Chapter 19

Temperature

Outline for W14,D3

Temperature (Ch. 17)

Phases of matter

Temperature scales and conversions

Thermal expansion

Thermometers

Homework

Ch. 17 Read 17.1-17.4, 17.6-17.9, skim 18.1

P. 3,4,8,10,11,20,30,33,34,35,37,43 Due Mon

Ch. 19 Read 19.1-19.9

P. 1,6,8,9,20,21,32,33,35,36,40,49

MisConQ: 7,10-13 Due next Fri

Notes: I will put up scores on Canvas soon

Labs: thermal expansion, specific heat of Cu

Course evaluations

Return Ch. 11 hwk, (9.5/10).

Outline for W15,D1

Ways temperature change affects other physical properties

Thermal expansion (linear, areal, volume)

Electrical resistance

Thermal radiation

Gas pressure – need ideal gas law

Homework

Ch. 17 Read 17.1-17.4, 17.6-17.9, skim 18.1

P. 3,4,8,10,11,20,30,33,34,35,37,43 Due Today

Ch. 19 Read 19.1-19.9

P. 1,6,8,9,20,21,32,33,35,36,40,49

MisConQ: 7,10-13 Due Fri

Notes: I put up scores on Canvas

Labs: thermal expansion, specific heat of Cu

Course evaluations

Outline for W15,D2

Ideal gas law

1st Law of thermodynamics. $\Delta E_{int}=Q-W$

- Gases: $Q = nC_v\Delta T$ or $nC_p\Delta T$
- Solids and liquids $Q=mc\Delta T$, $Q=\pm mL$
- W by gases = $\int P\,dV$

Homework

Ch. 17 Read 17.1-17.4, 17.6-17.9, skim 18.1

P. 3,4,8,10,11,20,30,33,34,35,37,43 Due Today

Ch. 19 Read 19.1-19.9

P. 1,6,8,9,20,21,32,33,35,36,40,49

MisConQ: 7,10-13 Due Fri

Notes: NEW STUFF – added equations

Labs: thermal expansion, specific heat of Cu

Course evaluations

Final exam is on Monday, 12/16, 4:15 pm.

Outline for W15,D3

Final Exam Info

1^{st} Law of thermodynamics. $\Delta E_{int}=Q-W$

W by gases = $\int P\,dV$

Gas processes and the first law

Homework

Ch. 19 Read 19.1-19.9

P. 1,6,8,9,20,21,32,33,35,36,40,49

MisConQ: 7,10-13 Due Today

Notes:

Pick up graded material during office hrs today

Course evaluations

Final exam is on Monday, 12/16, 4:15 – 6:15 pm.

Final Exam Info

<u>Logistics</u>
Monday, 4:15-6:15 pm
Place: Me 114 (usual classroom)
Spread out
Use only calculator and writing utinsels

<u>Format</u>
Like Exams I and II, but a little longer (5 pages)
Multiple choice, T or F, Fill-in, problems
Will give thermodynamics equations and Exam II equations on p. 6.
Partial credit for starting with correct formulas and figures.
Show units
Make final answers clear (put box around them)

Coverage (over)
Kinematics and forces (Chs. 1-4) ~1 page

Final Exam Info (cont.)

Coverage

Kinematics and forces (Chs. 1-5) ~1 page

Work and Energy, Momentum (Chs. 7-9) ~ 1 page

Rotational Physics (Chs. 10-11) ~ 1 page

Thermodynamics (Ch. 17-19) ~ 2 pages

Skip 17.5, 17.10, 18.2-18.8, 19.9-19.10

Study Aids

Reviewing Exams I & II

Online “Final Exam Review”

Online “Assorted equations”

Hwk keys (Chs. 17, 19 now available) – compare to your hwks

Textbook end-of-chapter summaries, boldface terms.

Temperature

- We associate the concept of temperature with how hot or cold an object feels
- Our senses provide us with a qualitative indication of temperature
- Our senses are unreliable for this purpose
- We need a reliable and reproducible method for measuring the relative hotness or coldness of objects
  - We need a technical definition of temperature

Thermal Contact

- Two objects are in **thermal contact** with each other if energy can be exchanged between them
  - The exchanges we will focus on will be in the form of heat or electromagnetic radiation
  - The energy is exchanged due to a temperature difference

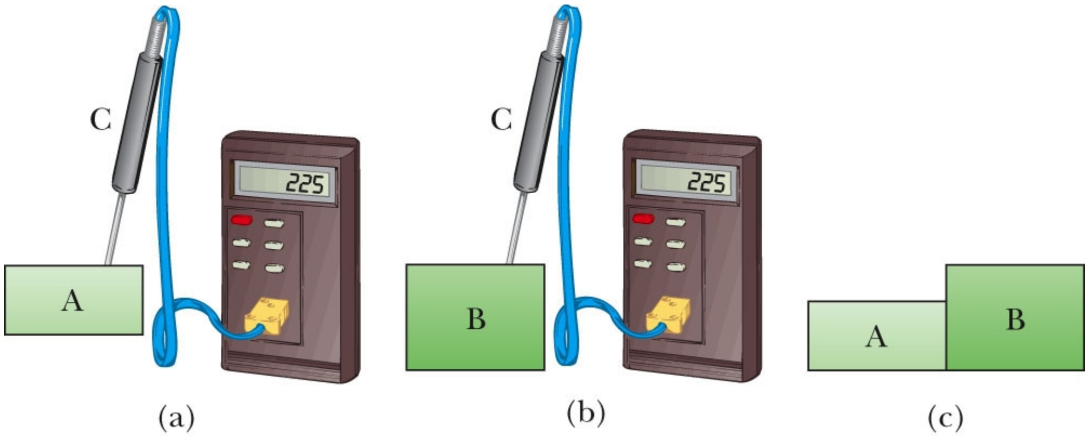
Thermal Equilibrium

- **Thermal equilibrium** is a situation in which two objects would not exchange energy by heat or electromagnetic radiation if they were placed in thermal contact
  - The thermal contact does not have to also be physical contact

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
  - Let object C be the thermometer
  - Since they are in thermal equilibrium with each other, there is no energy exchanged among them

Zeroth Law of Thermodynamics, Example



- Object C (thermometer) is placed in contact with A until they achieve thermal equilibrium
  - The reading on C is recorded
- Object C is then placed in contact with object B until they achieve thermal equilibrium
  - The reading on C is recorded again
- If the two readings are the same, A and B are also in thermal equilibrium

Temperature – Definition

- **Temperature** can be thought of as the property that determines whether an object is in thermal equilibrium with other objects
- Two objects in thermal equilibrium with each other are at the same temperature
  - If two objects have different temperatures, they are not in thermal equilibrium with each other

Thermometers

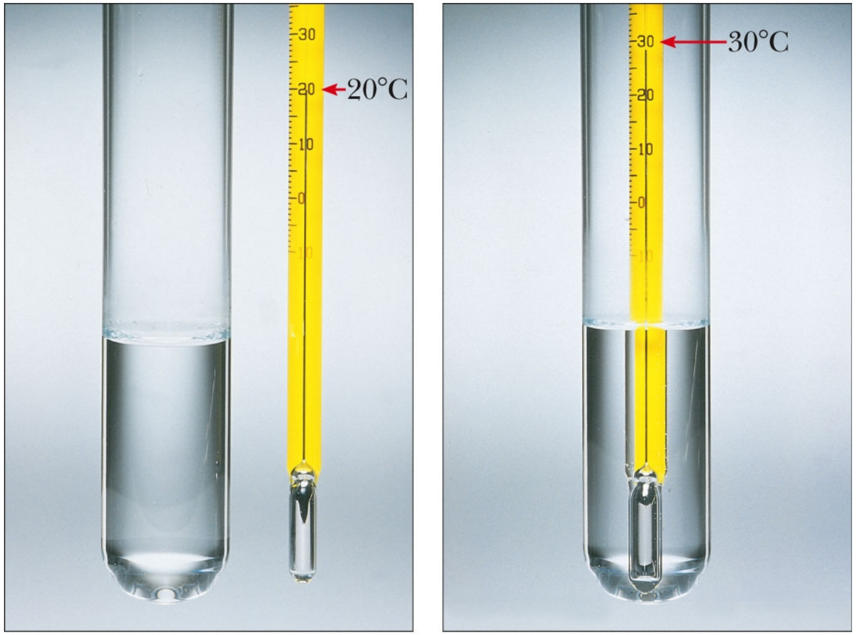
- A **thermometer** is a device that is used to measure the temperature of a system
- Thermometers are based on the principle that some physical property of a system changes as the system's temperature changes

Thermometers, cont

- These properties include:
  - The volume of a liquid
  - The dimensions of a solid
  - The pressure of a gas at a constant volume
  - The volume of a gas at a constant pressure
  - The electric resistance of a conductor
  - The color of an object
- A temperature scale can be established on the basis of any of these physical properties

Thermometer, Liquid in Glass

- A common type of thermometer is a liquid-in-glass
- The material in the capillary tube expands as it is heated
- The liquid is usually mercury or alcohol



Calibrating a Thermometer

- A thermometer can be calibrated by placing it in contact with some natural systems that remain at constant temperature
- Common systems involve water
  - A mixture of ice and water at atmospheric pressure
    - Called the *ice point* of water
  - A mixture of water and steam in equilibrium
    - Called the *steam point* of water
- Once these points are established, the length between them can be divided into a number of segments

Celsius Scale

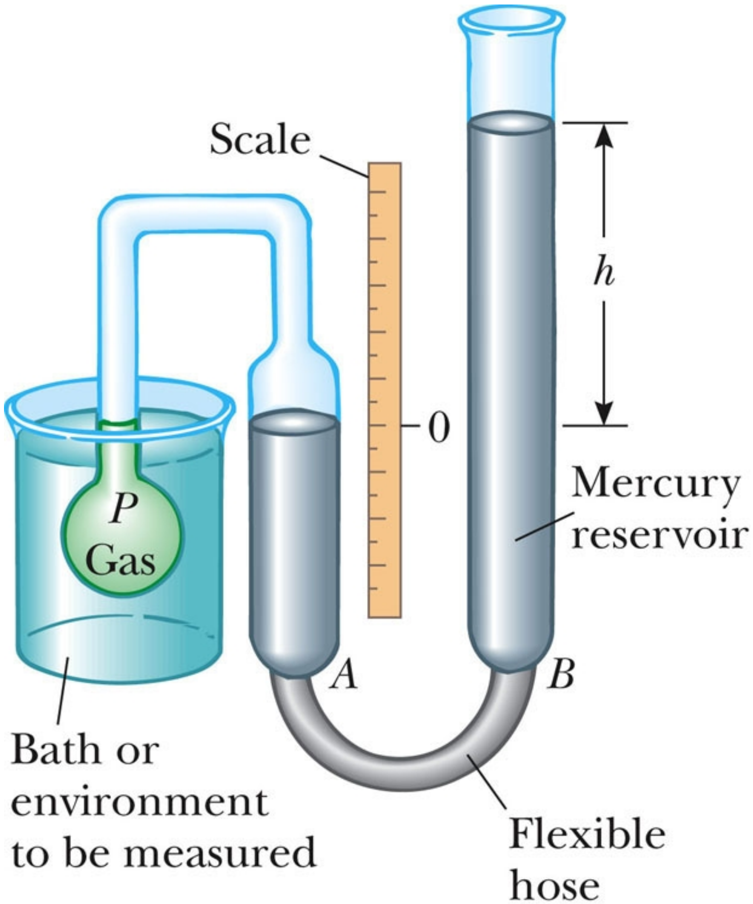
- The ice point of water is defined to be 0^o C
- The steam point of water is defined to be 100^o C
- The length of the column between these two points is divided into 100 increments, called degrees

Problems with Liquid-in-Glass Thermometers

- An alcohol thermometer and a mercury thermometer may agree only at the calibration points
- The discrepancies between thermometers are especially large when the temperatures being measured are far from the calibration points
- The thermometers also have a limited range of values that can be measured
  - Mercury cannot be used under –39^{o} C
  - Alcohol cannot be used above 85^{o} C

Constant-Volume Gas Thermometer

- The physical change exploited is the variation of pressure of a fixed volume gas as its temperature changes
- The volume of the gas is kept constant by raising or lowering the reservoir B to keep the mercury level at A constant

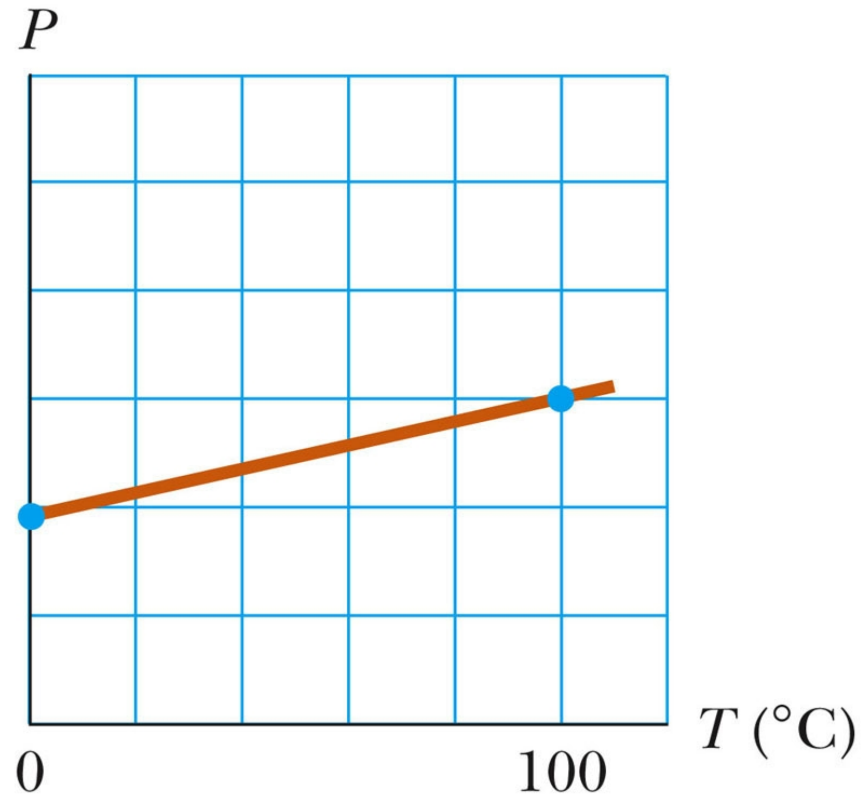


Constant-Volume Gas Thermometer, cont

- The pressure is indicated by the height difference between reservoir B and column A
- The thermometer is calibrated by using a ice water bath and a steam water bath
- The pressures of the mercury under each situation are recorded
  - The volume is kept constant by adjusting A
- The information is plotted

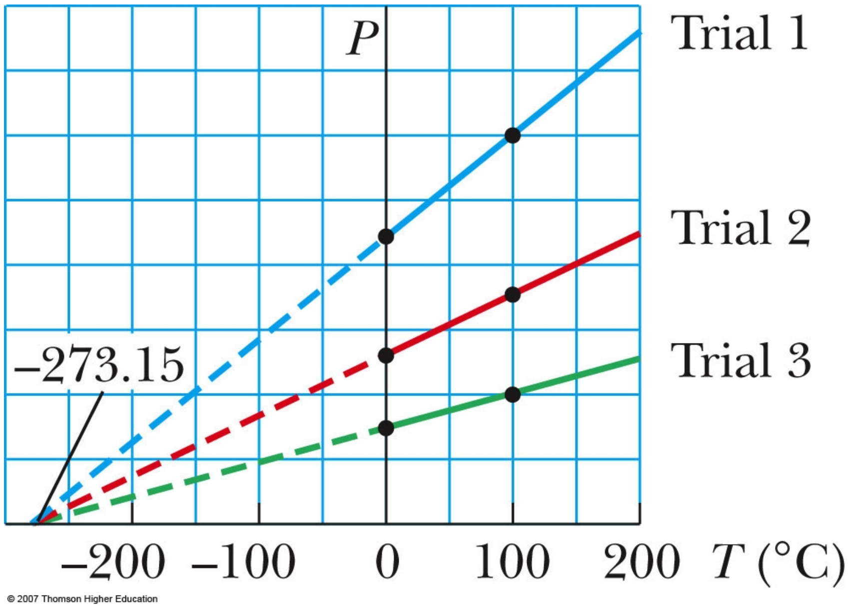
Constant-Volume Gas Thermometer, final

- To find the temperature of a substance, the gas flask is placed in thermal contact with the substance
- The pressure is found on the graph
- The temperature is read from the graph



Absolute Zero

- The thermometer readings are virtually independent of the gas used
- If the lines for various gases are extended, the pressure is always zero when the temperature is –273.15° C
- This temperature is called **absolute zero**



Absolute Temperature Scale

- Absolute zero is used as the basis of the absolute temperature scale
- The size of the degree on the absolute scale is the same as the size of the degree on the Celsius scale
- To convert:
  - $T_C = T - 273.15$

Absolute Temperature Scale, 2

- The absolute temperature scale is now based on two new fixed points
  - Adopted by in 1954 by the International Committee on Weights and Measures
  - One point is absolute zero
  - The other point is the **triple point** of water
    - This is the combination of temperature and pressure where ice, water, and steam can all coexist

Absolute Temperature Scale, 3

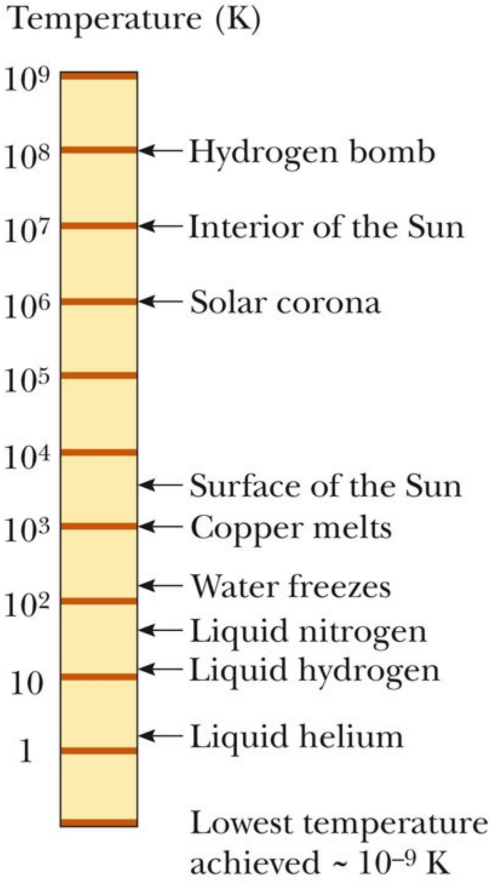
- The triple point of water occurs at 0.01° C and 4.58 mm of mercury
- This temperature was set to be 273.16 on the absolute temperature scale
  - This made the old absolute scale agree closely with the new one
  - The units of the absolute scale are **kelvins**

Absolute Temperature Scale, 4

- The absolute scale is also called the Kelvin scale
  - Named for William Thomson, Lord Kelvin
- The triple point temperature is 273.16 K
  - No degree symbol is used with kelvins
- The kelvin is defined as 1/273.16 of the difference between absolute zero and the temperature of the triple point of water

Some Examples of Absolute Temperatures

- The figure at right gives some absolute temperatures at which various physical processes occur
- The scale is logarithmic
- The temperature of absolute zero cannot be achieved
  - Experiments have come close



Fahrenheit Scale

- A common scale in everyday use in the US
- Named for Daniel Fahrenheit
- Temperature of the ice point is 32^{o}F
- Temperature of the steam point is 212^{o}F
- There are 180 divisions (degrees) between the two reference points

Comparison of Scales

- Celsius and Kelvin have the same size degrees, but different starting points
  - $T_C = T - 273.15$
- Celsius and Fahrenheit have different sized degrees and different starting points

$$T_F = \frac{9}{5} T_C + 32^\circ F$$

Comparison of Scales, cont

- To compare changes in temperature

$$\Delta T_C = \Delta T = \frac{5}{9}\Delta T_F$$

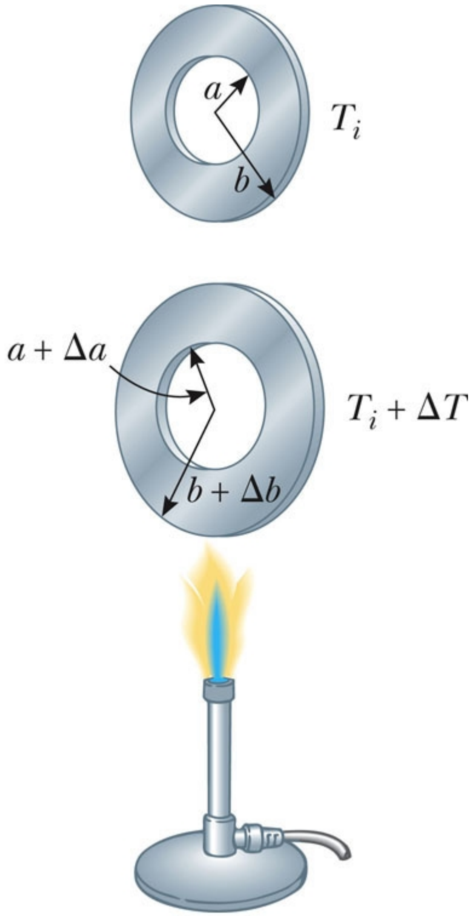
- Ice point temperatures
  - $0^{\circ}C = 273.15\ K = 32^{\circ}\ F$
- Steam point temperatures
  - $100^{\circ}C = 373.15\ K = 212^{\circ}\ F$

Thermal Expansion

- Thermal expansion is the increase in the size of an object with an increase in its temperature
- Thermal expansion is a consequence of the change in the average separation between the atoms in an object
- If the expansion is small relative to the original dimensions of the object, the change in any dimension is, to a good approximation, proportional to the first power of the change in temperature

Thermal Expansion, example

- As the washer shown at right is heated, all the dimensions will increase
- A cavity in a piece of material expands in the same way as if the cavity were filled with the material
- The expansion is exaggerated in this figure
- Use the active figure to change temperature and material



Linear Expansion

- Assume an object has an initial length L
- That length increases by ΔL as the temperature changes by ΔT
- We define the **coefficient of linear expansion** as

$$\alpha = \frac{\Delta L / L_i}{\Delta T}$$

- A convenient form is $\Delta L = \alpha L_i \Delta T$

Linear Expansion, cont

- This equation can also be written in terms of the initial and final conditions of the object:
  - $L_f - L_i = \alpha L_i (T_f - T_i)$
- The coefficient of linear expansion, α, has units of $(^{\circ}C)^{-1}$

Some Coefficients

TABLE 19.1

Average Expansion Coefficients for Some Materials Near Room Temperature

Material	Average Linear Expansion Coefficient (α) $(°C)^{-1}$	Material	Average Volume Expansion Coefficient (β) $(°C)^{-1}$
Aluminum	24×10^{-6}	Alcohol, ethyl	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[a] at 0°C	3.67×10^{-3}
Concrete	12×10^{-6}	Helium[a]	3.665×10^{-3}

[a] Gases do not have a specific value for the volume expansion coefficient because the amount of expansion depends on the type of process through which the gas is taken. The values given here assume the gas undergoes an expansion at constant pressure.

Linear Expansion, final

- Some materials expand along one dimension, but contract along another as the temperature increases
- Since the linear dimensions change, it follows that the surface area and volume also change with a change in temperature
- A cavity in a piece of material expands in the same way as if the cavity were filled with the material

Volume Expansion

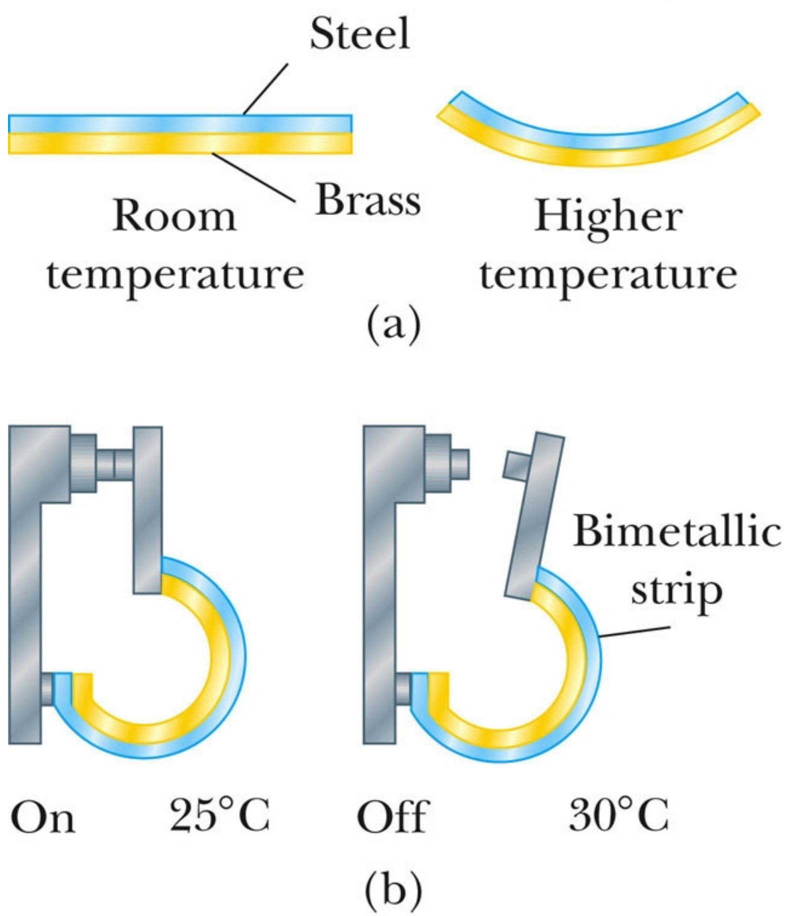
- The change in volume is proportional to the original volume and to the change in temperature
- $\Delta V = \beta V_i \Delta T$
  - β is the coefficient of volume expansion
  - For a solid, $\beta = 3\alpha$
    - This assumes the material is isotropic, the same in all directions
  - For a liquid or gas, β is given in the table

Area Expansion

- The change in area is proportional to the original area and to the change in temperature:
  - $\Delta A = 2\alpha A_i \Delta T$

Bimetallic Strip

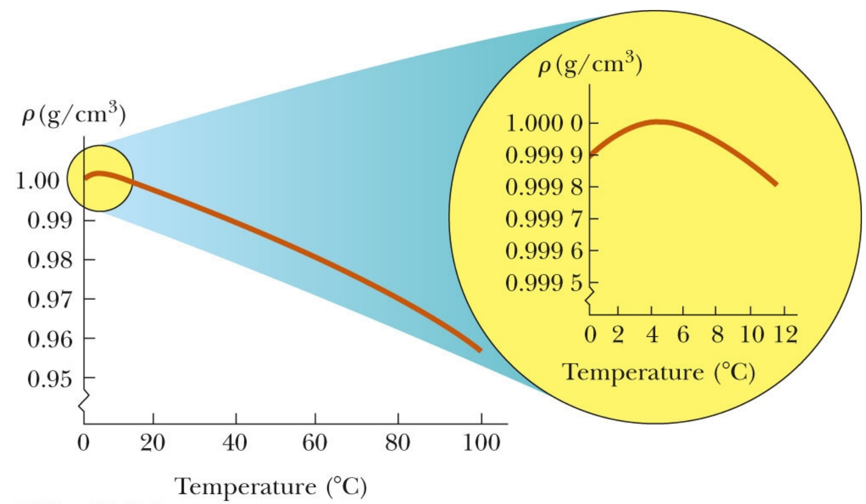
- Each substance has its own characteristic average coefficient of expansion
- This can be made use of in the device shown, called a bimetallic strip
- It can be used in a thermostat



Thermal Radiation

Water’s Unusual Behavior

- As the temperature increases from 0^{o}C to 4^{o}C, water contracts
  - Its density increases
- Above 4^{o}C, water expands with increasing temperature
  - Its density decreases
- The maximum density of water (1.000 g/cm^{3}) occurs at 4^{o}C



An Ideal Gas

- For gases, the interatomic forces within the gas are very weak
  - We can imagine these forces to be nonexistent
- Note that there is no equilibrium separation for the atoms
  - Thus, no “standard” volume at a given temperature

Ideal Gas, cont

- For a gas, the volume is entirely determined by the container holding the gas
- Equations involving gases will contain the volume, V, as a variable
  - This is instead of focusing on ΔV

Gas: Equation of State

- It is useful to know how the volume, pressure and temperature of the gas of mass m are related
- The equation that interrelates these quantities is called the **equation of state**
  - These are generally quite complicated
  - If the gas is maintained at a low pressure, the equation of state becomes much easier
  - This type of a low density gas is commonly referred to as an ideal gas

Ideal Gas Model

- The ideal gas model can be used to make predictions about the behavior of gases
  - If the gases are at low pressures, this model adequately describes the behavior of real gases

The Mole

- The amount of gas in a given volume is conveniently expressed in terms of the number of moles
- One **mole** of any substance is that amount of the substance that contains **Avogadro's number** of constituent particles
  - Avogadro's number $N_A = 6.022 \times 10^{23}$
  - The constituent particles can be atoms or molecules

Moles, cont

- The number of moles can be determined from the mass of the substance: $n = m / M$
  - M is the molar mass of the substance
    - Can be obtained from the periodic table
    - Is the atomic mass expressed in grams/mole
      - Example: He has mass of 4.00 u so M = 4.00 g/mol
  - m is the mass of the sample
  - n is the number of moles

Gas Laws

- When a gas is kept at a constant temperature, its pressure is inversely proportional to its volume (Boyle's law)
- When a gas is kept at a constant pressure, its volume is directly proportional to its temperature (Charles and Gay-Lussac's law)
- When the volume of the gas is kept constant, the pressure is directly proportional to the temperature (Guy-Lussac's law)

Ideal Gas Law

- The equation of state for an ideal gas combines and summarizes the other gas laws

  $$PV = nRT$$

- This is known as the **ideal gas law**
- R is a constant, called the Universal Gas Constant
  - R = 8.314 J/mol · K = 0.08214 L · atm/mol · K
- From this, you can determine that 1 mole of any gas at atmospheric pressure and at 0° C is 22.4 L

Ideal Gas Law, cont

- The ideal gas law is often expressed in terms of the total number of molecules, *N*, present in the sample
- $PV = nRT = (N/N_A)\,RT = Nk_B T$
  - k_B is Boltzmann's constant
  - $k_B = 1.38 \times 10^{-23}$ J/K
- It is common to call *P*, *V*, and *T* the **thermodynamic variables** of an ideal gas
- If the equation of state is known, one of the variables can always be expressed as some function of the other two