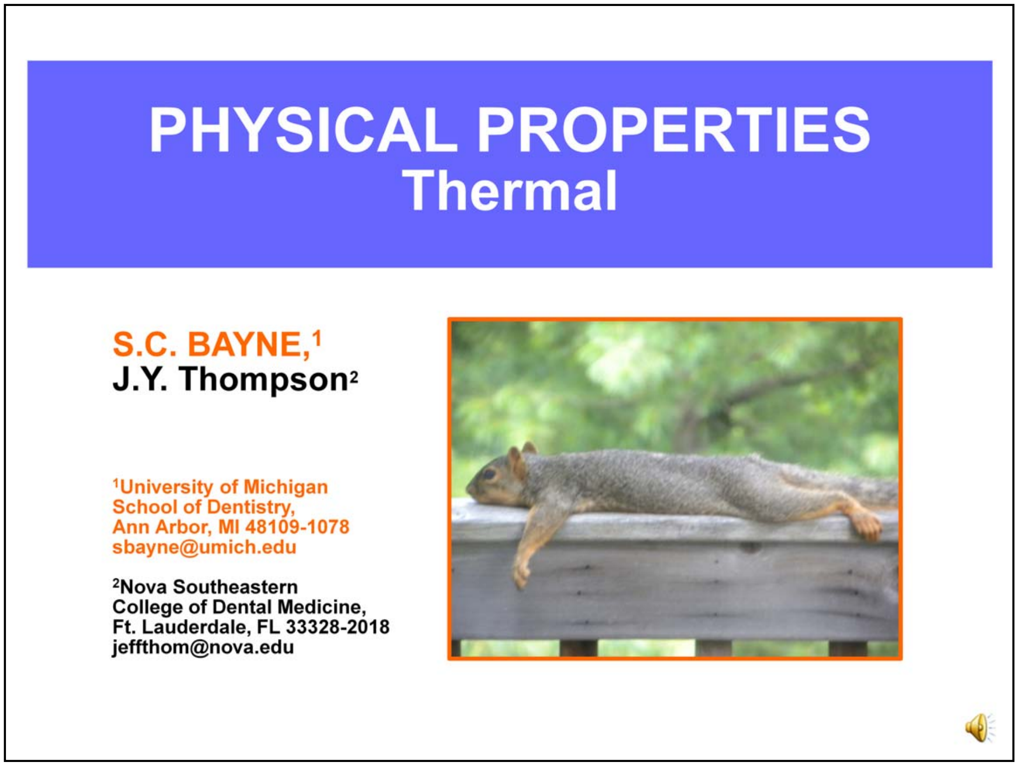
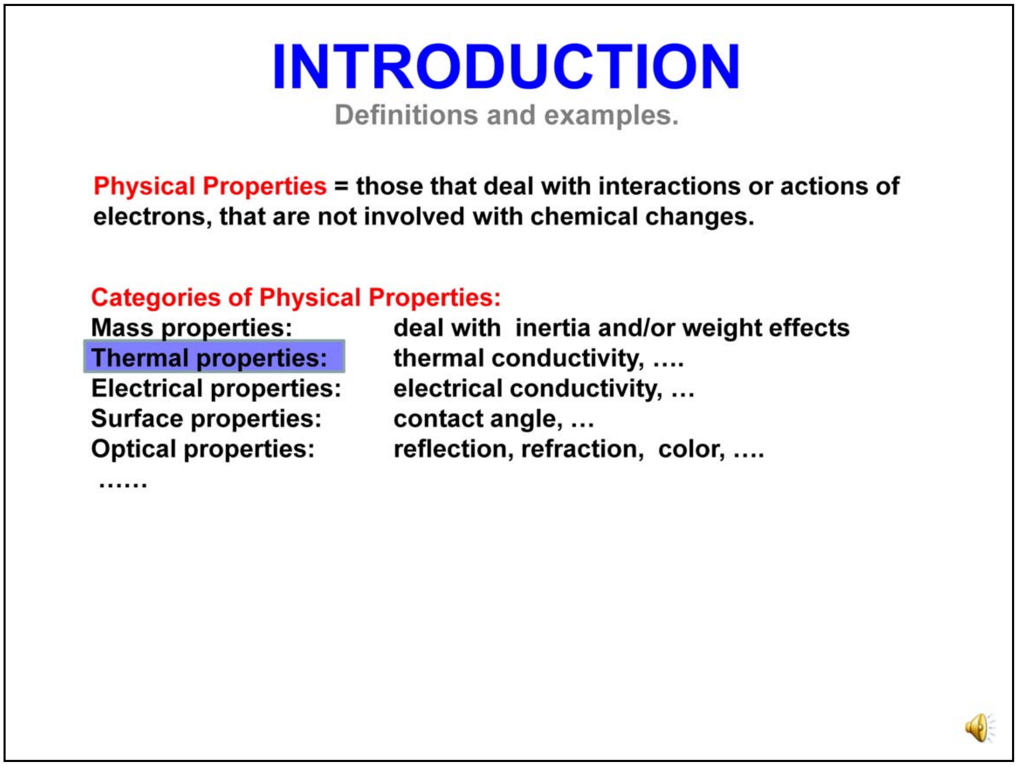
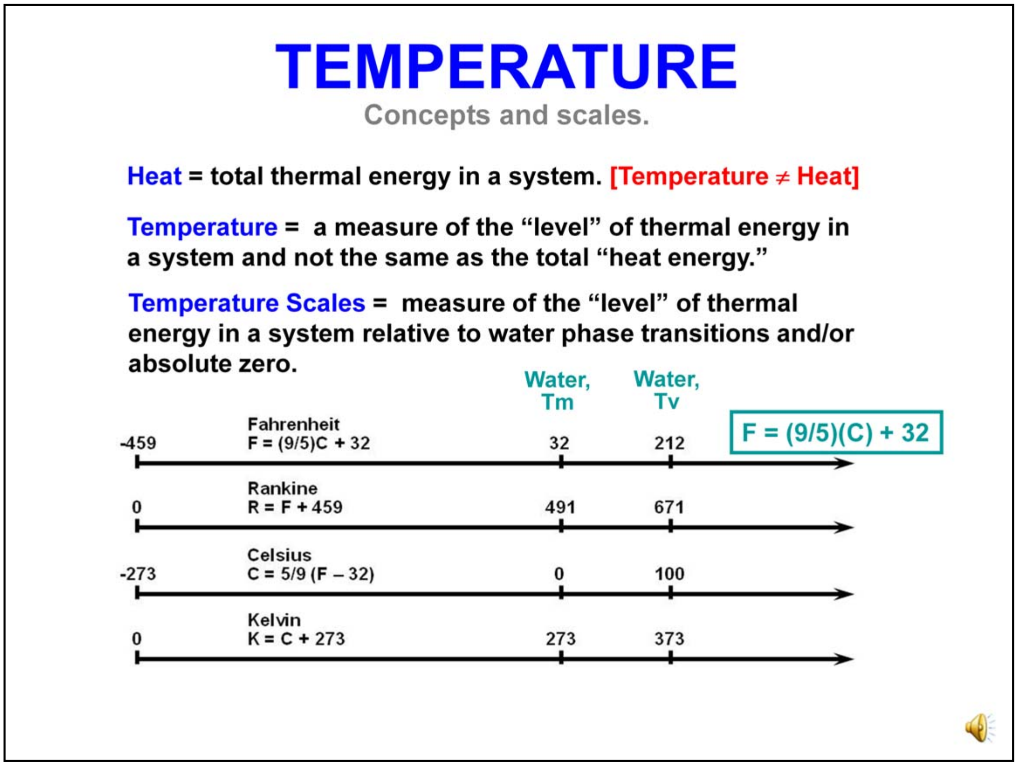


Remember our perspective to the approach to the basic science of materials. Materials are grouped as metals, ceramics, polymers, and composites. Structure is defined in terms of arrangement, bonding, composition, and defects. Properties are grouped into physical, mechanical, chemical, and biological ones. Structure defines properties. Now let's examine "physical properties" and focus on thermal ones.



Perhaps the simplest way to approach the definition of physical properties is to consider them as things involving "interactions with their environment (heat, light, gravity) that do not involve chemical changes or major changes in their microstructure." **[CLICK]** Quite a few types of physical properties are possible and they tend to be clustered as those involving mass, thermal properties, electrical properties, surface properties, optical properties, and others. **[CLICK]** For the purpose of this module, we will focus only on thermal properties. We will consider the other ones later in the context of specific dental materials.



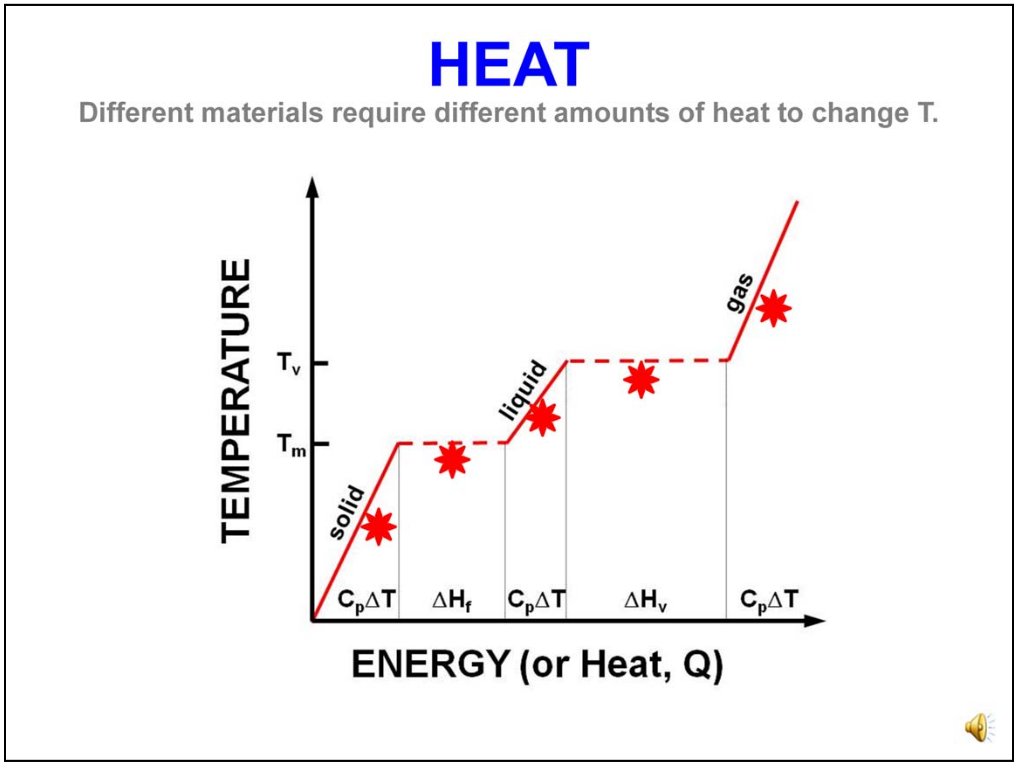
Temperature and heat are two different things. Heat is the total quantity of thermal energy in the system. Temperature is just a measure of the level or intensity of thermal energy. This may still not be intuitive to you, so consider the following. As the temperature drops through the freezing point, a huge amount of thermal energy is released during crystallization. This is far greater than the thermal energy lost dropping the temperature from 1 degree above the freezing temperature to the freezing temperature.

Different scales have been developed historically to measure temperature with respect to the boiling and/or melting temperatures for water – and with respect to the absolute zero of temperature.

The Fahrenheit scale was developed first and in the Netherlands -- with its references simply as the melting (Tm for melting or Tf for freezing) **[CLICK]** and boiling points (Tv for vaporization or Tc for condensation) for water. **[CLICK]** At first, no one knew anything about the absolute zero of temperature. The temperature scale was simply something of convenience to monitor the world outside and small range events. On the arbitrary Fahrenheit Scale, water melted at 32 F and vaporized at 212 F at one atmosphere of pressure. The Celsius Scale attempted to make the range between melting and vaporization a standard amount of 100 grads or centigrades. Later on, when absolute zero was known, Rankine and Kelvin Scales were developed that were referenced to absolute zero. The relationships are shown in the figure.

[CLICK] It is important to know simple conversions between F and C scales. Also, please memorize the following:

32 F = 0 C, 68 F = 20 C, 77 F = 25 C, 98.6 F = 37 C, 212 F = 100 C



We just explained that TEMPERATURE and THERMAL ENERGY are not the same things. Now let's look at the relationships between them. Start at high temperature in the top right-hand portion of the diagram and follow the curve down to the bottom left. Temperature is the y-axis. Energy or heat is the x-axis.

[CLICK] The slope of the line is the heat capacity of a gas or vapor phase. **[CLICK]** At the condensation (or vaporization) temperature, the line becomes flat while the material condenses by nucleation and growth into a liquid. A tremendous amount of heat is released (the heat of vaporization). When the liquid has formed, the temperature drops again. **[CLICK]** The slope of the next portion of the line is now the heat capacity of the liquid and is different than that for the vapor. **[CLICK]** At the fusion (or melting) temperature, the liquid undergoes a change to solid by nucleation and growth, giving off a huge amount of energy. **[CLICK]** After that the temperature begins to fall again. The slope of the line for the solid is the heat capacity of the solid.

THERMAL CONDUCTIVITIY

Definitions and examples.

Thermal Conductivity = heat flow
per area/thickness, A/th
per unit time, t
per temperature difference, ΔT

$k = (\Delta Q)/(A/th)/(\Delta t)/(\Delta T)$

Metals: **generally good conductors**
Ceramics: **may be conductors but usually insulators**
Polymer: **generally insulators**

Next, let's consider the heat flowing through a solid object from a higher temperature to a lower one. There are 2 quantities of interest – the thermal conductivity and thermal diffusivity. We will focus only on the first. The conductivity is a measure of the heat flowing through a material per unit cross-sectional area per unit of time per degree of temperature difference.

As you may have already guessed, **[CLICK**] metals are generally good conductors with their valence electrons being shared broadly by all the atoms and ready to move to transport electrical energy. There is no energy bad gap. Semi-conductors have small band gaps and with the appropriate push and can be made to conduct. Polymers under most circumstances are insulators. Their electrons are tied up in covalent bonds.

THERMAL EXPANSION

Scales, and calculations.

Coefficient of Thermal Expansion = change in volume per degree of change in the temperature.

Linear Coefficient of Thermal Expansion (LCTE or α) = $(\Delta L/L) / \Delta T$ = fractional change in length $[(L_2-L_1)/L_1]$ per change in the temperature $(T_2-T_1) = \Delta T$

LCTE (gold alloys) = 0.000018 / °C = 18 ppm / °C

Imagine that a molten gold alloy to create a 10 mm (10,000 um) wide gold crown that is cast at 1025 °C and cooled down to room temperature (25 °C).

- **How much smaller does it get on cooling?**
  LCTE = $\alpha = (\Delta L/L) / \Delta T$ ----- or
  $\Delta L = (L)(\alpha)(\Delta T)$ = (10,000 µm) (0.000018/°C)(1000°C) = 180 µm.
- **What is the shrinkage during cooling?**
  $(\Delta L/L) = (\alpha)(\Delta T)$ = (0.000018/°C)(1000°C) = 0.018 = 1.8%

As the temperature of an object increases, it tends to expand. As the temperature decreases, it tends contract. There are only a couple of special exceptions to this process. Imagine the atoms in a crystalline solid as the temperature is going up. They vibrate more around their equilibrium positions and push each other farther apart.

[CLICK] Technically we define rate of thermal expansion or the coefficient of thermal expansion as the fractional change in VOLUME per unit of change in temperature. Usually we measure the change in only one dimension and define the LINEAR COEFFICIENT OF THERMAL EXPANSION.

[CLICK] The actual LCTE is a very small number per degree of temperature change. For gold alloys used for dentistry, the change is 0.000018 / °C or 18 ppm **/** °C. There will be a different number if one uses a Fahrenheit scale. Usually LCTE is defined in terms of degrees Centigrade.

[CLICK] Now let's see what this means. **[CLICK]** Imagine that a molten gold alloy to create a 10 mm (10,000 um) wide gold crown that is cast at 1025 °C and cooled down to room temperature (25 °C).

[CLICK] >How much smaller does it get on cooling? **[CLICK]**

LCTE = $\alpha = (\Delta L/L) / \Delta T$ or $\Delta L = (L)(\alpha)(\Delta T)$ = (10,000 µm) (0.000018 / °C) (1000 °C) = 180 µm.

[CLICK] >What is the shrinkage during cooling? **[CLICK]**

$(\Delta L/L) = (\alpha) (\Delta T)$ = (0.000018 / °C) (1000 °C) = 0.018 = 1.8%

THERMAL EXPANSION RANGES

Values for different dental materials.

Units for LCTE (α) are "in/in/F" or "cm/cm/C" or "ppm/C"

General Ranges:	ppm/C
METALS	1-15
CERAMICS	10-30
POLYMERS	30-600

Aluminous Porcelains	**4 ppm/C**
Dental Cements	**8-10**
TOOTH STRUCTURE	**9-11**
Porcelain and Alloys for PFM	**14**
GOLD CASTING ALLOYS	**16-18**
DENTAL AMALGAM	**25**
POSTERIOR COMPOSITES	**25-35**
Anterior Composites	**35-45**
PMMA	**72-83**
DENTAL WAX	**260-600**

While there are different ways to express the LCTE, we almost always report the values as ppm/C. **[CLICK]** There are general ranges that are important to know. Memorize these. Metals are usually 1-15 ppm/C. Ceramics usually are 10-30 ppm/C. Organics and polymers are normally 30-600 ppm/C.

[CLICK] You will later encounter the values for almost all dental materials. Memorize the capitalized values in the table. **[CLICK]** Tooth structure is 9-11 ppm/C and the goal is to have restorative materials match that as a target.

If the restoration and tooth structure do not expand and contract at the same rate during temperature changes, then strain will develop at their interfaces and gaps might form at some point. Opening and closing of gaps along interfaces allow oral fluids to be drawn in and pushed out in a process called PERCOLATION. There are only bad events that arise if that process occurs.

QUICK REVIEW

Review of heat, temperature, scales, and thermal events.

- **What is the difference between HEAT and TEMPERATURE?**
  HEAT IS TOTAL THERMAL ENERGY AND TEMPERATURE IS A SCALE MEASURING AVERAGE LEVEL OF THERMAL ENERGY.
- **What is 20C on the Fahrenheit scale?**
  20C = 68F, USING THE CONVERSION OF F = (9/5)C +32
- **Is the heat capacity for ice and water the same?**
  NO, THE SOLID HEAT CAPACITY IS GREATER THAN THE LIQUID.
- **What is the abbreviation and typical units for the linear coefficient of thermal expansion?**
  LCTE = ALPHA = α, WHICH HAS UNITS OF ppm/C
- **What is the LCTE value for DENTAL AMALGAM?**
  LCTE = 25 ppm/C
- **What is percolation?**
  OPENING AND CLOSING OF INTERFACE DUE TO DIFFERENT LCTE VALUES FOR TOOTH AND RESTORATION.

Here is a quick review of the concepts from this module.

[CLICK] (1) What is the difference between HEAT and TEMPERATURE?
[CLICK]

[CLICK] (2) What is 20C on the Fahrenheit scale?
[CLICK]

[CLICK] (3) Is the heat capacity for ice and water the same?
[CLICK]

[CLICK] (4) What are the abbreviation and typical units for the linear coefficient of thermal expansion?
[CLICK]

[CLICK] (5) What is the LCTE value for DENTAL AMALGAM?
[CLICK]

[CLICK] (6) What is percolation?
[CLICK]

THANK YOU

THANK YOU.