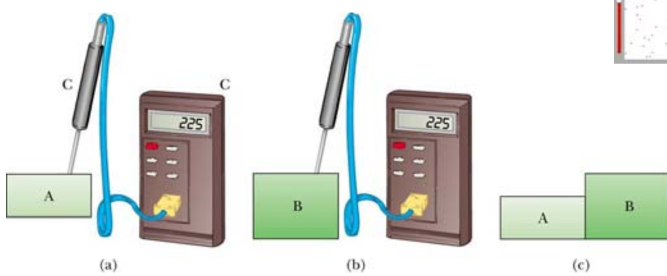
Chap 11 Heat and Temperature

HEAT

is a form of energy that can be transferred from one object to another because of a difference in temperature.

SI Unit of heat: calorie or joule



Temperature Scales

Temperature Scales:

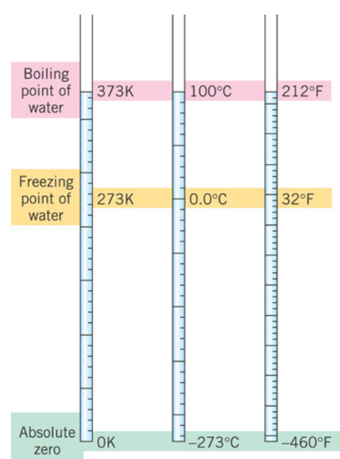
Fahrenheit

Celsius (Centigrade)

Absolute (Kelvin)

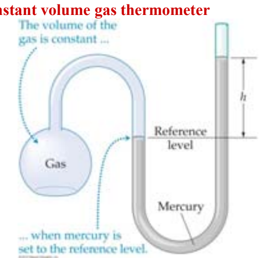
$$T_C = T - 273.15$$

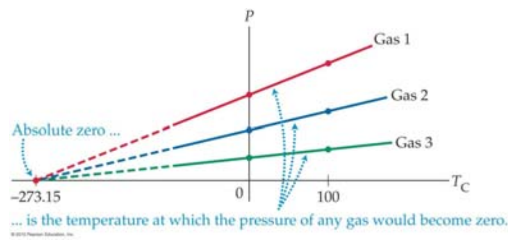
$$T_F = \tfrac{9}{5} T_C + 32$$



Thermometers and Temperature Scales

constant volume gas thermometer



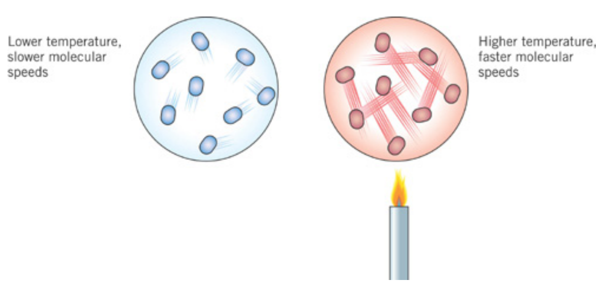


Any physical property which changes sensitively with the temperature can be used as thermometer. For example, the pressure of gas at a constant volume is an indicator of temperature. Celsius and Fahrenheit are artificially defined temperature scales. The absolute temperature (Kelvin) scale defines an absolute zero as a lower bound for physical processes.

$$T = T_C + 273.15$$

Atomic Basis of Temperature

Temperature is actually a measure of the magnitude of the average speed of atoms and molecules, including their vibrations --- that is, the kinetic energy of the particles that make matter. **The higher an object's temperature, the faster its atoms or molecules move.**



Examples

1. Convert the following Fahrenheit temperatures to kelvins.
   a. 120°F c. 11,500°F
   b. −40°F d. −456°F
2. Convert the following Celsius temperatures to Fahrenheit.
   a. 300°C c. 6,000°C
   b. −180°C d. 40°C
3. Convert the following kelvin temperatures to Celsius.
   a. 80 K c. 6000 K
   b. 300 K d. 545 K
4. At what temperature is the Celsius and Fahrenheit value th same?
5. Convert 70°F to degrees Celsius and to kelvins.

Thermal Expansion

The length of a solid object changes (usually expands) as temperature is raised.

The length of a solid object (with an initial length L_0 at temperature T_0) changes by ΔL for a change ΔT in temperature:

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

$$L - L_0 = \Delta L = \alpha L_0 (T - T_0)$$

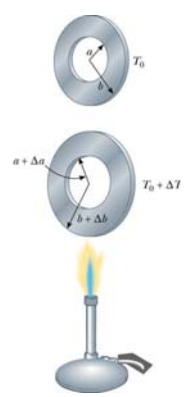
α is the coefficient of linear expansion.

The volume change of an object with a change in temperature is

Thermal expansion

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

β is the coefficient of volume expansion. Usually, $\beta = 3\alpha$.



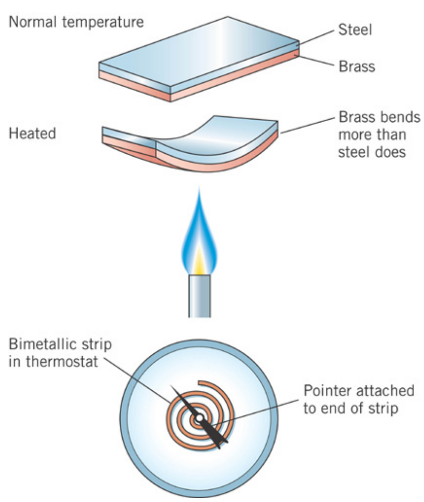
Thermal Expansion

ppm/°C

Sapphire	5.3[25]
alpha-Quartz	12-16/6-9[24]
Glass, borosilicate	3.3 [17]
CFRP	– 0.8[15]
Kapton	20[19]
Steel	11.0 ~ 13.0
Sitall	0±0.15[29]
Zerodur	≈0.007-0.1[33]
Aluminium nitride	4.2 a-axis, 5.3 c-axis[14]
PP	150
Aluminium	23.1
Benzocyclobutene	42
Brass	19
Carbon steel	10.8
Concrete	12
Copper	17
Diamond	1

Thermal Expansion Applications

bi-metallic material

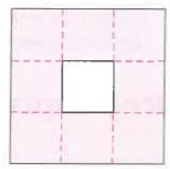


Examples

6. The coefficient of linear expansion for a silver strip is 19 :
10^{-6}/°C. What is its length on a hot day when the tempera
ture is 37°C if the strip is 0.20000 m long when it is −10°C

7. If a 50-m steel footbridge experiences extreme temperature
between −15°C and 45°C, what is the range in size of thi
bridge if it measures exactly 50 m at 20°C? (Steel has a cc
efficient of linear expansion of 0.000011/°C)

3. A square hole is cut out of a piece of sheet metal, as shown in the figure. When the temperature of the metal is raised, the metal expands. What happens to the size of the square hole? (*Hint:* Break up the piece of metal into eight smaller square pieces of sheet metal, then raise the temperature, then put them back together.)



4. Suppose your gold wedding ring

Heat and Internal Energy

Internal energy is the energy associated with the motion of atoms and molecules.

When heat is absorbed or emitted, the internal energy of a substance changes, usually with a corresponding change in its temperature. (Not always!)

Heat Capacity and Specific Heat

Heat Capacity is a measure of how much heat an object can absorb. It depends on the size of the object.

Specific Heat is defined as the quantity of heat required to raise the temperature of 1 gram of that material by 1°C.

Specific Heat

J/gram/°C

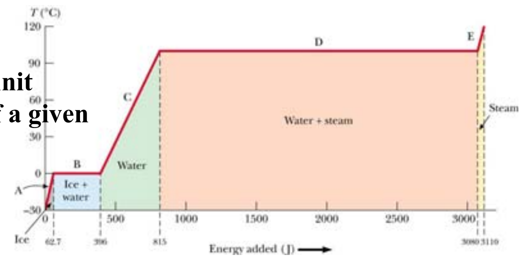
Silica (fused)	solid	0.703
Silver[2]	solid	0.233
Sodium	solid	1.230
Steel	solid	0.466
Tin	solid	0.227
Titanium	solid	0.523
Tungsten[2]	solid	0.134
Uranium	solid	**0.116**
Water at 100 °C (steam)	gas	**2.080**
Water at 25 °C	liquid	**4.1813**

Latent Heat

Latent Heat:

is the energy required, per unit mass, to change the phase of a given pure substance.

$$Q = \pm m L$$



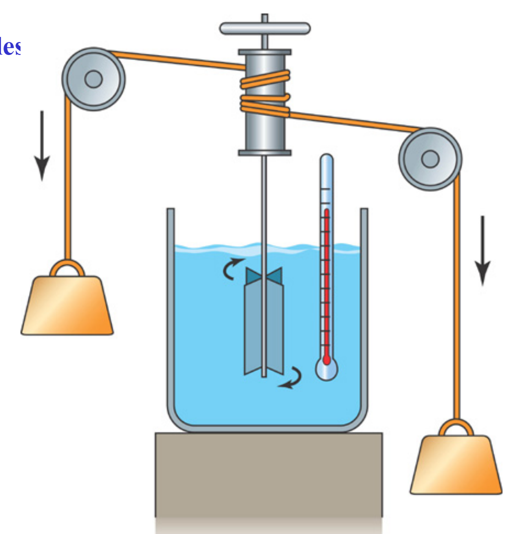
Latent Heat of Fusion: is the heat required for melting or freezing.

Latent Heat of Vaporization: is the heat required for vaporization or condensation

Latent Heat of Sublimation: is the heat required to sublime a solid directly to a gas, or to condense a gas to solid.

The Mechanical Equivalent of Heat

1 calorie = 4.186 joules



Thermal Conduction

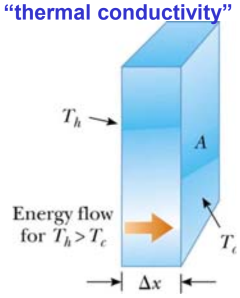
The rate of energy transfer is the amount of heat transferred across a plane in a unit time. It has units of power (watts). Heat flow is proportional to the "temperature gradient" and the cross-sectional area of the conduction path. It is also proportional to the "thermal conductivity" of the material.

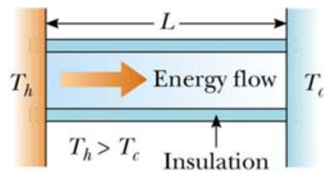
$$P = \frac{Q}{\Delta t} \propto A \frac{\Delta T}{\Delta x}$$

$$\frac{\Delta T}{\Delta x} = \frac{T_h - T_c}{L}$$

$$P = k\, A\left(\frac{T_h - T_c}{L}\right)$$

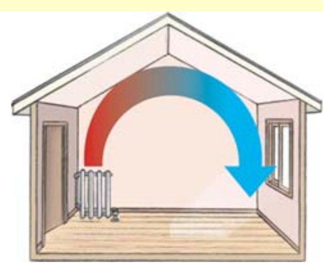
thermal conductivity   J s^{-1} m^{-1} $^{o}C^{-1}$





Energy Transfer by Convection and Radiation

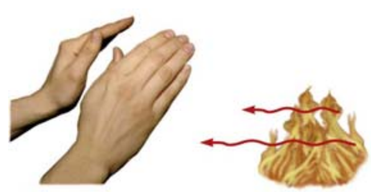
Energy transfer characterized by the movement of a substance is known as transfer by convection.



All objects emit radiation at a rate of

$$P = \sigma A e T^4$$

$\sigma = 5.6696 \times 10^{-8}$ W m^{-2} K^{-4}
e: emissivity (a number between 0 and 1)
e = 1 perfect absorber (black body)



Chap 12 The First Law of Thermodynamics

Heat as a form of energy

The interchangeability of energy.

Kinetic Energies

Potential Energies

Nuclear Energies

$$E = MC^2$$

First Law of Thermodynamics

First Law of Thermodynamics

The internal energy of a system changes from an initial value U_i to a final value of U_f due to heat Q and work W:

$$\Delta U = U_f - U_i = Q - W$$

The internal energy depends only on the state of a system, not on the method (path) by which the system arrives at a given state.

For an isolated system, for a cyclic process, or for an isothermal (constant temperature) process,

$\Delta U = 0$
$W = -Q$

Work
Isothermal

Examples

6. Above Earth's atmosphere we receive about 1400 W/m^2 of energy from the Sun. If you could convert 100% of this energy into usable electricity, how large a collecting area of solar cells would be necessary to produce a 1-gigawatt power plant?

7. In the Sun, 1 g of hydrogen consumed in nuclear fusion reactions produces 0.9929 g of helium; the other 0.0071 g of material is converted into other forms of energy.

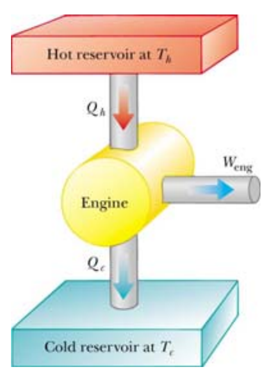
a. How much energy does this process produce in joules?

b. How high could you raise the Mt. Palomar 5-m telescope (4.5×10^5 kg) with this energy? (*Recall:* Work = Force [Newtons] × Distance [meters]; also remember the definition of *force* from Newton's law in Chapter 4.)

c. If you could convert 1 g of hydrogen into energy every second through nuclear fusion, the energy produced would be equivalent to how many 1-gigawatt power plants?

Chap 13 Entropy and The Second Law of Thermodynamics

A heat engine is a device that converts internal energy to other useful forms of energy.

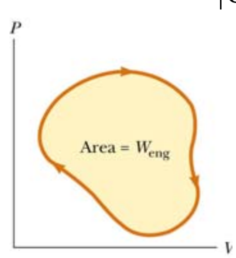


In a complete cycle

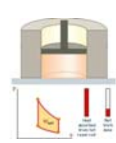
$$W = |Q_h| - |Q_c|$$

Efficiency

$$e = \frac{W}{|Q_h|} = 1 - \frac{|Q_c|}{|Q_h|}$$



second law of thermodynamics: it is impossible to construct a heat engine that is 100% efficient.



Entropy And Disorder

The change in entropy for reversible processes is $\Delta S = Q/T$ with T expressed in Kelvin scale. Entropy is a measure of the "disorder" of a system. It is related to the number of possible ways the total energy of a system can be subdivided into its individual components.

$$S = k_B \ln W$$

Another version of the second law of thermodynamics

The total entropy of the universe does not change when a reversible process occurs ($\Delta S_{universe} = 0$) and increases when an irreversible process occurs ($\Delta S_{universe} > 0$).