Thermodynamics
Thermal Expansion

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Last time

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

Overview

- temperature scales problems
- thermal expansion

Group Work Problems

#1

Confirm that there are 1.8 (or 9/5) degrees Fahrenheit for every degree Celsius.

You can use the fact that the freezing point of water is 0°C and 32°F and the boiling point of water is 100°C and 212°F.

#2

At what temperature do the Fahrenheit and Celsius scales coincide?

That is, for what temperature is the number of degrees Celsius the same as the number of degrees Fahrenheit?

Reminder: $([^\circ\text{F}] - 32) \div 1.8 = [^\circ\text{C}]$

Question

On a very cold day in upstate New York, the temperature is -25°C, which is equivalent to what Fahrenheit temperature?

(A) -46°F
(B) 18°F
(C) -25°F
(D) -13°F

[1] Serway & Jewett, Objective question 14, page 582.

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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.

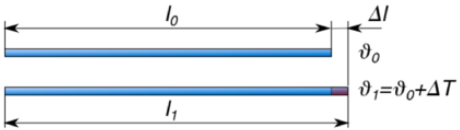
Thermal Expansion

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.

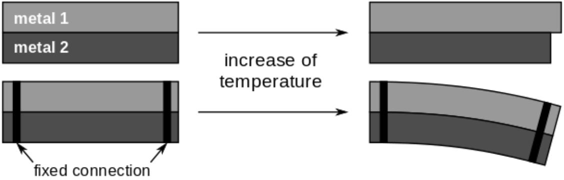
$$\Delta L = \alpha L_i \Delta T$$

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

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

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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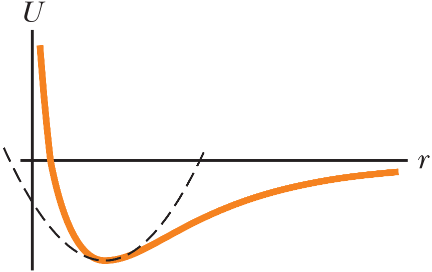
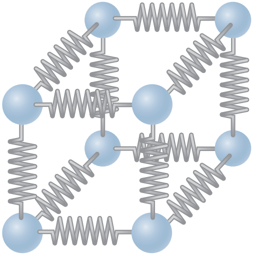
Thermal Expansion: Why does it happen?

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.)

Volume Thermal Expansion

Suppose $V_i = \ell wh$

$$\Delta V \approx (\Delta\ell)wh + \ell(\Delta w)h + \ell w(\Delta h)$$

Summary

- temperature problems
- thermal expansion