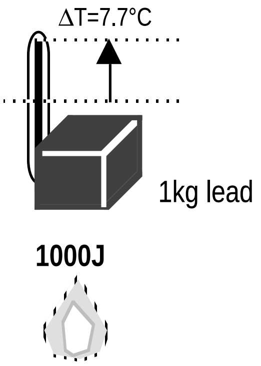
Heat capacity is defined as the energy required to raise the temperature of an object by 1°C. If the object has a great deal of mass, this number will be high. If the molecules in the substance absorb energy through vibration and rotation, this number will also be high since the addition of energy does not result in as great an increase in translational molecular motion.

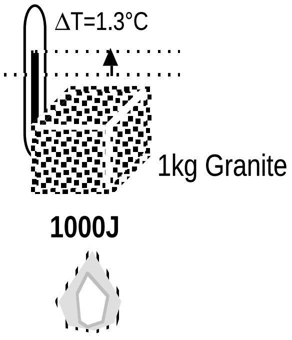
To compare the ability different substances have of absorbing energy without undergoing a dramatic increase in temperature, the quantity called *specific heat* is used.

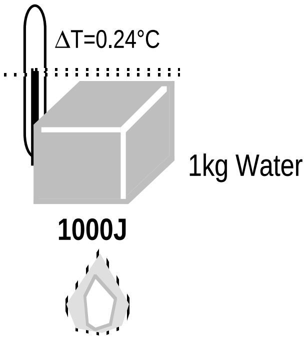
Specific heat (or **specific heat capacity**) is the amount of heat required to raise the temperature of 1kg of a substance by 1°C. Specific heat capacity can also be stated as the amount of heat that must be lost by 1kg of a substance as it cools by 1°C. Conceptually, it often helps to think of specific heat as "thermal inertia." Just as an object resists a change in motion when acted on by a force due to its inertia, a substance resists a change in temperature when heat is added or taken away due to its “thermal inertia”—specific heat.

Through specific heat, substances can be compared based only on the way their molecules absorb heat energy. Mass is eliminated as a factor since a standard of 1kg is used for all substances.

If 1000J of heat is added to 1kg of the following substances, the increase in temperature for each will be different (based on specific heat capacity):







In general, the increase in temperature (ΔT) is

1. Directly proportional to the amount of heat energy (Q) added. More heating results in a greater increase in temperature.

2. Inversely proportional to the mass (m) of the object being heated. A small mass undergoes a greater increase in temperature than a large mass when an equal amount of heat is added to each.

3. Inversely proportional to the specific heat (c) of the substance being heated. A substance with a high specific heat capacity undergoes a small increase in temperature when heat is added.

Taken together, the statements above can be expressed as an equation:

$$\boxed{\Delta T = Q/mc}$$

this equation is often written for heat as:

$$\boxed{Q = mc\Delta T}$$

$\Delta T \equiv$ change in temperature [$\Delta T = T - T_0$] (°C or K)
$Q \equiv$ heat energy added (J)
$m \equiv$ mass (kg)
$c \equiv$ specific heat capacity [from table] (J/kg·°C)

Both versions are valid ***only*** *if there is no* change of phase *involved. For example, if you find that water goes from 20°C to 150°C, you must consider energy involved in the changes of phase.*