Lecture 10

HEAT

Phases of matter
Temperature
Temperature Scales
Thermal expansion
Phases of matter

Solid
Some movement of molecules is possible, all linked by spring-like forces. Average positions of molecules are fixed. Solid has rigidity and retains shape.

Liquid
Molecules are freer to move but always remaining close to each other. A liquid flows and does not retain shape.

Gas
Molecules move anywhere with little interaction with each other. A gas flows and does not retain shape.
Temperature and Heat

Molecules are in constant disordered motion.

Velocities distributed over a large range.

**Average kinetic energy directly related to temperature**

Greater their average kinetic energy
- Greater their speed
- Higher the temperature

Energy exchange between two objects at different temperatures is called **heat**.

**Temperature** is a characteristic of an object related to the average kinetic energy of atoms and molecules in the object.
Temperature

Temperature is a measure of the average kinetic energy of atoms and molecules.

Robert Brown, English botanist noticed in 1828 that tiny particles mixed in with pollen exhibited an incessant, irregular motion in a liquid.

**Brownian motion**

Remained largely unexplained until

Einstein paper in 1905

"On the motion of small particles suspended in a stationary liquid demanded by the molecular-kinetic theory of heat"

indirect confirmation of existence of molecules and atoms

A suspended small particle is constantly and randomly bombarded from all sides by molecules of the liquid.
Temperature and Heat

Brownian motion

polystyrene particles, 1.9 micrometer in diameter, in water

T = 25 °C

in any short period of time

• random number of impacts
• random strength
• random directions

Brownian motion is a clear demonstration of the existence of molecules in continuous motion
Temperature scales

There are 3 temperature scales:

Anders Celsius (1701-1744) - Celsius (°C)

Gabriel Fahrenheit (1686 -1736) - Fahrenheit (°F)

Lord Kelvin (1824-1907) - Kelvin (K)

Differ by (a) the basic unit size or degree (°)  
(b) zero temperature

Celsius and Fahrenheit are defined by the freezing point and the boiling point of water (at standard atmospheric pressure):

Freezing point of water: 0°C or 32°F

Boiling point of water: 100°C or 212°F

Range—freezing to boiling point of water

Celsius, 100 degrees.  Fahrenheit, 180 degrees
Temperature scales

-273.15 oC = 0 K (absolute)

0 oC = 32 oF = 273.15 K (absolute)

100 oC = 212 oF = 373.15 K (absolute)

SI unit of temperature is the Kelvin

Room temperature
20 oC
68 oF
293 K
Gas pressure depends on temperature

**Example**
Tyres have higher pressure when hot compared with cold.

**Ideal gas:**
*Is a collection of atoms or molecules*
- move randomly
- exert no long-range forces on each other.
- considered to be point-like
- occupy negligible volume.

Most gases at **atmospheric pressure** and **room temperature** behave approximately as ideal gases.
Kelvin Temperature Scale

Ideal gas

Constant Volume

Constant Pressure

Linear relationship exists between pressure and temperature

Linear relationship exists between volume and temperature

All plotted lines extrapolate to a temperature intercept of -273.15 °C regardless of initial low pressure or type of gas

Unique temperature called absolute zero

Fundamental importance
Kelvin (K) scale is the absolute scale: it is directly proportional to the average kinetic energy* in an ideal gas. It fixes the absolute lower limit of zero at 0 K, and has the same basic unit size as Celsius:

\[ T(K) = T(°C) + 273.15 \]

Example: Freezing point of water: 273.15 K
Boiling point of water: 373.15 K
Converting Temperatures

Celsius to Fahrenheit:

\[ T(\circ F) = \frac{9}{5} T(\circ C) + 32 \]

Fahrenheit to Celsius:

\[ T(\circ C) = \frac{5}{9} [T(\circ F) - 32] \]

Celsius and Fahrenheit scales allow for negative temperature

Thermometers

- Alcohol in glass
- Mercury in glass

Depends on expansion
Example.

Body temperature can increase from $98.6^0\text{F}$ to $107^0\text{F}$ during extreme physical exercise or during viral infections. Convert these temperatures to Celsius and Kelvin and calculate the difference in each case.
Temperature and Heat

Applications

In the oral environment temperature is not constant;
▪ Hot and cold food and drink

Dental pulp is sensitive, may be damaged if its temperature increases >5°C)

Dental drilling

Rise in temperature of pulp during drilling should be less than 5 °C

Important Information concerning materials
▪ Transfer of heat
▪ Dimensional changes: expansion and contraction
**Thermal expansion**

Most materials

- **expand when temperature is increased**
- **contract when temperature is decreased**

this is called thermal expansion and contraction

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**Origin:** When the average kinetic energy (or ‘speed’) of atoms is increased, they experience stronger collisions, increasing the separation between atoms.
Thermal expansion depends on:
• Material
• Size,
• Temperature change.

Assume no change in phase

Linear Thermal Expansion

Important, for example, for metals in buildings, bridges and _dental filling materials_ etc.

Bar of initial length $L$ changes by an amount $\Delta L$ when its temperature changes by an amount $\Delta T$.

Coefficient of linear expansion $\alpha$ for the material is defined as:

$$\alpha = \frac{\text{Fractional change in length}}{\text{Change in temperature}} = \frac{\Delta L/L}{\Delta T}$$
Thermal expansion

linear expansion:

$$\Delta L = (L)(\alpha)(\Delta T)$$

$\Delta L$ = change in length

$L$ = original length

$\Delta T$ = change in temperature

$\alpha$ = coefficient of linear expansion

units (${°C}^{-1}$ or $K^{-1}$)*

$\alpha$ depends on the type of material.

*Temperature interval is the same for Celsius and Kelvin scales
Thermal expansion

Important in restorations

Decayed dentine removed and replaced by filling.

Coefficient of thermal expansion of the restorative material should be similar to that of the tooth.

Thermal expansion/contraction due to hot and cold foods should not cause separation at the tooth-filling interface.

Large mismatch in expansion coefficients:
- Fluids leakage between filling and surrounding tooth

Composite material: repeated thermal cycling: bonded joint between the filling and the tooth may loosen.
Thermal expansion

Dimensional changes minimised by transient nature of thermal stimuli and the relatively low “thermal diffusivity” of non-metallic restorative materials

Example

10°C temperature change for 1 sec
- Little change in bulk material dimensions

<table>
<thead>
<tr>
<th>Coefficient of Thermal linear expansion</th>
<th>Enamel</th>
<th>Dentine</th>
<th>Amalgam</th>
<th>Composite filling material (“white”)</th>
<th>Gold</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>11.4 x 10^{-6} K^{-1}</td>
<td>8.3 X 10^{-6} K^{-1}</td>
<td>25 x 10^{-6} K^{-1}</td>
<td>≈30 x 10^{-6} K^{-1}</td>
<td>14.5x 10^{-6} K^{-1}</td>
</tr>
</tbody>
</table>

Composite material: repeated thermal cycling: bonded joint between the filling and the tooth may loosen.
Example
Amalgam 8 mm wide, oral temperature decreases by 10ºC. Compare contraction of amalgam with that of enamel.

<table>
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<th>Material</th>
<th>Coefficient of Thermal linear expansion (K^-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enamel</td>
<td>$11.4 \times 10^{-6}$</td>
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<td>$8.3 \times 10^{-6}$</td>
</tr>
<tr>
<td>Amalgam</td>
<td>$25 \times 10^{-6}$</td>
</tr>
<tr>
<td>Composite filling material</td>
<td>$\approx 30 \times 10^{-6}$</td>
</tr>
<tr>
<td>Gold</td>
<td>$14.5 \times 10^{-6}$</td>
</tr>
</tbody>
</table>
Thermal expansion

**Application**

**Thermostat**
Thermally activated
Electrical switch

**Bimetallic strip**
- brass
- steel

- 20°C
  - Switch closed
- 23°C
  - Switch open

**Brass has larger coefficient of thermal expansion**
Why is there a reservoir at the bottom of a thermometer?

\[ \alpha_{\text{mercury}} = 60 \times 10^{-6} \, ^{\circ}\text{C}^{-1} \]

If the length of the column is 10cm, and the range of temperature is 35 to 43°C, then the thermal expansion of the column is:
Area Thermal expansion

linear thermal expansion:
\[ \Delta L = (L)(\alpha)(\Delta T) \]

area thermal expansion:
\[ \Delta A = ? \]

Consider square, side length \( L \), area \( A = L^2 \)

New area: \( A + \Delta A = (L + \Delta L)^2 = L^2 + 2L \Delta L + \Delta L^2 \)

\[ A + \Delta A \approx L^2 + 2L \Delta L \]

Thus \( \Delta A = 2L \Delta L = 2L(L\alpha\Delta T) \)

\[ \Delta A = L^2(2\alpha)\Delta T = A(2\alpha)\Delta T \]

Thus, the coefficient of area expansion is approximately \( 2\alpha \)

**Exercise:** Show that the coefficient of volume expansion is \( \approx 3\alpha \)

\[ \Delta V = V(3\alpha)\Delta T \]
Example

A 50 ml glass container is filled to the brim with methanol at 0.0°C. If the temperature is raised to 40°C will any methanol spill out? If so, how much?

γ glass ≈ 9 x 10^{-6} (°C^{-1})

γ methanol ≈ 1200 x 10^{-6} (°C^{-1})
Exercise:

A steel measuring tape used by a civil engineer is 50 metres long and calibrated at 20° C. The tape measures a distance of 35.694 m at 35° C. What is the actual distance measured? Coefficient of linear expansion of steel

\[ \alpha = 1.2 \times 10^{-5} \, ^\circ C^{-1} \]
Example.
Concrete slabs of length 25 m are laid end to end to form a road surface. What is the width of the gap that must be left between adjacent slabs at a temperature of -15^0C to ensure they do not buckle at a temperature of +45^0C. Coefficient of thermal expansion for concrete $\alpha = 12 \times 10^{-6} \, ^0C^{-1}$