Physics I Lecture18-Temperature-I

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Outline

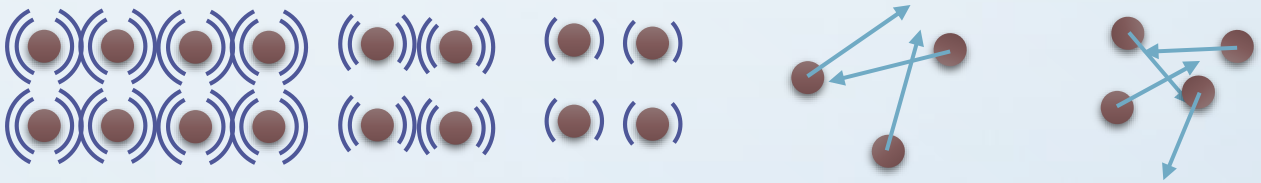
1. Temperature and The 0^{th} Law of Thermodynamics
2. Thermometers and The Celsius
3. The Absolute Temperature Scale
4. Thermal Expansion of Solids and Liquids
5. Thermodynamics of an Ideal Gas

1. TEMPERATURE AND THE 0^{TH} LAW OF THERMODYNAMICS

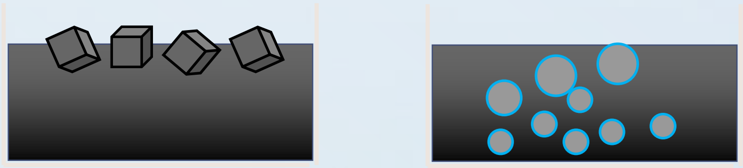
The new concepts for temperature: temperature is an estimate of the average thermal energy per atom for solid, liquid or gas systems.

$k_B T = E$, $T = E/k_{\mathrm{B}}$, k_B: Boltzmann constant

For the solid, the thermal energy drives atomic vibrations. In the gas system, the thermal energy drives linear, rotational or vibrational motions for gas molecules.

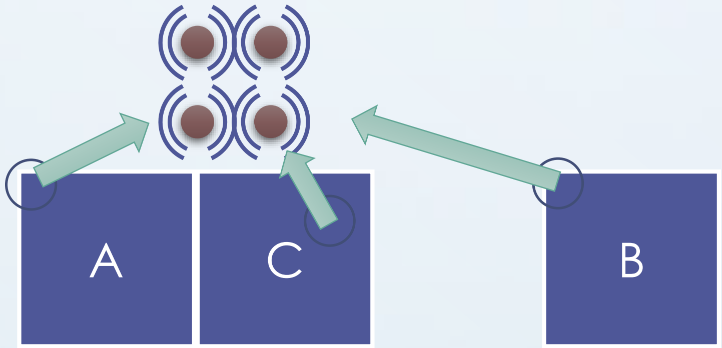


The scale of temperature was defined using the melting and the boiling point of liquid water.



1. TEMPERATURE AND THE 0^{TH} LAW OF THERMODYNAMICS

Zeroth law of thermodynamics: if objects A and B are separately in thermal equilibrium with a third object C, A and B are in equilibrium with each other.



From microscopic viewpoint, the equilibrium means the same average energy per atom for the two objects. Here the vibration is the ways to transfer “heat” or to reach the thermal equilibrium for atoms in solids.

2. THERMOMETERS AND THE CELSIUS

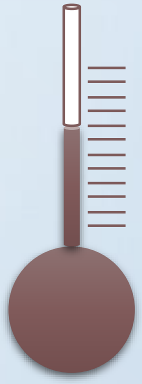
The physical properties used for designing thermometers:

1. The volume of a liquid, like mercury, Hg.
2. The length of a solid.
3. The volume of a gas held at constant pressure.
4. The pressure of a gas held at constant volume.
5. The electrical resistance of a conductor – Pt100 (four points probe).
6. The color of a hot object ($T_{blue} > T_{red}$).
7. Thermal voltage – thermocouple
   (a positive leg of 90% nickel, 10% chromium and a negative leg of 95% nickel,2% aluminum, 2% manganese and 1% silicon).

The Galileo Thermometer:

http://www.scientificglass.co.uk

2. THERMOMETERS AND THE CELSIUS



The volume of a liquid (like mercury or alcohol) is commonly used for the thermometer.

The volume expands into a glass capillary tube when heated.

The Celsius temperature scale:

The zero degree is defined at the ice point (freezing point) of water.

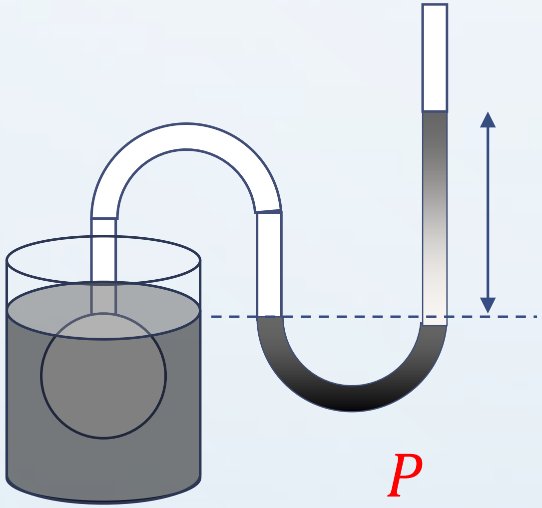
The one hundred degree is defined at the stream point or the boiling point of water.

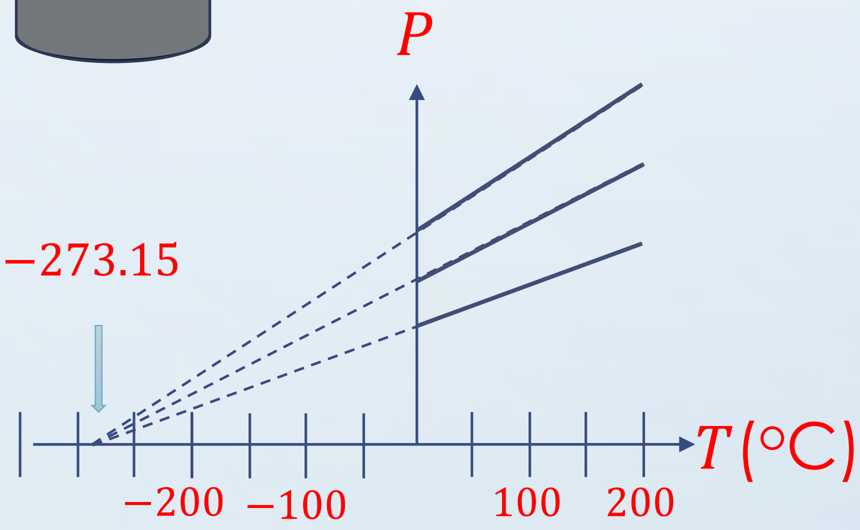
When the liquid level is defined at the two points, the length of the liquid column between the two points is divided into 100 equal segments.

Drawbacks: Nonlinear – one thermometer reads a temperature slightly different from the other one. Limited range: the boiling point of alcohol is 85°C.

3. THE ABSOLUTE TEMPERATURE SCALE

The pressure of a gas held at constant volume is used to make thermometers.





Physical Phenomena	T(K)
Laser Cooling	10^{-6}
Liquid Helium	4.2
Liquid Hydrogen	20
Liquid Nitrogen	78
Water Freezing Point	273
Copper Melting	1360
Surface of The Sun	5780
Hydrogen Bomb	10^{8}

3. THE ABSOLUTE TEMPERATURE SCALE

Conversion among Celsius, Fahrenheit, and Kelvin temperatures:

$$T_K = T_C + 273.15 \qquad T_C = T_K - 273.15$$

$$T_F = \frac{9}{5}T_C + 32 \qquad T_C = \frac{5}{9}(T_F - 32)$$

Example: Human body temperature is normally 98.6°F. What is this on the Celsius scale?

$$T_C = \frac{5}{9}(98.6 - 32) = 37.0^o\mathrm{C}$$

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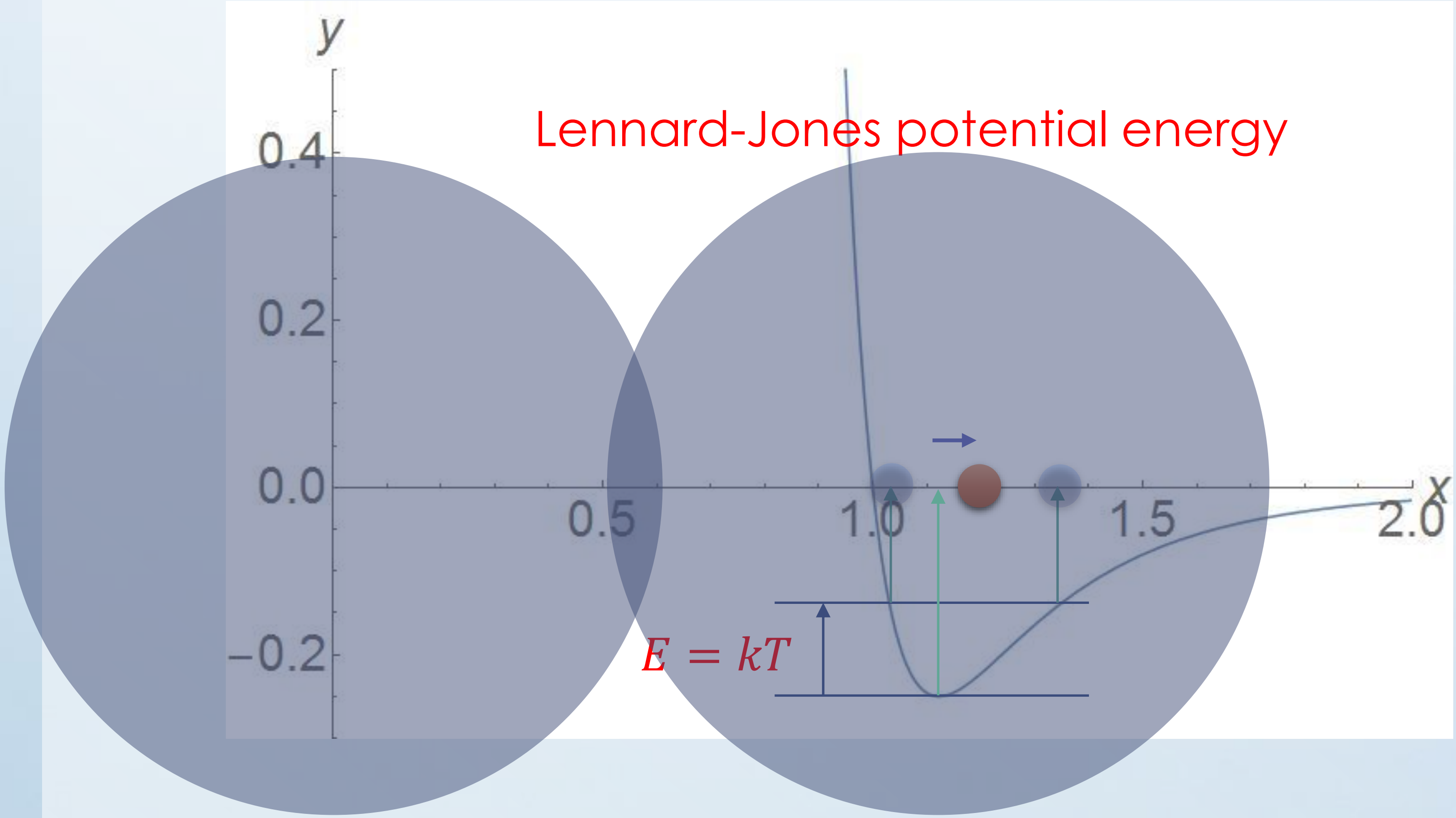
4. THERMAL EXPANSION OF SOLIDS AND LIQUIDS

The potential energy for atoms in a solid is asymmetric.



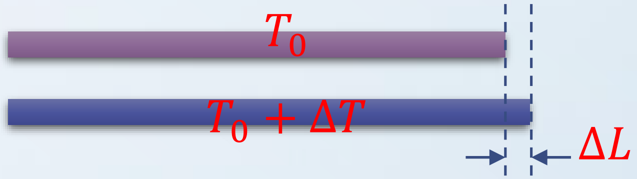
Negative Thermal Expansion:

1. flexible network
2. atomic radius contraction
3. magnetovolume effect.

4. THERMAL EXPANSION OF SOLIDS AND LIQUIDS

Linear expansion due to thermal energy:

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



Material	$\alpha\ (K^{-1})$
Ice	5.1×10^{-6}
Al	2.4×10^{-5}
Brass	1.9×10^{-5}
Steel	1.1×10^{-5}
Lead	2.9×10^{-5}
Glass	9.0×10^{-6}
Invar (Ni-Fe alloy)	9.0×10^{-7}

Area expansion:

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

$$\Delta A = (L_1 + \alpha L_1 \Delta T)(L_2 + \alpha L_2 \Delta T) - L_1 L_2$$

$$\Delta A \cong 2\alpha L_1 L_2 \Delta T \rightarrow \gamma = 2\alpha$$

Volume expansion:

$$\Delta V = \beta V \Delta T \rightarrow \beta = 3\alpha$$

Material	$\beta\ (K^{-1})$
Air	3.7×10^{-3}
Alcohol	1.1×10^{-3}
Water	2.1×10^{-4}

4. THERMAL EXPANSION OF SOLIDS AND LIQUIDS

Example: A hole of cross-sectional area 100 cm^2 is cut in a piece of steel at 20°C. What is the change in the area of the hole in the steel from 20°C to 100°C?

$$\alpha = 1.1 \times 10^{-5}\, K^{-1} \rightarrow \gamma = 2\alpha = 2.2 \times 10^{-5}\, (K^{-1})$$

$$\Delta A = \gamma A \Delta T = \left(2.2 \times 10^{-5}\right)(100)(100 - 20) = 0.18\, cm^2$$

Example: A steel bridge is 1000 m long. By how much does it expand when the temperature rises from 0 to 30°C? The Young's modulus of steel is 2.0X10^{11} N/m^2. Please estimate the stress in the steel bridge without expansion joints.

$$\alpha = 1.1 \times 10^{-5}\, (K^{-1}) \rightarrow \Delta L = \alpha L \Delta T = \left(1.1 \times 10^{-5}\right)(1000)(30 - 0) = 0.33\, m$$

$$\frac{F}{A} = Y \times \frac{\Delta L}{L} = (2.0 \times 10^{11})\frac{0.33}{1000} = 6.6 \times 10^{7}\, \frac{N}{m^2} \cong 660\, atm$$

4. THERMAL EXPANSION OF SOLIDS AND LIQUIDS

Example: While working in the laboratory, you fill a 1-L glass flask to the brim with water at 10°C. You heat the flask, raising the temperature of the water and flask to 30°C. How much water spills out of the flask? The volume expansion coefficient for water at 15°C is $1.5 X 10^{-4}$ K^{-1}.

$$\alpha_{glass} = 9.0 \times 10^{-6}\ (K^{-1}) \rightarrow \beta_{glass} = 2.7 \times 10^{-5}\ (K^{-1})$$

$$\beta_{water} = 1.5 \times 10^{-4}\ (K^{-1})$$

$$\Delta V = (\beta_{water} - \beta_{glass}) V \Delta T = (15 - 2.7) \times 10^{-5} (1000)(30 - 10)$$

$$\Delta V = 2.46\ mL$$

5. THERMODYNAMICS OF AN IDEAL GAS

Ideal gas: a collection of atoms or molecules that move randomly, exert no long-range forces on one another, and occupy a negligible fraction of the volume of their containers.

Avogadro's number: $N_A = 6.022 \times 10^{23}$

The number of moles of a substance: $n = m/M$, where M is the molar mass of the substance.

For an ideal gas, the macroscopic, thermodynamic variable are P, V, T.

Boyle–Mariotte law: $P \propto \frac{1}{V} \rightarrow PV = const$ at constant temperature and number of molecules.

Charles and Gay-Lussac's law: $V \propto T \rightarrow V = const \times T$ at constant pressure and number of molecules.

Ideal gas law: $PV = Nk_BT = nRT$, $k_B = 1.38 \times 10^{-23}\, J/K$, $R = N_A k_B = 8.314 \frac{J}{mol \cdot K}$

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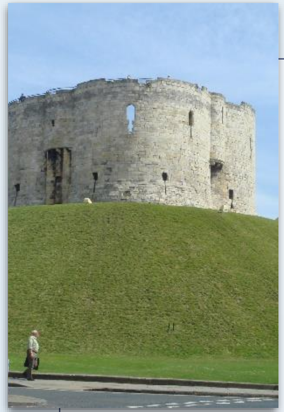

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