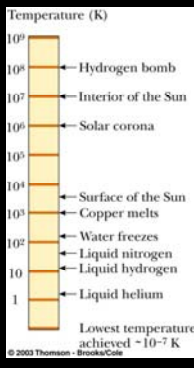
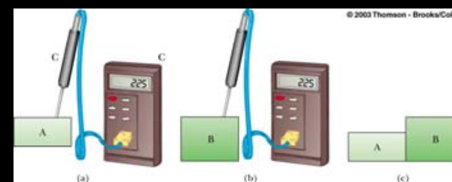
Chapter 10: Thermal physics



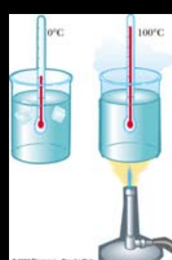
Zeroth law of thermodynamics

If objects A and B are separately in thermal equilibrium with a third object C, then A and B are in thermal equilibrium with each other.



Thermometers in celsius scale

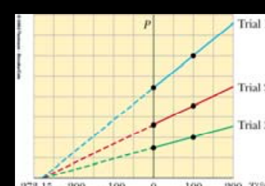
The celsius temperature scale is defined in terms of the freezing point and the boiling point of water.



Other scales for temperature

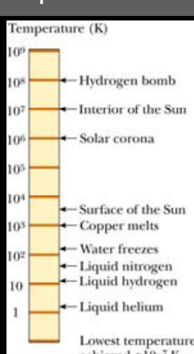
Kelvin scale used the absolute zero and the triple point of water to be the references, and the size of a degree is made the same as the celsius scale

$$T_c = T - 273.15$$



1 Kelvin (SI unit of temperature) is 1/273.16 of the temperature of the triple point of water.

Temperature in Kelvin

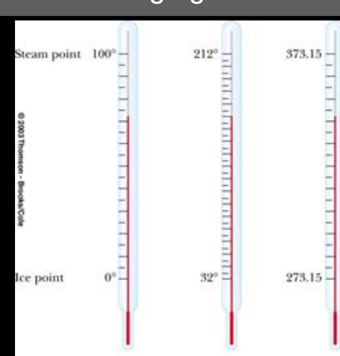


Thermometers: changing scales

$$T_c = T - 273.15$$

$$T_F = \frac{9}{5} T_c + 32$$

$$T_c = \frac{5}{9}(T_F - 32)$$



Temperature: question time

A child is measuring a temperature of 42^{0}C in a european thermometer. What should you do?

a) Send the child to the playground to play?
b) Put the child in a warm bath so her temperature can increase?
c) Give the child tylonol to reduce the fever?

Thermal linear expansion in solids

The length increase of a solid with initial length L_0 is proportional to the change in temperature.

$$\Delta L = \alpha L_0 \Delta T$$

Coefficient of linear expansion

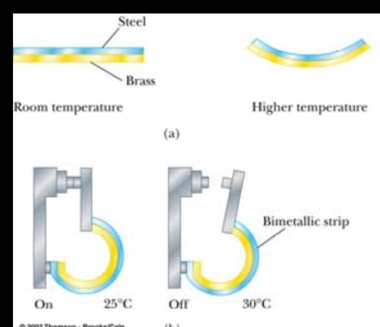
TABLE 10.1 Average Coefficients of Expansion for Some Materials Near Room Temperature

Material	Average Coefficient of Linear Expansion [(°C)$^{-1}$]	Material	Average Coefficient of Volume Expansion [(°C)$^{-1}$]
Aluminum	24×10^{-6}	Ethyl alcohol	1.12×10^{-4}
Brass and bronze	19×10^{-6}	Benzene	1.24×10^{-4}
Copper	17×10^{-6}	Acetone	1.5×10^{-4}
Glass (ordinary)	9×10^{-6}	Glycerin	4.85×10^{-4}
Glass (Pyrex®)	3.2×10^{-6}	Mercury	1.82×10^{-4}
Lead	29×10^{-6}	Turpentine	9.0×10^{-4}
Steel	11×10^{-6}	Gasoline	9.6×10^{-4}
Invar (Ni-Fe alloy)	0.9×10^{-6}	Air	3.67×10^{-3}
Concrete	12×10^{-6}	Helium	3.665×10^{-3}

Linear expansion: question time

A steel railroad track has a length of 30.000 m when the temperature if 0.00 ^{0}C. What is its length in a hot day when the temperature is 40.0 ^{0}C? If the track is nailed down and cannot expand, what would the stress be due to the temperature change?

Linear expansion: thermostats

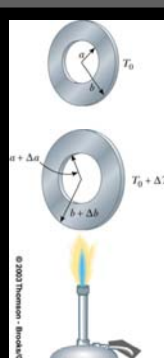


Thermal expansion in solids

The area increase of a solid with initial area A_0 is proportional to the change in temperature.

$$\Delta A = \gamma A_0 \Delta T$$

Coefficient of area expansion



Thermal expansion in solids

The volume increase of a solid with initial volume V_0 is proportional to the change in temperature.

$$\Delta V = \beta V_0 \Delta T$$

Coefficient of volume expansion

If expansion is the same in all directions:

$$\gamma = 2\alpha \qquad \beta = 3\alpha$$

Volume expansion: question time

Estimate the fractional change in the volume of the Earth's oceans due to an average temperature increase of 1 ^{0}C.

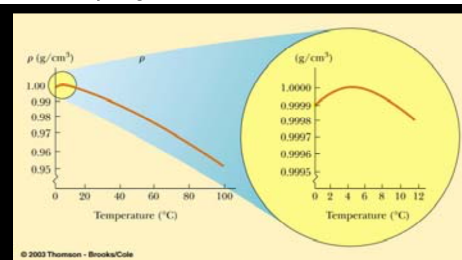
Use the fact that the depth of the ocean is 4.00 x 10^3 m to estimate the change in depth.

Note that β=2.07x10^4 (^{0}C)$^{-1}$.

Unusual behaviour of water

Why to ponds freeze from the top?

Why can pipes in your apartment break when you go home for Xmas break?



Ideal gas: macroscopic description

The pressure P, the volume V, the temperature T and the amount of gas n, are related to each other through the **equation of state**

Ideal gas:
Collection of atoms or molecules considered point-like, that move randomly and exert no long-range forces on each other.

Avogardo's number: number of particle per mole

$$N_A = 6.02 \times 10^{23}$$

Ideal gas: equation of state

The ideal gas law is: $PV = nRT$

Universal gas constant R=8.31 J/mol/K

Ideal gas: question time

An ideal gas at 20.0 ^{0}C and pressure 1.50x10^5 Pa is in a container of volume 1.00 L.

a) Determine the number of moles of gas in the container
b) The gas pushes against the piston, expanding to twice its original volume, while the pressure falls to atmospheric pressure. Find the final temperature.

Ideal gas: question time

A beachcomber finds a corked bottle containing a message. The air in the bottle is at atmospheric pressure and temperature 30.0 ^{0}C. The cork has a cross sectional area of 2.30 cm^2. The beachcomber places the bottle over the fire, assuming the increase pressure will push out the cork. At the temperature of 99 ^{0}C the cork is ejected from the bottle.

a) What was the pressure in the bottle just before the cork was ejected.
b) What force of friction held the cork in place?

Ideal gas: kinetic theory

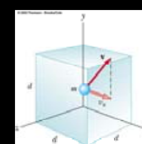
Assumptions:

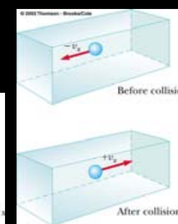
1. The number of molecules in a gas is large and the average separation between them is large compared with their dimension.
2. The molecules obey Newton's laws of motion, but as a whole they move randomly.
3. The molecules interact only via short-range forces during elastic collisions.
4. The molecules make elastic collisions with the walls
5. All molecules in the gas are identical

Ideal gas: kinetic theory

The pressure is proportional to the number of molecules per unit volume and to the average translational kinetic energy of a molecule.

$$P = \frac{2}{3}\left(\frac{N}{V}\right)\left(\frac{1}{2}mv^2\right)$$





Molecular interpretation of temperature

Temperature of a gas is a direct measure of the average molecular kinetic energy of the gas

$$T = \frac{2}{3k_B}\left(\frac{1}{2}mv^2\right)$$

where $k_B = R / N_A$

The total translational kinetic energy of a system of molecules is proportional to the absolute temperature of the system.

$$KE_{tot} = N\left(\frac{1}{2}mv^2\right) = \frac{3}{2}Nk_BT = \frac{3}{2}nRT$$

Internal energy

The internal energy for a monoatomic gas is:

$$U = \frac{2}{3}nRT$$

The root mean square speed is:

$$v_{rms} = \sqrt{\langle v^2 \rangle} = \sqrt{\frac{3k_BT}{m}} = \sqrt{\frac{3RT}{M}}$$

Root mean square speed

TABLE 10.2 Some rms Speeds

Gas	Molar Mass (kg/mol)	v_{rms} at 20°C (m/s)
H_2	2.02×10^{-3}	1902
He	4.0×10^{-3}	1352
H_2O	18×10^{-3}	637
Ne	20.1×10^{-3}	603
N_2 and CO	28×10^{-3}	511
NO	30×10^{-3}	494
CO_2	44×10^{-3}	408
SO_2	48×10^{-3}	390

Kinetic theory: question time

A cylinder contains 2.00 mol of helium gas at 20.0 ^{0}C. Assume the helium behaves like an ideal gas.

a) Find the total internal energy of the system.
b) What is the average kinetic energy per molecule?
c) How much energy would you have to add to the system to double the rms speed?