Temperature

By:

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Topics

- Temperature and the Zeroth Law of Thermodynamics
- Thermometers and the Celsius Temperature Scale
- The Constant-Volume Gas Thermometer and the Absolute Temperature Scale
- Thermal Expansion of Solids and Liquids
- Macroscopic Description of an Ideal Gas

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Temperature

- Temperature: how hot or cold an object feels when we touch it.
- In this way, our senses provide us with a qualitative indication of temperature.
- Our senses, however, are unreliable and often mislead us.
  - Example: Carpet vs Floor, Wood vs Metals
- The two objects feel different because tile transfers energy by heat at a higher rate than carpet does.
- Your skin “measures” the rate of energy transfer by heat rather than the actual temperature.

The Zeroth Law of Thermodynamics

- Two objects at different initial temperatures eventually reach some intermediate temperature when placed in contact with each other.
- If the objects are at different temperatures, energy is transferred between them, even if they are initially not in physical contact with each other.
- 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.

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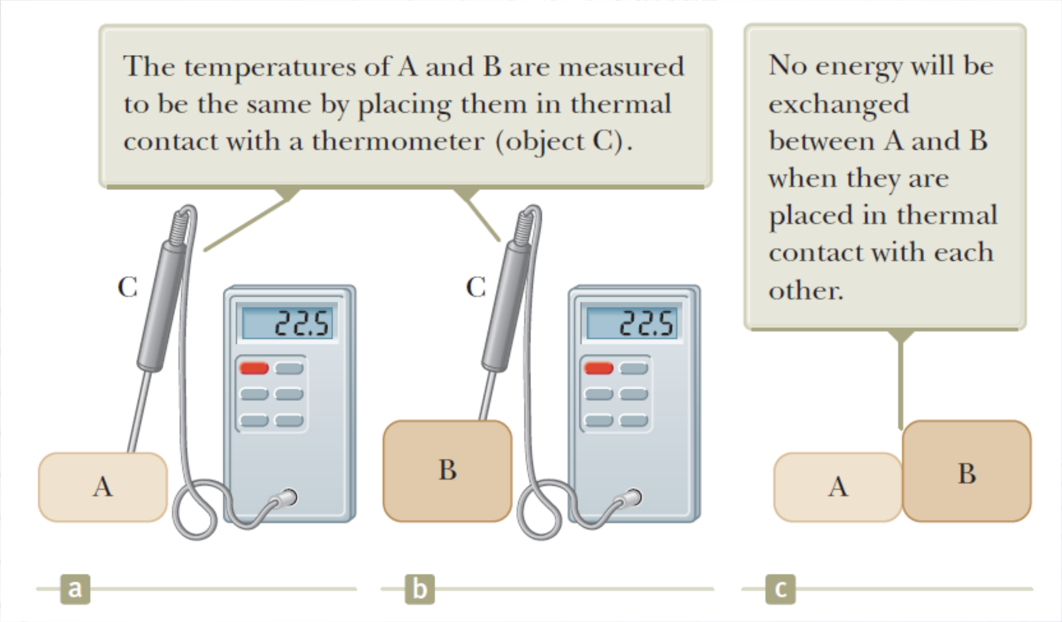
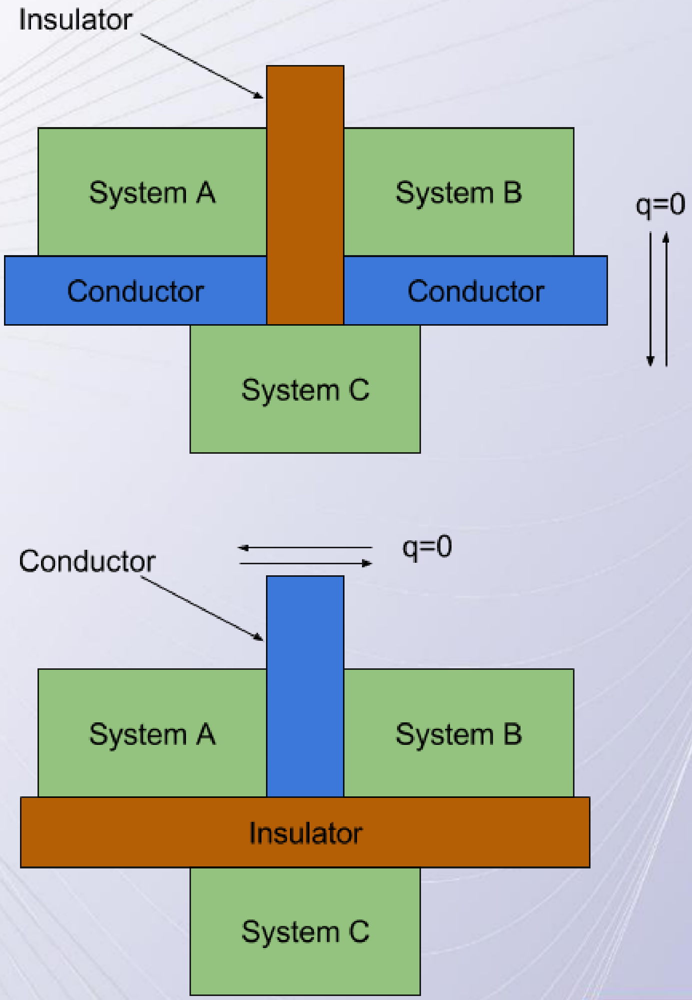
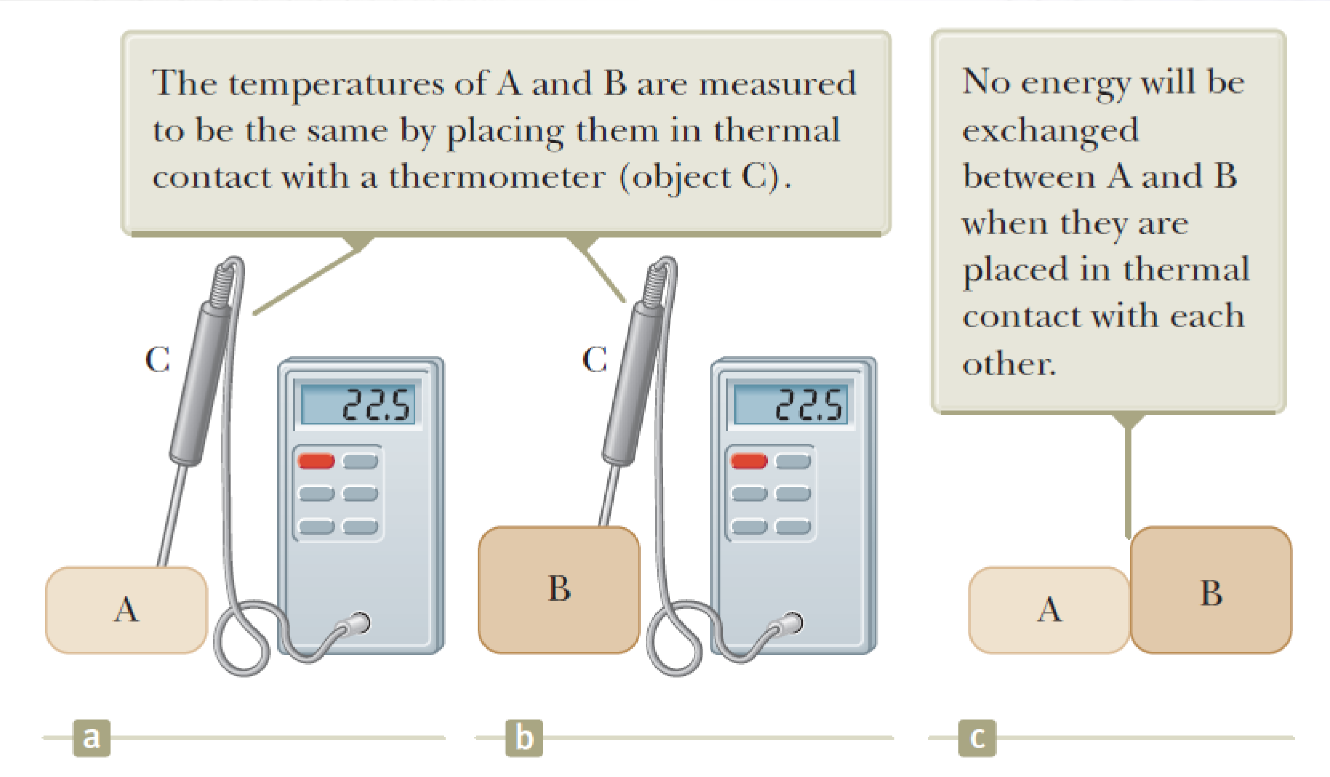
- The Zeroth Law of Thermodynamics:
  - **If objects A and B are separately in thermal equilibrium with a third object C, then A and B are in thermal equilibrium with each other.**







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- We can think of temperature 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.

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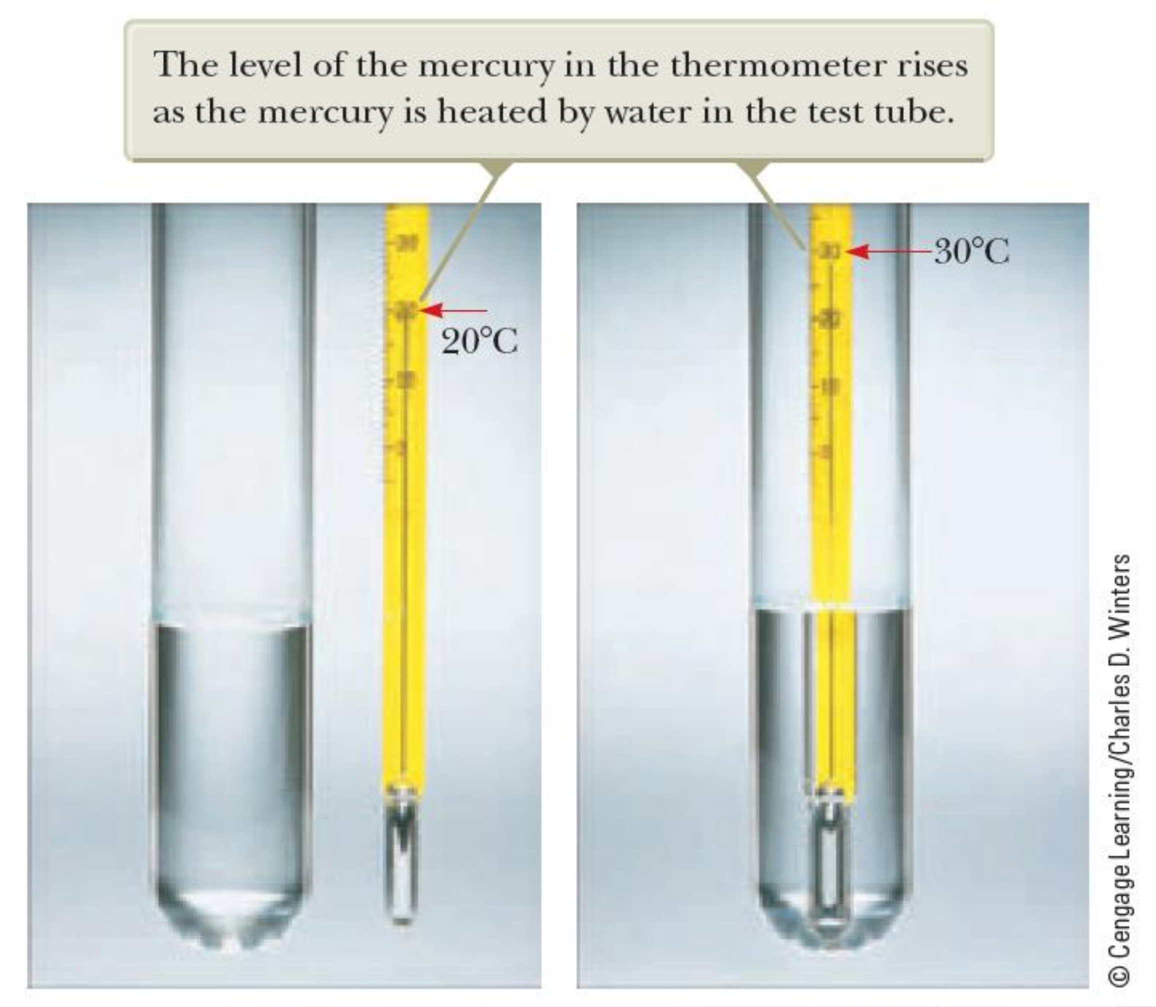
Thermometers

- Thermometers are devices used to measure the temperature of a system.
- All thermometers are based on the principle that some physical property of a system changes as the system's temperature changes.
- Some physical properties that change with temperature are:
  - the volume of a liquid,
  - the dimensions of a solid,
  - the pressure of a gas at constant volume,
  - the volume of a gas at constant pressure,
  - the electric resistance of a conductor, and
  - the color of an object.



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- The thermometer can be calibrated by placing it in thermal contact with a natural system that remains at constant temperature.
- On the Celsius temperature scale, this mixture is defined to have a temperature of zero degrees Celsius, which is written as 0 ^{o}C; this temperature is called the ice point of water.
- Another commonly used system is a mixture of water and steam in thermal equilibrium at atmospheric pressure; its temperature is defined as 100 ^{o}C, which is the steam point of water.

- Thermometers calibrated in this way present problems when extremely accurate readings are needed.
- For instance, the readings given by an alcohol thermometer calibrated at the ice and steam points of water might agree with those given by a mercury thermometer only at the calibration points.
- Because mercury and alcohol have different thermal expansion properties, when one thermometer reads a temperature of, for example, 50 ^{o}C, the other may indicate a slightly different value.
- The discrepancies between thermometers are especially large when the temperatures to be measured are far from the calibration points.

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- An additional practical problem of any thermometer is the limited range of temperatures over which it can be used.
- A mercury thermometer cannot be used below the freezing point of mercury, which is -39 ^{o}C,
- An alcohol thermometer is not useful for measuring temperatures above 85 ^{o}C, the boiling point of alcohol.
- To surmount this problem, we need a universal thermometer whose readings are independent of the substance used in it.

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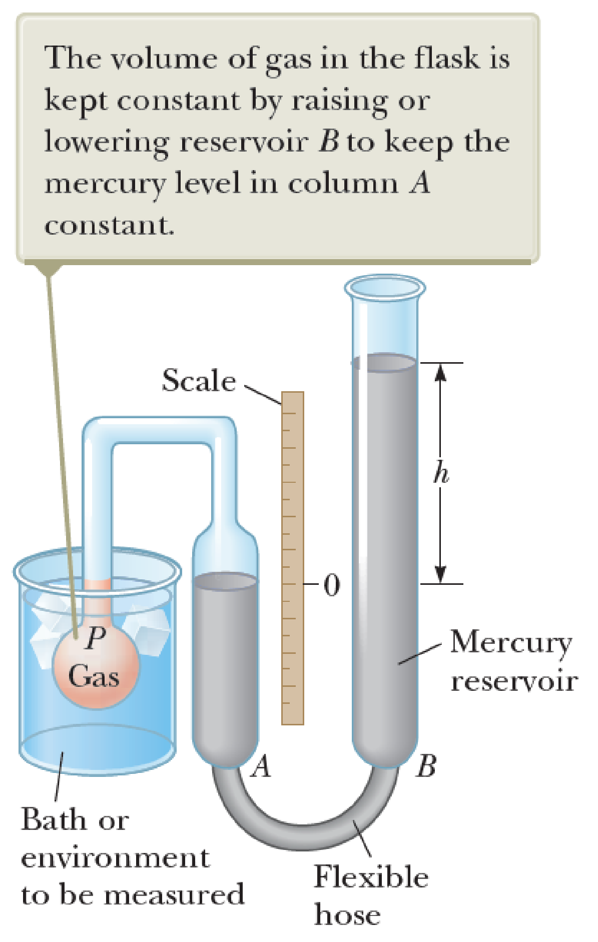
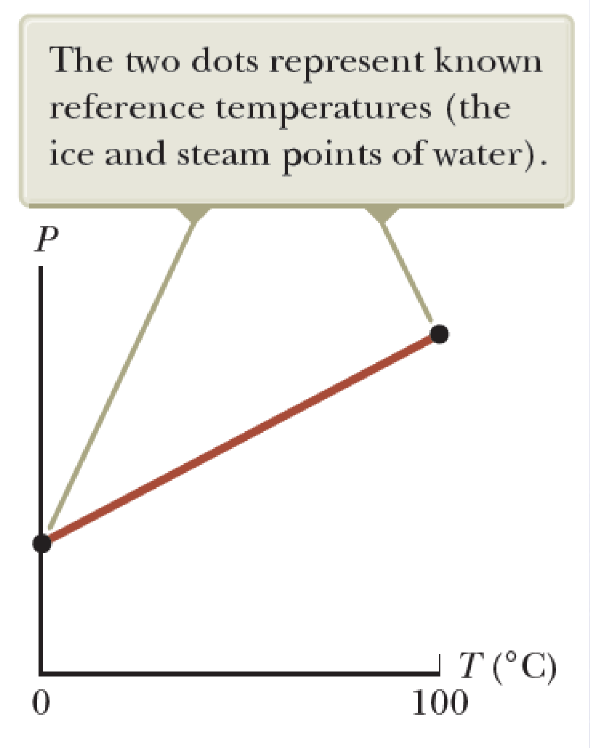
Constant-Volume Gas Thermometer

- The constant-volume gas termometer use the variation of pressure of a fixed volume of gas with temperature.
- The flask is immersed in an ice-water bath, and mercury reservoir B is raised or lowered until the top of the mercury in column A is at the zero point on the scale.
- The height *h*, the difference between the mercury levels in reservoir B and column A, indicates the pressure in the flask at 0 ºC by means of Equation:

$$P = P_0 + \rho g h$$



- The flask is then immersed in water at the steam point.
- Reservoir B is readjusted until the top of the mercury in column A is again at zero on the scale, which ensures that the gas's volume is the same as it was when the flask was in the ice bath (hence the designation "constant-volume").
- This adjustment of reservoir B gives a value for the gas pressure at 100 ^{o}C.
- The line connecting the two points serves as a calibration curve for unknown temperatures.



- To measure the temperature of a substance, the gas flask is placed in thermal contact with the substance and the height of reservoir B is adjusted until the top of the mercury column in A is at zero on the scale.
- The height of the mercury column in B indicates the pressure of the gas; knowing the pressure, the temperature of the substance is found using the graph.
- Experiments show that the thermometer readings are nearly independent of the type of gas used as long as the gas pressure is low and the temperature is well above the point at which the gas liquefies.
- The agreement among thermometers using various gases improves as the pressure is reduced.

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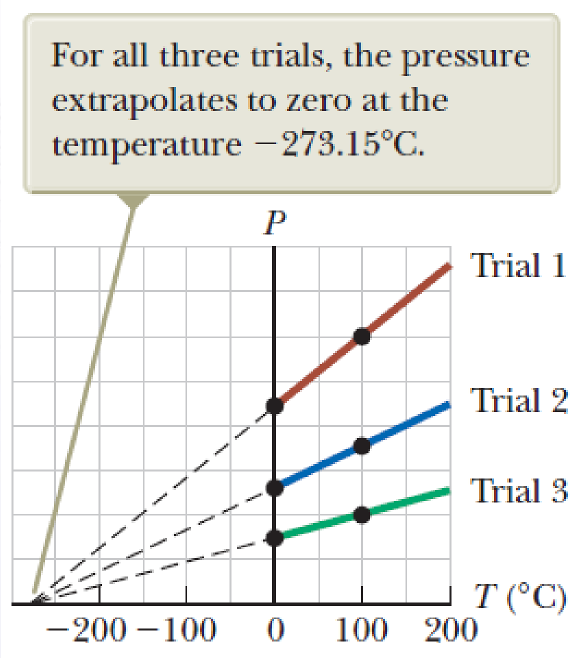
Absolute Temperature Scale

- We extend the straight lines in Figure 19.5 toward negative temperatures, we find a remarkable result: in every case, the pressure is zero when the temperature is 273.15 ºC!
- It is used as the basis for the absolute temperature scale, which sets 273.15 ºC as its zero point.
- This temperature is often referred to as absolute zero



- An absolute temperature scale based on two new fixed points:
  - The first point is absolute zero.
  - The second reference temperature for this new scale was chosen as the triple point of water, which is the single combination of temperature and pressure at which liquid water, gaseous water, and ice (solid water) coexist in equilibrium.
- On the new scale, which uses the unit kelvin, the temperature of water at the triple point was set at 273.16 kelvins, abbreviated 273.16 K.
- This choice was made so that the old absolute temperature scale based on the ice and steam points would agree closely with the new scale based on the triple point.

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The Celsius, Fahrenheit, and Kelvin Temperature Scales

- Group Discussion
  - Celsius
  - Reaumur
  - Fahrenheit
  - Kelvin
  - Rankine

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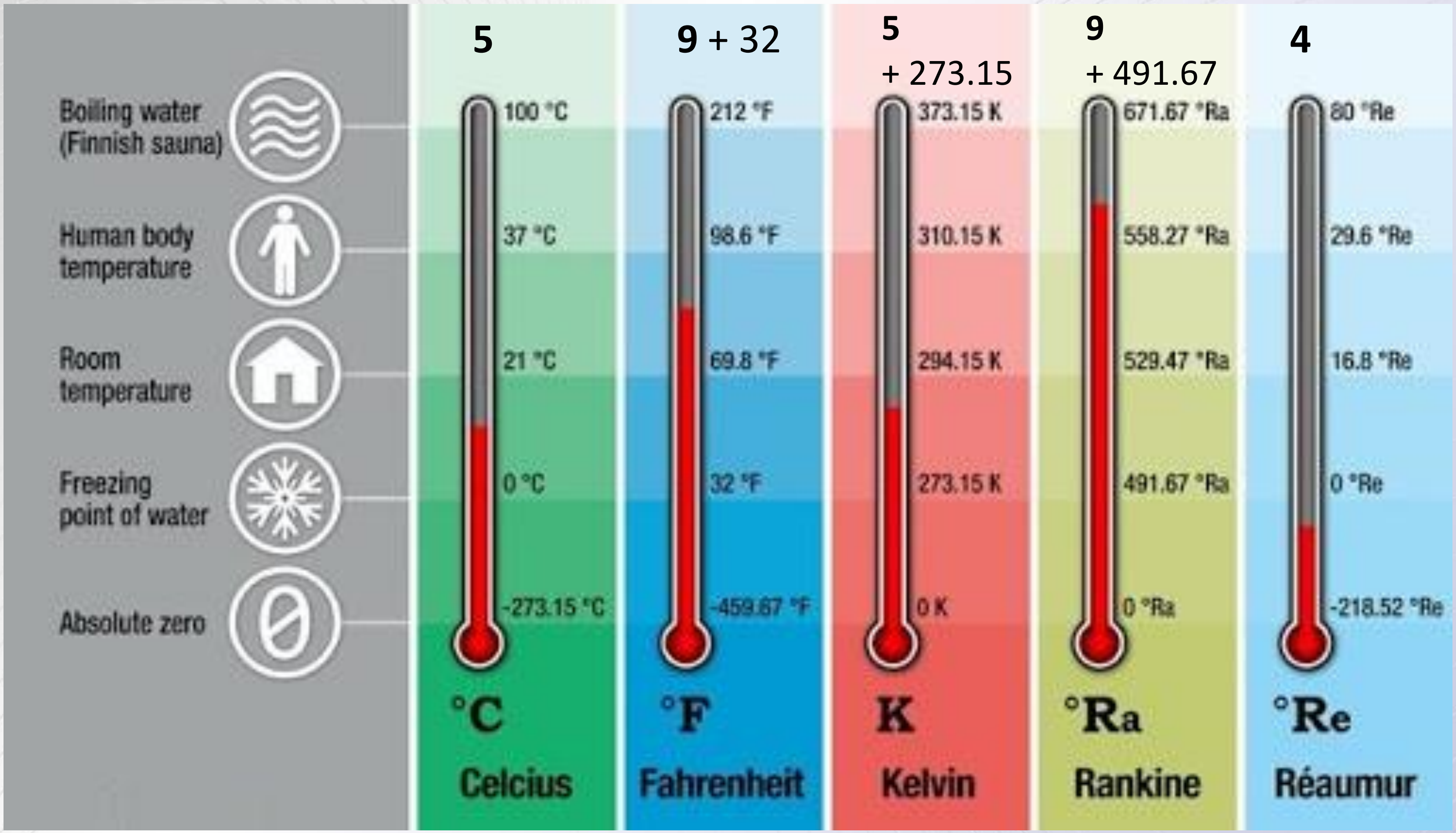

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Dari	ke			
	Celsius	Reamur	Fahrenheit	Kelvin
Celsius		$\frac{4}{5}C$	$\frac{9}{5}C+32$	$C+273$
Reamur	$\frac{5}{4}R$		$\frac{9}{4}R+32$	$\frac{5}{4}R+273$
Fahrenheit	$\frac{5}{9}(F-32)$	$\frac{4}{9}(F-32)$		
Kelvin	$K-273$	$\frac{4}{5}(K-273)$		

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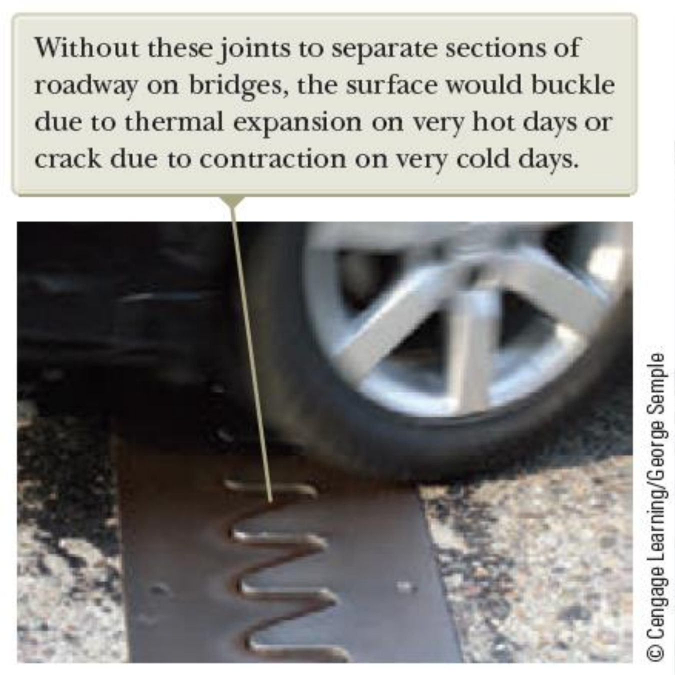
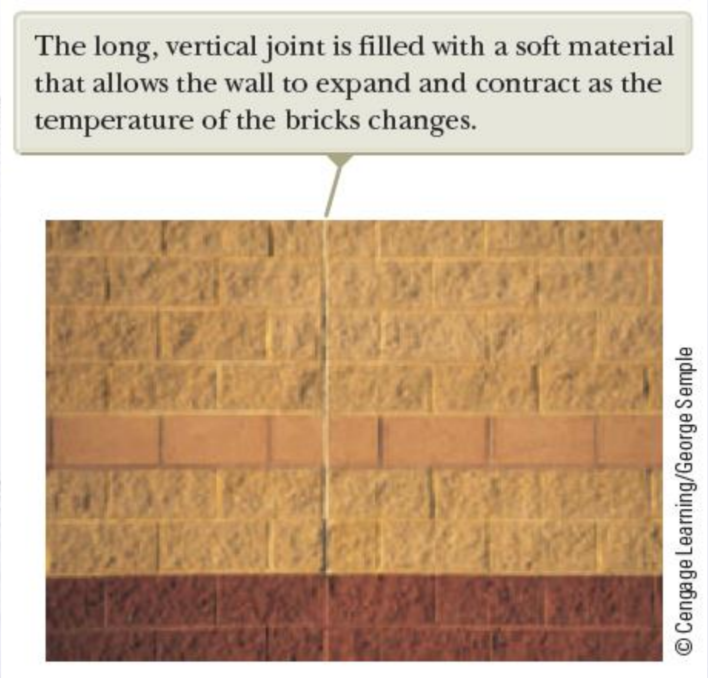
Thermal Expansion of Solids and Liquids

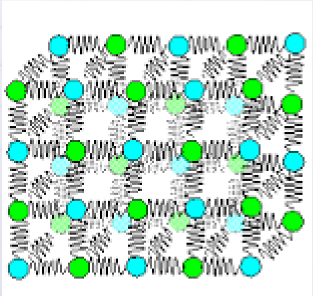
- The best-known changes in a substance: as its temperature increases, its volume increases -> Thermal Expansion

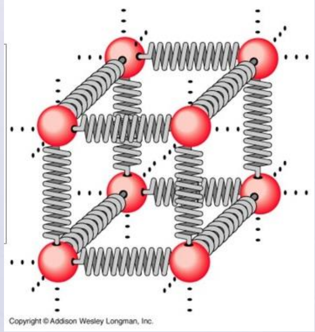


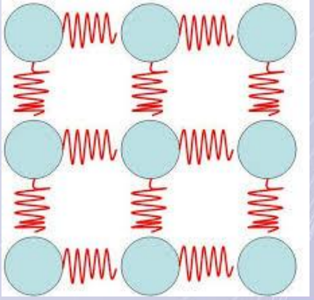


- Thermal expansion is a consequence of the change in the average separation between the atoms in an object.

- To understand this concept, let’s model the atoms as being connected by stiff springs.
- At ordinary temperatures, the atoms in a solid oscillate about their equilibrium positions with an amplitude of approximately 10^{-11} m and a frequency of approximately 10^{13} Hz. The average spacing between the atoms is about 10^{10} m.
- As the temperature of the solid increases, the atoms oscillate with greater amplitudes; as a result, the average separation between them increases.
- Consequently, the object expands.







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- If thermal expansion is sufficiently small relative to an object's initial dimensions, the change in any dimension is, to a good approximation, proportional to the first power of the temperature change.
- Suppose an object has an initial length L_i along some direction at some temperature and the length changes by an amount ΔL for a change in temperature ΔT.
- Because it is convenient to consider the fractional change in length per degree of temperature change, we define the average coefficient of linear expansion as:

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

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- Experiments show that α is constant for small changes in temperature.

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

$$L_f - L_i = \alpha L_i (T_f - T_i)$$

- where L_f is the final length, T_i and T_f are the initial and final temperatures, and the proportionality constant α is the average coefficient of linear expansion for a given material and has units of $(^oC)^{-1}$.
- It may be helpful to think of thermal expansion as an effective magnification or as a photographic enlargement of an object.

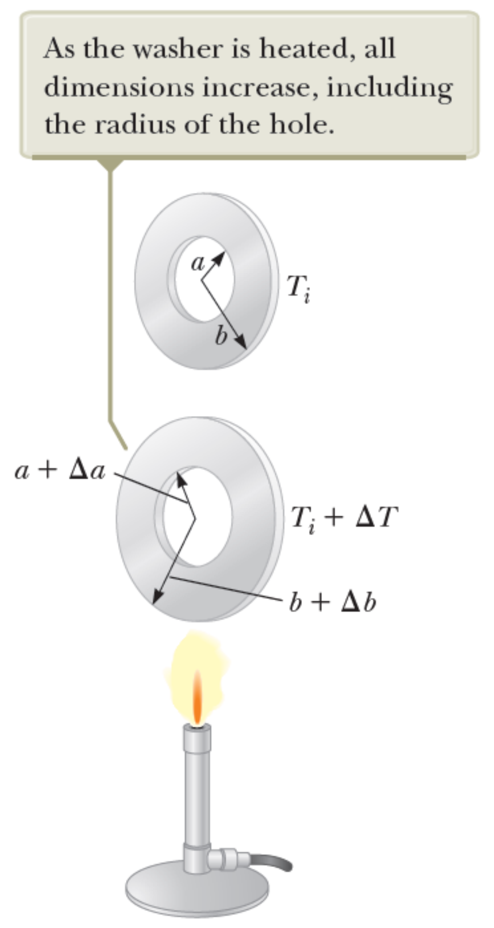

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Table 19.1 Average Expansion Coefficients for Some Materials Near Room Temperature

Material (Solids)	Average Linear Expansion Coefficient $(\alpha)(°C)^{-1}$	Material (Liquids and Gases)	Average Volume Expansion Coefficient $(\beta)(°C)^{-1}$
Aluminum	24×10^{-6}	Acetone	1.5×10^{-4}
Brass and bronze	19×10^{-6}	Alcohol, ethyl	1.12×10^{-4}
Concrete	12×10^{-6}	Benzene	1.24×10^{-4}
Copper	17×10^{-6}	Gasoline	9.6×10^{-4}
Glass (ordinary)	9×10^{-6}	Glycerin	4.85×10^{-4}
Glass (Pyrex)	3.2×10^{-6}	Mercury	1.82×10^{-4}
Invar (Ni–Fe alloy)	0.9×10^{-6}	Turpentine	9.0×10^{-4}
Lead	29×10^{-6}	Air[a] at 0°C	3.67×10^{-3}
Steel	11×10^{-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.

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- Some substances - calcite (CaCO3) is one example - expand along one dimension (positive a) and contract along another (negative a) as their temperatures are increased.
- Because the linear dimensions of an object change with temperature, it follows that surface area and volume change as well.
- The change in volume is proportional to the initial volume V_i and to the change in temperature according to the relationship

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

- where β is the average coefficient of volume expansion.

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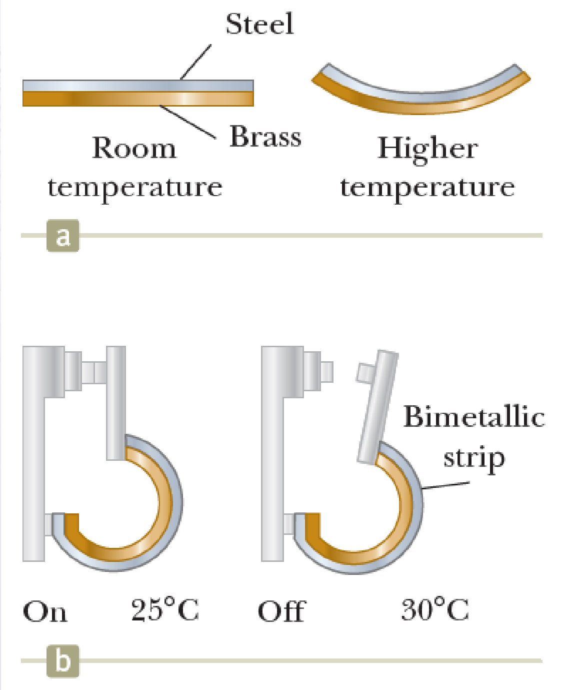
- To find the relationship between β and α, assume the average coefficient of linear expansion of the solid is the same in all directions; that is, assume the material is isotropic.
- Consider a solid box of dimensions l, w, and h. Its volume at some temperature T_i is $V_i = lwh$.
- If the temperature changes to $T_i + \Delta T$, its volume changes to $V_i + \Delta V$

$$V_i + \Delta V = (\ell + \Delta\ell)(w + \Delta w)(h + \Delta h)$$

$$\frac{\Delta V}{V_i} = 3\alpha\,\Delta T + 3(\alpha\,\Delta T)^2 + (\alpha\,\Delta T)^3$$

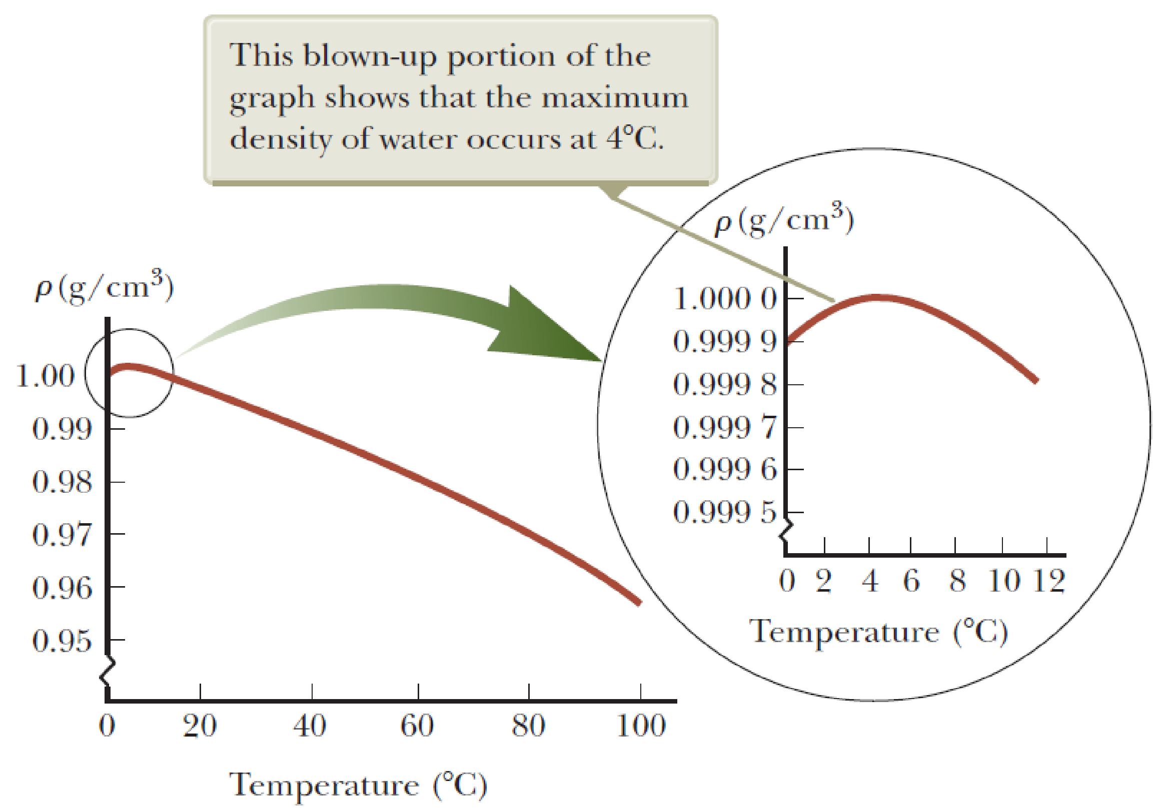
- Because $\alpha\,\Delta T << 1$ for typical values of ΔT ($<< 100\ ^oC$), we can neglect the terms $3(\alpha\,\Delta T)^2$ and $(\alpha\,\Delta T)^3$.
- $\frac{\Delta V}{V_i} = 3\alpha\,\Delta T \;\rightarrow\; \Delta V = (3\alpha)V_i\,\Delta T$ maka: $\beta = 3\alpha$

- A simple mechanism called a bimetallic strip, found in practical devices such as mechanical thermostats, uses the difference in coefficients of expansion for different materials.
- It consists of two thin strips of dissimilar metals bonded together.
- As the temperature of the strip increases, the two metals expand by different amounts and the strip bends as shown in Figure.



The Unusual Behavior of Water

- Liquids generally increase in volume with increasing temperature and have average coefficients of volume expansion about ten times greater than those of solids.



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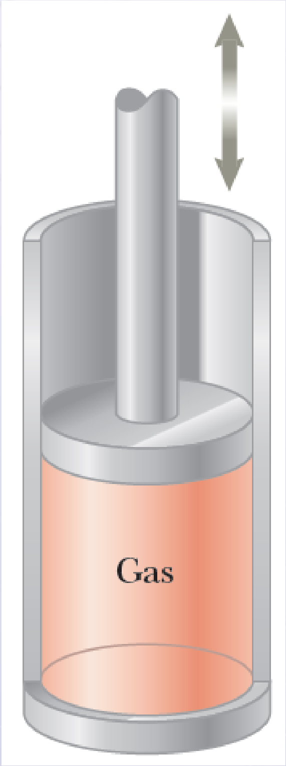
Macroscopic Description of an Ideal Gas

- The volume expansion equation is based on the assumption that the material has an initial volume V_i before the temperature change occurs.
- The case for gases is completely different.
- The interatomic forces within gases are very weak, and, in many cases, we can imagine these forces to be nonexistent and still make very good approximations.
- Therefore, there is no equilibrium separation for the atoms and no "standard" volume at a given temperature; the volume depends on the size of the container.
- Equations involving gases contain the volume V, rather than a change in the volume from an initial value, as a variable.



- For a gas, it is useful to know how the quantities volume V, pressure P, and temperature T are related for a sample of gas of mass m.
- In general, the equation that interrelates these quantities, called the equation of state, is very complicated.
- We use the *ideal gas model* to make predictions that are adequate to describe the behavior of real gases at low pressures.
- Number of mol n: $n = \frac{m}{M}$
- where M is the molar mass and m is the mass of the substance
- One mole of any substance is that amount of the substance that contains Avogadro's number $N_A = 6.022 \times 10^{23}$ of constituent particles (atoms or molecules)

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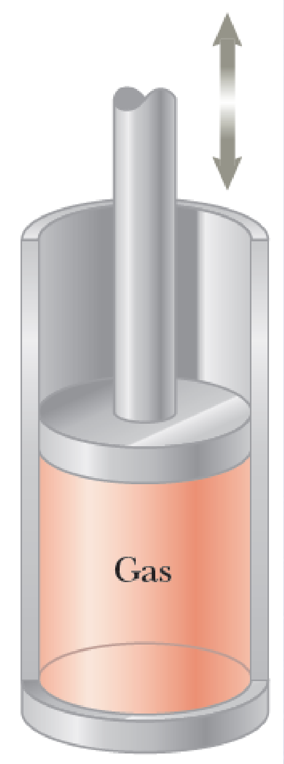
Ideal Gas Law

- When the gas is kept at a constant temperature, its pressure is inversely proportional to the volume. (This behavior is described historically as Boyle's law.)
- When the pressure of the gas is kept constant, the volume is directly proportional to the temperature. (This behavior is described historically as Charles's law.)
- When the volume of the gas is kept constant, the pressure is directly proportional to the temperature. (This behavior is described historically as Gay–Lussac's law.)



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- The equation of state for an ideal gas:

$$PV = nRT$$

- R is called the universal gas constant:
  - SI Unit $R = 8.314 \text{ J/mol} \cdot \text{K}$
  - Other Unit $R = 0.082\,06 \text{ L} \cdot \text{atm/mol} \cdot \text{K}$
- Other form of Ideal Gas Law:

$$PV = nRT = \frac{N}{N_A} RT$$

$$PV = Nk_B T$$

- with

$$k_B = \frac{R}{N_A} = 1.38 \times 10^{-23} \text{ J/K}$$

- It is common to call quantities such as P, V, and T the thermodynamic variables of an ideal gas

- Terima kasih

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