De Anza College

Thermodynamics
Thermal Expansion

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April 19, 2018

Last time

- heat, thermal equilibrium, and the 0th law
- temperature

Overview

- thermal expansion

Thermal Expansion

Most substances (solid, liquid, or gas) expand when heated.

This is due to the fact that in substances at higher temperatures, the molecules move around faster and more violently, so they spread out more.

Different substances expand by different amounts for a given temperature change.

Thermal Expansion

Thermal expansion has been a common cause of derailments of trains.

Thermal Expansion

Different rates of thermal expansion can cause glass to shatter.

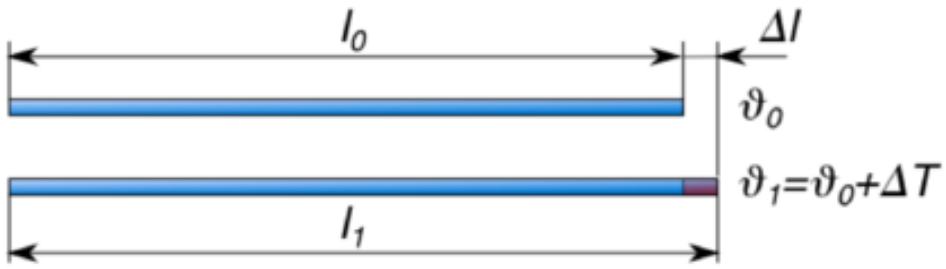
Thermal Expansion

This expansion is taken into account by civil engineers when designing bridges, pipes, and buildings.

Expansion joints are built into sections of bridges to allow for expansion without buckling.

[0]Picture from Serway & Jewett.

Thermal Expansion



A **coefficient of linear expansion** α for a solid relates how much it will expand when its temperature changes by an amount ΔT.

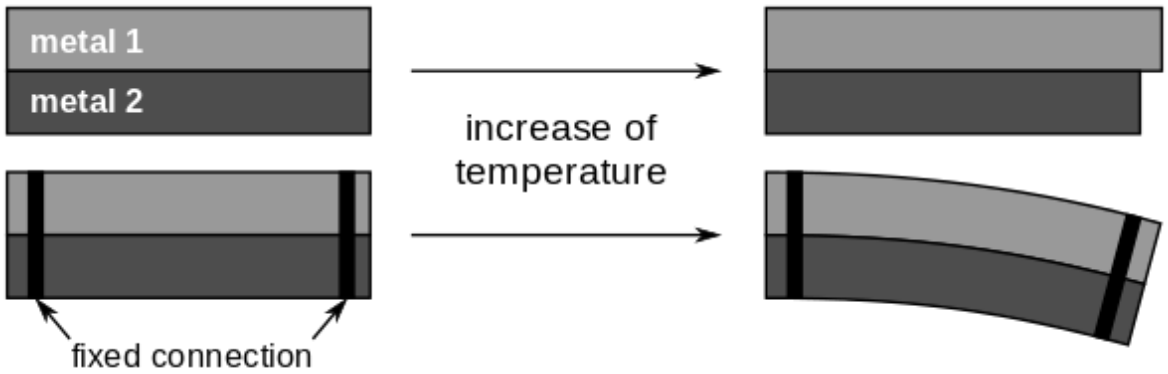
$$\Delta L = \alpha L_i \Delta T$$

L_i is the original length of the solid before the temperature change.

α takes different values for different substances, but is almost always a positive number.

Thermal Expansion: Bimetallic Strip

A bimetallic strip is a strip made of two kinds of metal, very often brass and iron, that have quite different coefficients of linear expansion.



The strip curves downward when heated and can curl upward when it is chilled.

Used in thermostats and thermometers, its deformation can make or break an electrical contact.

Bimetallic Strip Question

Suppose a bimetallic strip is composed of 0.10 m of brass and iron bound together at room temperature (20°C).

The strip is heated 15°C. How much longer is the brass part than the iron part?

$\alpha_{\text{brass}} = 19 \times 10^{-6} (^\circ\text{C})^{-1}$
$\alpha_{\text{iron}} = 12 \times 10^{-6} (^\circ\text{C})^{-1}$

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1.05×10^{-5} m $= 0.0105$ mm

Thermal Expansion Question

The pendulum of a certain pendulum clock is made of brass. When the temperature increases, what happens to the period of the clock?

(A) It increases.

(B) It decreases.

(C) It remains the same.

[1] Serway & Jewett, Objective question 4, page 581.

Thermal Expansion Question

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Period of an ideal pendulum: $T = 2\pi\sqrt{\frac{L}{g}}$

Period of a physical pendulum $T = 2\pi\sqrt{\frac{I}{mgd}}$

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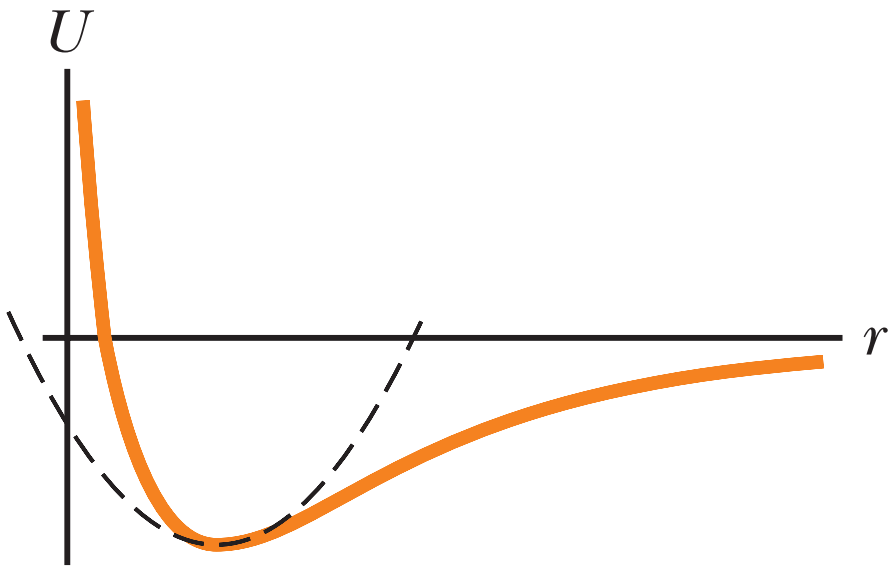
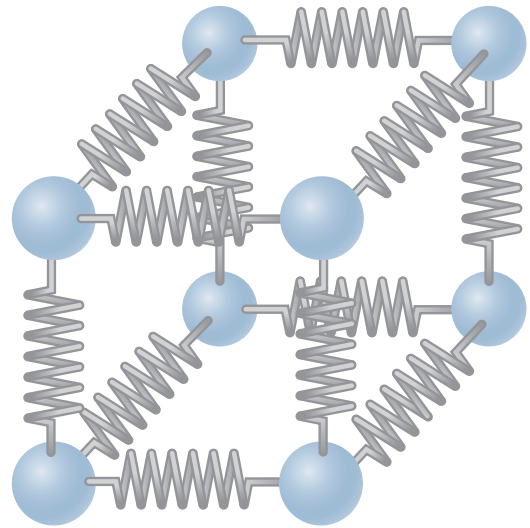
Thermal Expansion: Why does it happen?

As the kinetic energy of the atoms / molecules increase, they can move further out of their potential wells.



The Lennard-Jones potential



bonds modeled as springs

The average inter-atom spacing increases.

[1] Diagrams from Serway & Jewett, 9th ed, page 460.

Volume Thermal Expansion

We can model volume expansion in a similar way:

$$\Delta V = \beta V_i \Delta T$$

β is the average coefficient of volume expansion.

If the material is *isotropic* (the same in all directions, symmetry wrt rotations of coordinate systems) then:

$$\beta = 3\alpha$$

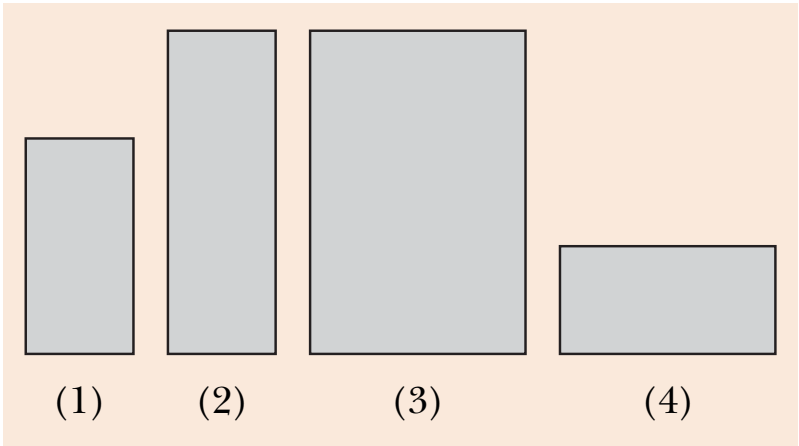
using the fact that $\alpha \Delta T \ll 1$.

(This entire model is only approximately true over a restricted range of temperatures.)

Thermal Expansion Question

The figure here shows four rectangular metal plates, with sides of L, $2L$, or $3L$. They are all made of the same material, and their temperature is to be increased by the same amount. Rank the plates according to the expected increase in

(a) their vertical heights greatest first.



(A) 1, 2, 3, 4

(B) (2 and 3), 1, 4

(C) 3, 2, (1 and 4)

(D) all the same

[1]Halliday, Resnick, Walker, page 483.

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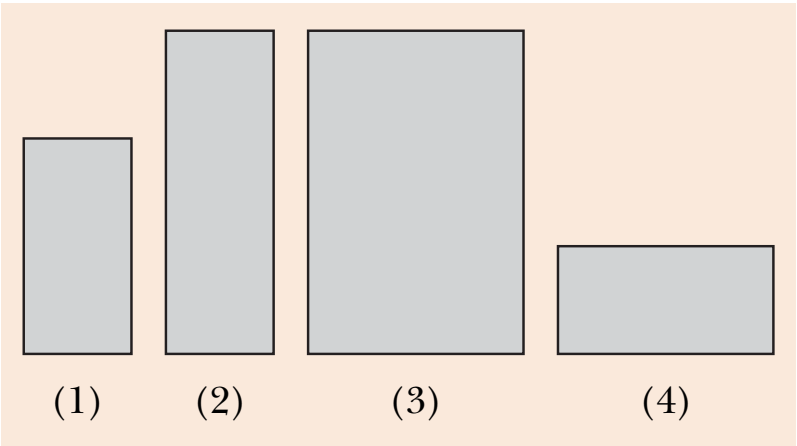

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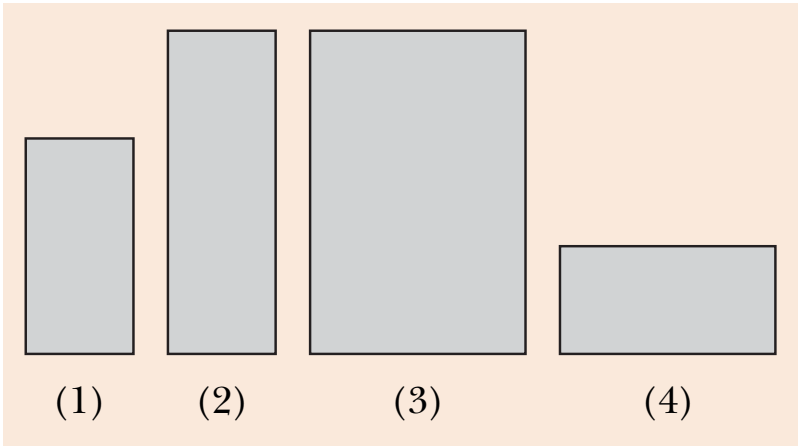
(b) their areas greatest first.



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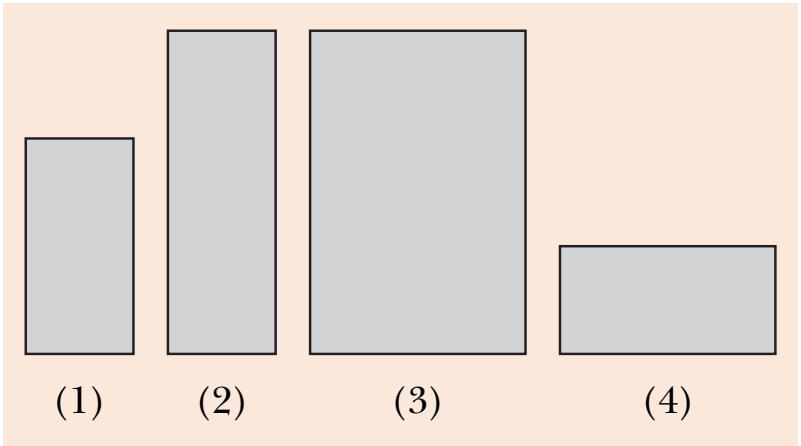

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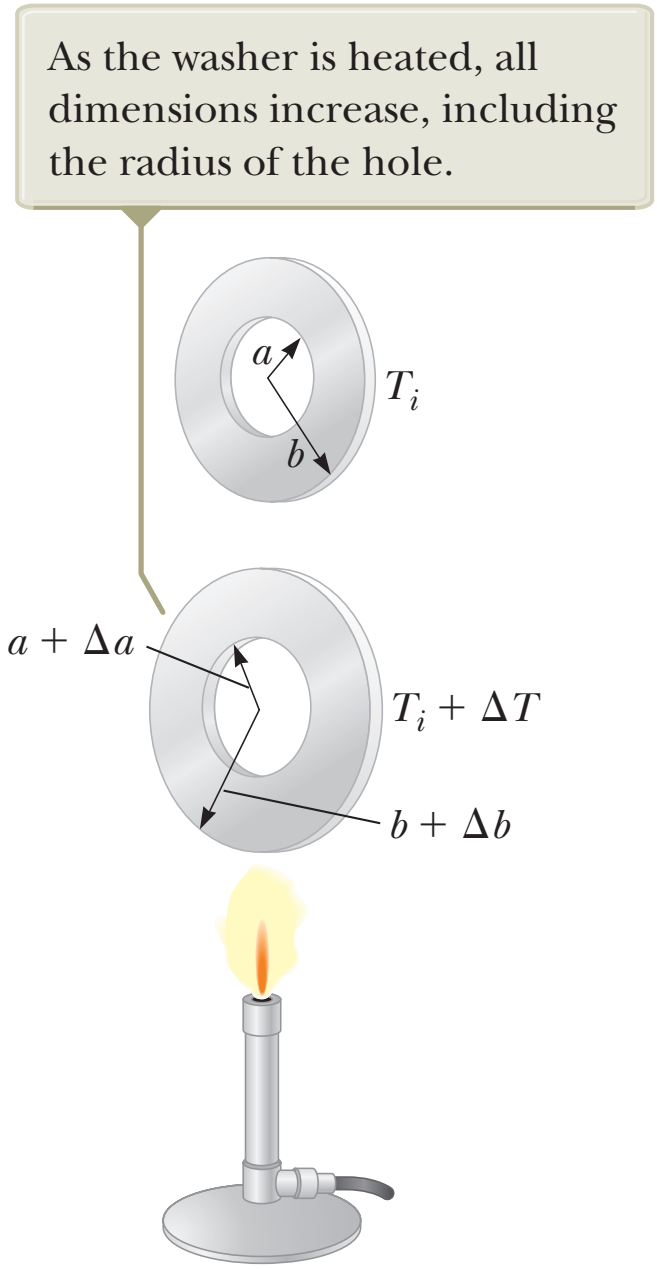
Thermal Expansion of Rings



Question

Quick Quiz 19.4[1] Two spheres are made of the same metal and have the same radius, but one is hollow and the other is solid. The spheres are taken through the same temperature increase. Which sphere expands more?

(A) The solid sphere expands more.

(B) The hollow sphere expands more.

(C) They expand by the same amount.

(D) There is not enough information to say.

[1] Serway & Jewett, pg575.

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Thermal Expansion and Water

Water has a strange behavior with temperature change.

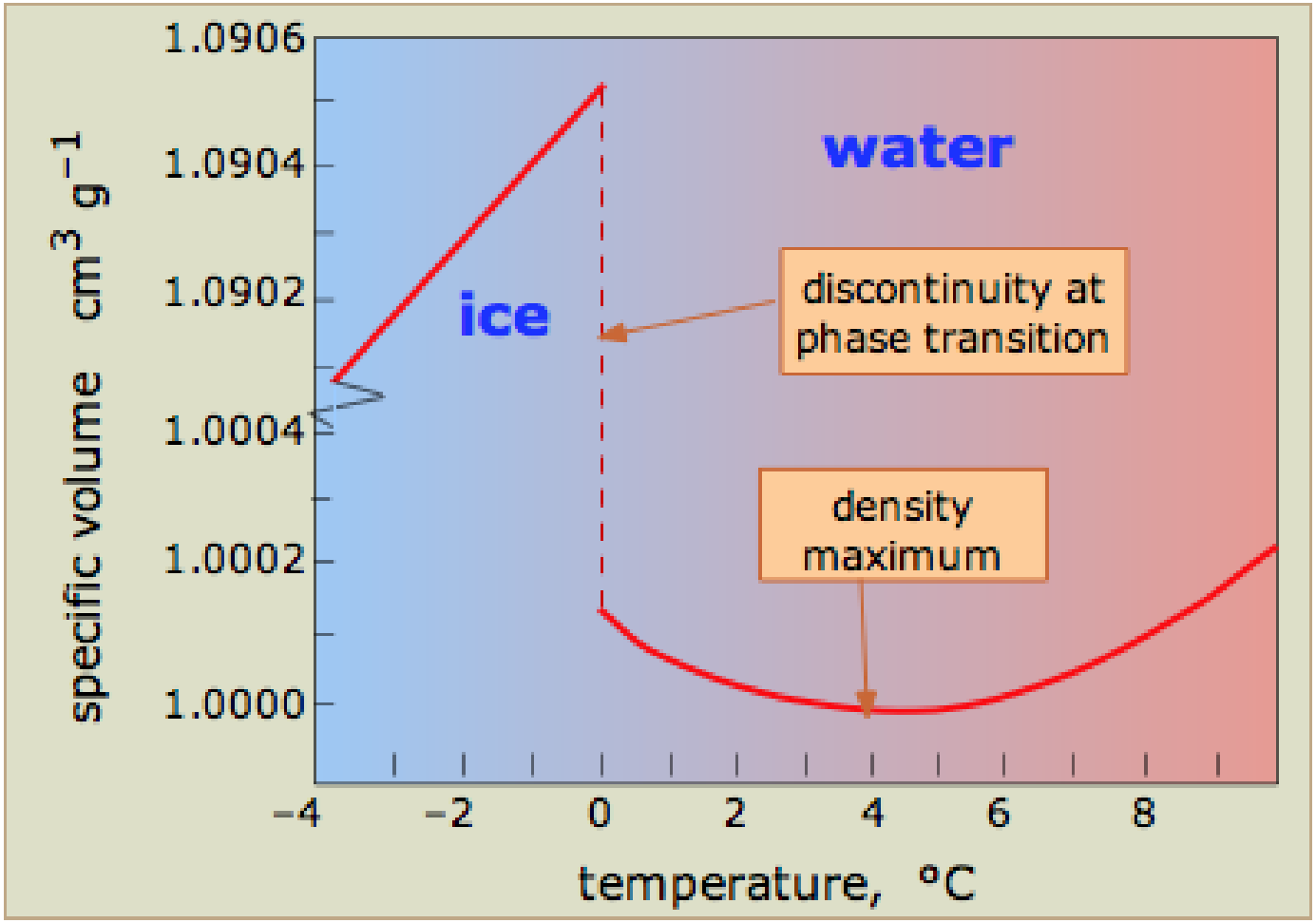
Ice is less dense than water, but even in its liquid phase, water *expands* as it cools between 4°C and 0°C.

Water forms crystals as it freezes. Those crystals have a greater volume than liquid water.

Between 4°C and 0°C some small crystals begin to form, expanding the volume of the water.

[1] Image from its.caltech.edu.

Thermal Expansion and Water



[1]Figure from Chemwiki ucdavis.edu.

Summary

- thermal expansion

(Uncollected) Homework

Serway & Jewett:

- Ch 19, onward from page 581. Probs: 11, 13, 17, 21, 23, 51, 57, 61, 62, 67