Lecture 2 (Temperature and Thermal Expansion)

Physics 161-01 Spring 2012

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Thermodynamics

- Up until now, we have looked at the physics of individual objects, whether that would mean a “point particle” or a solid object.
- The study of thermodynamics involves a collection of objects, usually atomic in size, and how they behave as a system.
- We will discuss the “state” of a system later, but for now, as we did for mechanics, we have to define some variables that we will use to make measurements of a system.

Temperature

- Each of us has a general idea of the feeling of "hotness" or "coldness", but what exactly are we feeling?
- The temperature of something is a measure of the ***average*** kinetic energy of its constituents.
- We will explore this more a bit later, but first we need to understand some aspects of temperature (so we know how to measure it) and then we will need to develop a temperature scale.

Energy vs. Temperature

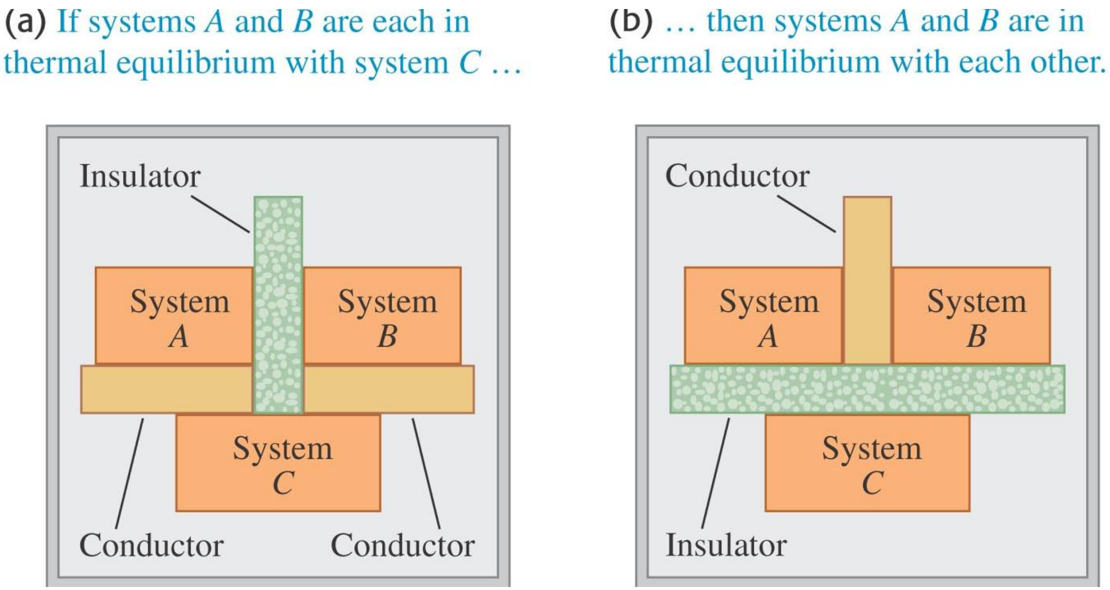
- Which one has a higher temperature?
- Which one has a higher *average* kinetic energy?
- Which one has more thermal energy?

Thermal Equilibrium

- When two objects of different temperatures are placed in thermal contact, heat (thermal energy) will be transferred from the object with the higher temperature to the object with the lower temperature.
- When they reach the same temperature, they are said to be in thermal equilibrium, at which point no further heat will be exchanged.

Zeroth Law of Thermodynamics

- Is temperature measureable in a reliable way?
- What would happen if we take two objects both of the same temperature and put them in contact with each other?
- *Zeroth law of thermodynamics*: If *C* is initially in thermal equilibrium with both *A* and *B*, then *A* and *B* are in thermal equilibrium with each other.



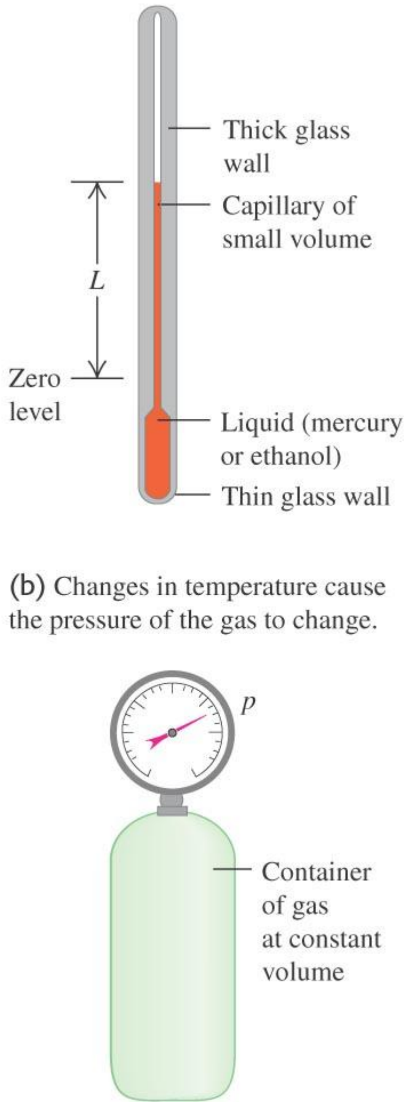
Thermal Equilibrium

- In order to measure temperature in a reliable way, we will have to place an object (a thermometer) in contact with the system we are measuring.
- Our thermometer must then react (change) to reflect the temperature of the system.
- Ideally then, the thermometer must be at the same temperature as the system (or be small enough not to affect the measured system).
- Modern thermometers use other methods which we will discuss later.

Temperature Effects

- As we will see shortly, temperature has an effect on the volume (for solids and liquids) or pressure (for gasses) that we can exploit to make thermometers.

(a) Changes in temperature cause the liquid's volume to change.



(b) Changes in temperature cause the pressure of the gas to change.

Temperature Scales

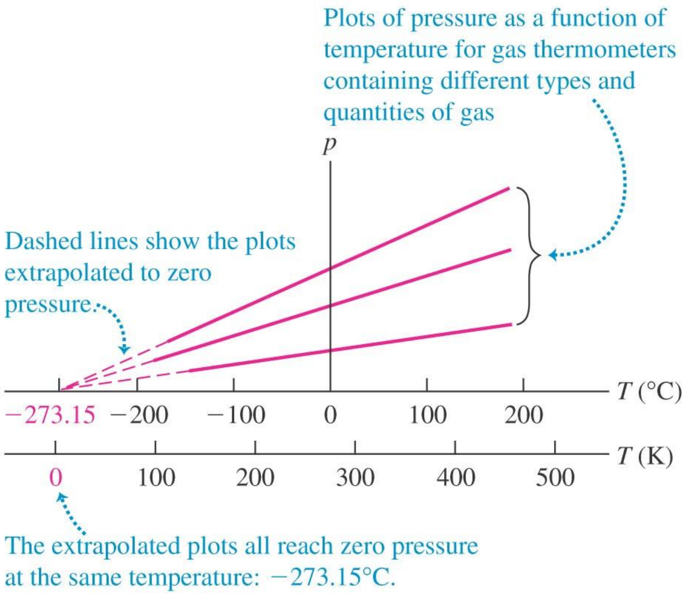
- As in the case of distance, or time, we need a scale to be able to represent aspects of nature to each other in a reproducible way.
  - For distance, we take some length to be a standard (distance from here to there, say, a meter), and then subdivide it into parts (centimeters, millimeters, etc.).
  - For time, we use one revolution of the earth as a day, divide that into 24 parts (hours), then divide each of those into 60 parts (minutes), and then divide each of those into 60 parts (seconds). (Yuk! Like yards and feet and inches.)
- For temperature then, we need two standard temperatures (here and there), and some way to represent temperatures in a measureable way.

Temperature Scales

- On the *Celsius* (or *centigrade*) *temperature scale*, 0°C is the freezing point of pure water and 100°C is its boiling point.
- On the *Fahrenheit temperature scale*, 32°F is the freezing point of pure water and 212°F is its boiling point.
- On the *Kelvin* (or *absolute*) *temperature scale*, 0 K is the extrapolated temperature at which a gas would exert no pressure.

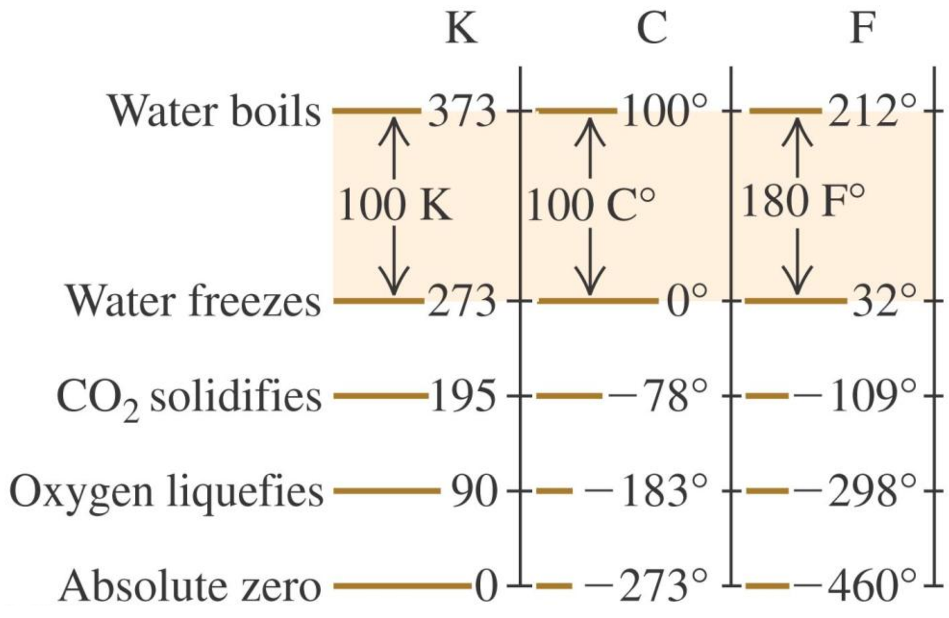
(a) A constant-volume gas thermometer

(b) Graphs of pressure versus temperature at constant volume for three different types and quantities of gas



Temperature Conversions

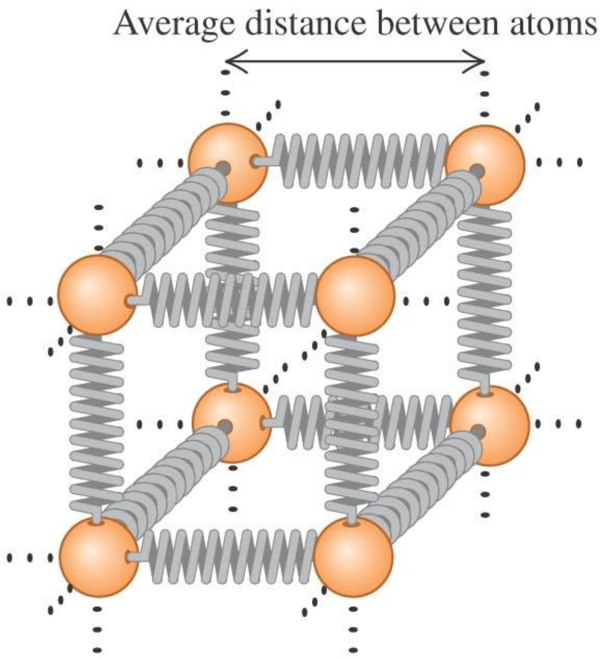
- The following conversion equations are useful:
  - $T_F = 9/5\ T_C + 32°$ $\quad T_C = 5/9\ (T_F - 32°)$ $\quad T_K = T_C + 273.15$
- The chart in the figure below shows the relationship between temperature scales, rounded to the nearest degree.



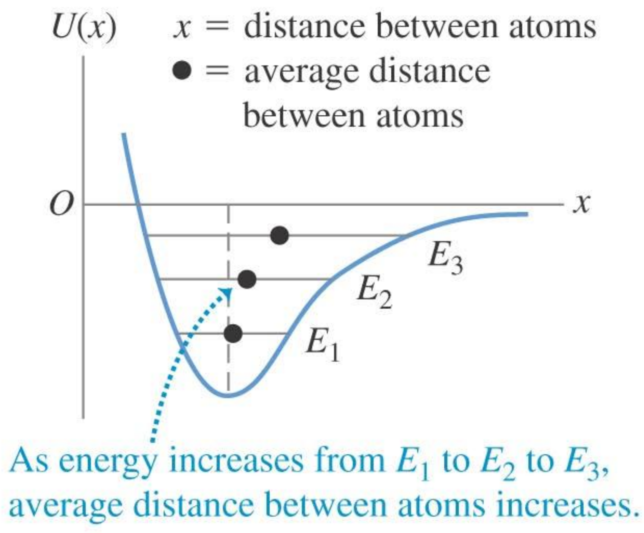
Thermal Expansion

- Let us try to understand what happens to a substance when heated by modeling the atoms as being held together by springs.

(a) A model of the forces between neighboring atoms in a solid

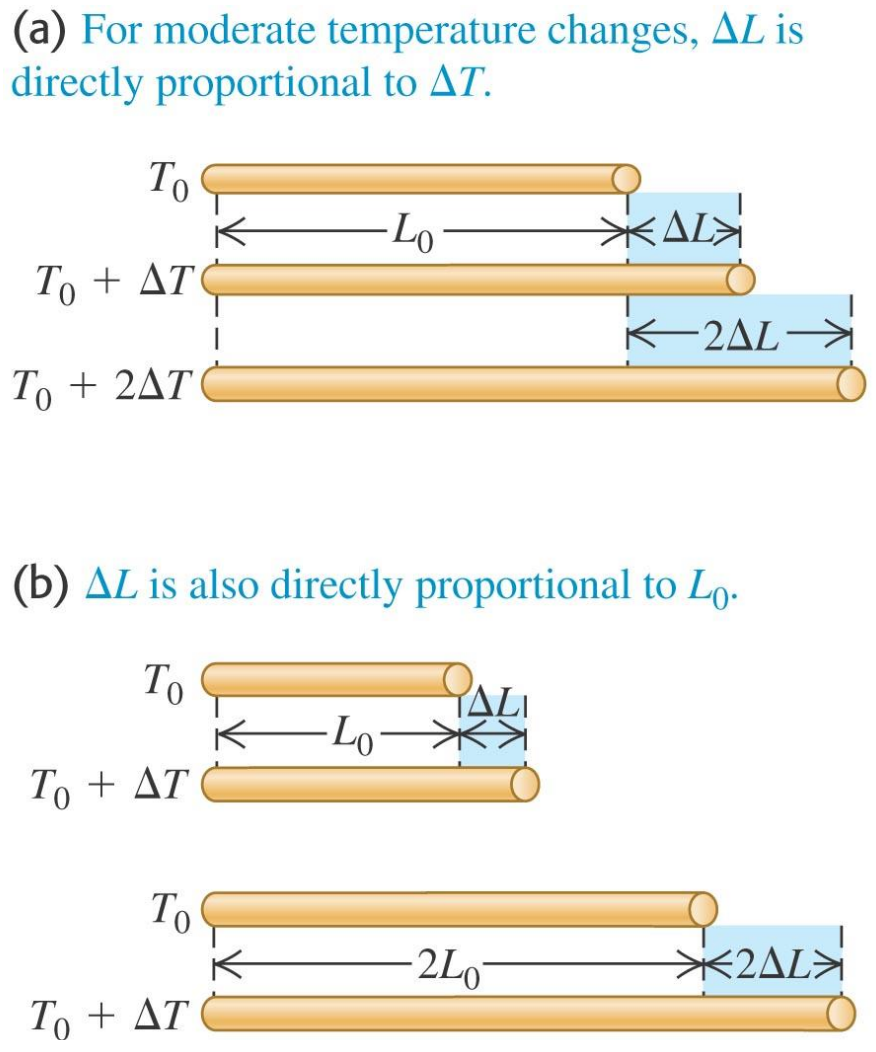


(b) A graph of the "spring" potential energy $U(x)$



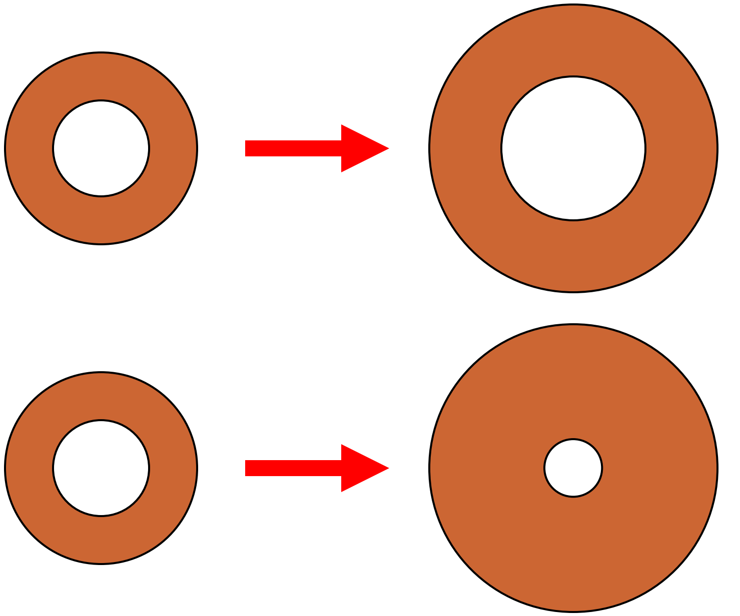
Thermal Expansion

- Increasing the temperature of a rod causes it to expand.
- The change in length is given by $\Delta L = \alpha L_0 \Delta T$, where α is the *coefficient of linear expansion* of the material.



CPS Question 2-1

A solid object has a hole in it. Which of these illustrations more correctly shows how the size of the object and the hole change as the temperature increases?



#2

A. illustration #1

B. illustration #2

C. The answer depends on the material of which the object is made.

D. The answer depends on how much the temperature increases.

E. Both C. and D. are correct.

CPS Question 2-1

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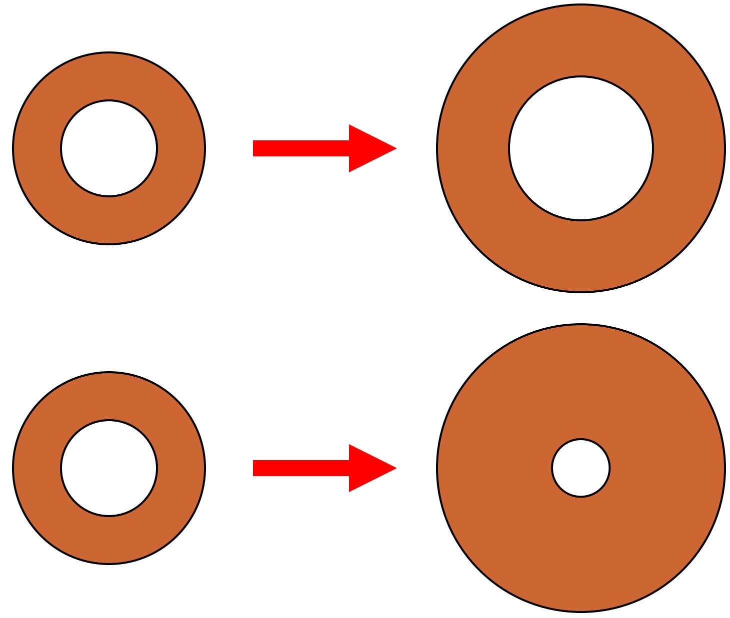
#2



A. illustration #1

B. illustration #2

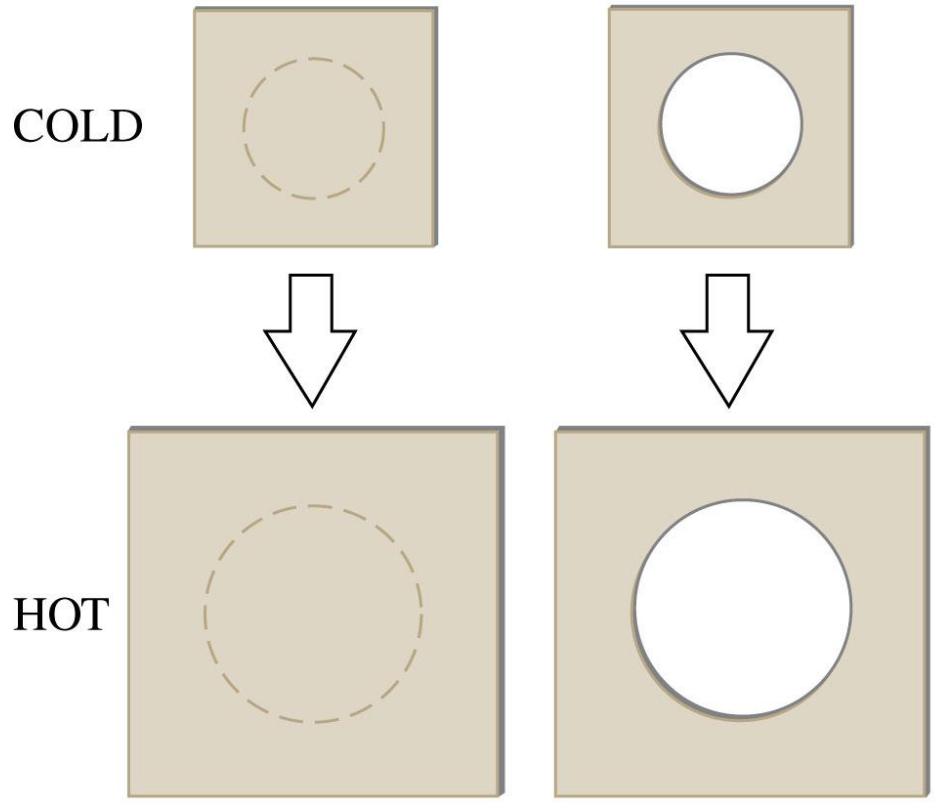
C. The answer depends on the material of which the object is made.

D. The answer depends on how much the temperature increases.

E. Both C. and D. are correct.

Thermal Expansion

- If an object has a hole in it, the hole also expands with the object, as shown in the figure at right. The hole does *not shrink*.
- The change in volume due to thermal expansion is given by $\Delta V = \beta V_0 \Delta T$, where β is the *coefficient of volume expansion* and is equal to 3α.



A plate expands when heated . . .

. . . so a hole cut out of the plate must expand, too.

Coefficients of Thermal Expansion

Table 17.1 Coefficients of Linear Expansion

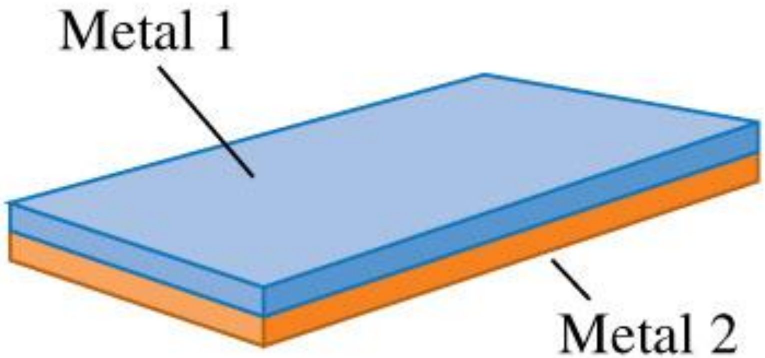
Material	$\alpha\ [\mathrm{K}^{-1}\ \text{or}\ (\mathrm{C}^\circ)^{-1}]$
Aluminum	2.4×10^{-5}
Brass	2.0×10^{-5}
Copper	1.7×10^{-5}
Glass	$0.4\text{–}0.9 \times 10^{-5}$
Invar (nickel–iron alloy)	0.09×10^{-5}
Quartz (fused)	0.04×10^{-5}
Steel	1.2×10^{-5}

Table 17.2 Coefficients of Volume Expansion

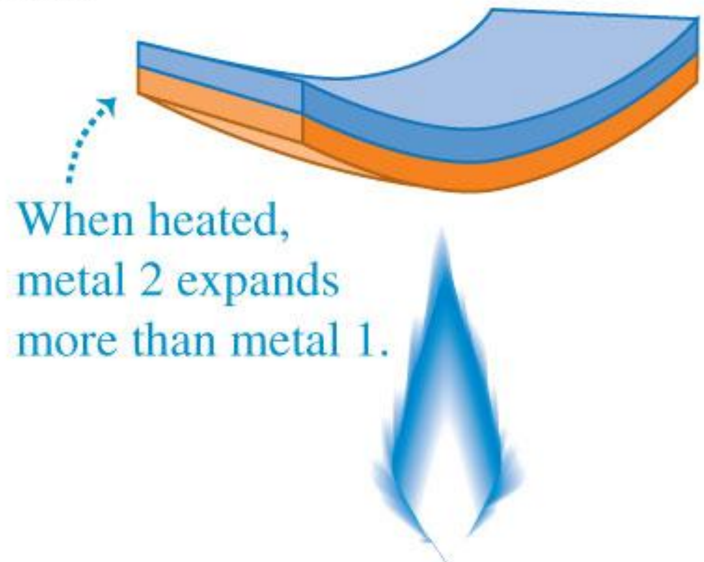
Solids	$\beta\ [\mathrm{K}^{-1}\ \text{or}\ (\mathrm{C}^\circ)^{-1}]$	Liquids	$\beta\ [\mathrm{K}^{-1}\ \text{or}\ (\mathrm{C}^\circ)^{-1}]$
Aluminum	7.2×10^{-5}	Ethanol	75×10^{-5}
Brass	6.0×10^{-5}	Carbon disulfide	115×10^{-5}
Copper	5.1×10^{-5}	Glycerin	49×10^{-5}
Glass	$1.2\text{–}2.7 \times 10^{-5}$	Mercury	18×10^{-5}
Invar	0.27×10^{-5}		
Quartz (fused)	0.12×10^{-5}		
Steel	3.6×10^{-5}		

Bi-metal Strips

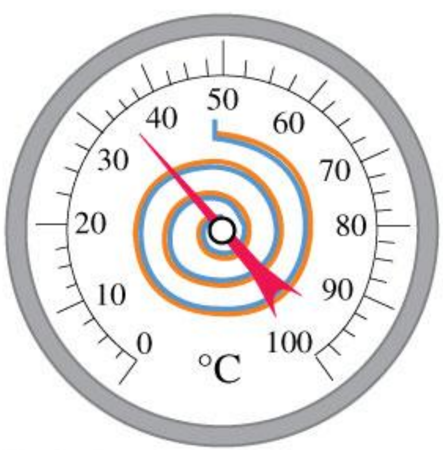
(a) A bimetallic strip



(b) The strip bends when its temperature is raised.

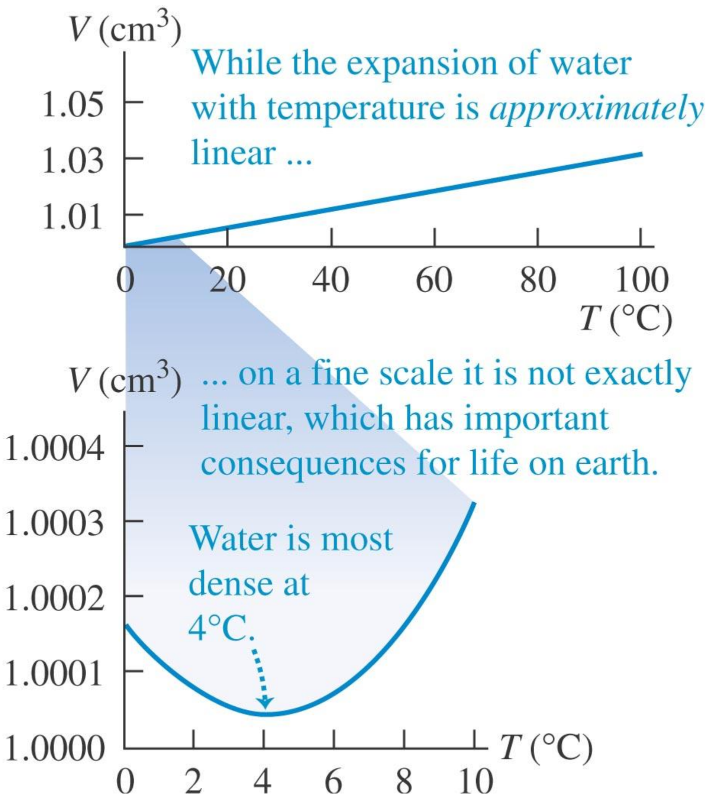


(c) A bimetallic strip used in a thermometer



Thermal Expansion of Water

- Between 0°C and 4°C, water *decreases* in volume with increasing temperature.



Thermal Expansion of Water

- This behavior is paramount to life on earth.
- Because of this anomalous behavior, lakes freeze from the top down instead of from the bottom up.
- The entire lake must reach $4^{o}C$ before it will start to freeze.