Introduction to Heat

(and thermodynamics)

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Chapter one

1-What is the heat

Heat, energy that is transferred from one body to another as the result of a difference in temperature. If two bodies at different temperatures are brought together, energy is transferred—i.e., heat flows—from the hotter body to the colder. The effect of this transfer of energy usually, but not always, is an increase in the temperature of the colder body and a decrease in the temperature of the hotter body. A substance may absorb heat without an increase in temperature by changing from one physical state (or phase) to another, as from a solid to a liquid (melting), from a solid to a vapour (sublimation), from a liquid to a vapour (boiling), or from one solid form to another (usually called a crystalline transition). The important distinction between heat and temperature (heat being a form of energy and temperature a measure of the amount of that energy present in a body) was clarified during the 18th and 19th centuries.

2-Heat as a form of energy

Because all of the many forms of energy, including heat, can be converted into work, amounts of energy are expressed in units of work, such as joules, foot-pounds, kilowatt-hours, or calories. Exact relationships exist between the amounts of heat added to or removed from a body and the magnitude of the effects on the state of the body. The two units of heat most commonly used are the calorie and the British thermal unit (BTU). The calorie (or gram-calorie) is the amount of energy required to raise the temperature of one gram of water from 14.5 to 15.5 °C; the BTU is the amount of energy required to raise the temperature of one pound of water from 63 to 64 °F. One BTU is approximately 252 calories. Both definitions specify that the temperature changes are to be measured at a constant pressure of one atmosphere, because the amounts of energy involved depend in part on pressure. The calorie used in measuring the energy content of foods is the large calorie, or kilogram-calorie, equal to 1,000 gram-calories.

In general, the amount of energy required to raise a unit mass of a substance through a specified temperature interval is called the **heat capacity**, or the specific heat, of that substance. The quantity of energy necessary to raise the temperature of a body one degree varies depending upon the restraints imposed. If heat is added to a gas confined at constant volume, the amount of heat needed to cause a one-degree temperature rise is less than if the heat is added to the same gas free to expand (as in a cylinder fitted with a movable piston) and so do work. In the first case, all the energy goes into raising the temperature of the gas, but in the second case, the energy not only contributes to the temperature increase of the gas but also provides the energy necessary for the work done by the gas on the piston. Consequently, the specific heat of a substance depends on these conditions. The most commonly determined specific heats are the specific heat at constant volume and the specific heat at constant pressure. The heat capacities of many solid elements were shown to be closely related to their atomic weights by the French scientists **Pierre-Louis Dulong** and **Alexis-Thérèse Petit** in 1819. The so-called law of **Dulong** and Petit was useful in determining the atomic weights of certain metallic elements, but there are many exceptions to it; the deviations were later found to be explainable on the basis of quantum mechanics.

It is incorrect to speak of the heat in a body, because heat is restricted to energy being transferred. Energy stored in a body is not heat (nor is it work, as work is also energy in transit). It is customary, however, to speak of sensible and latent heat. The latent heat, also called the heat of vaporization, is the amount of energy necessary to change a liquid to a vapour at constant temperature and pressure. The energy required to melt a solid to a liquid is called the heat of fusion, and the heat of sublimation is the energy necessary to change a solid directly to a vapour, these changes also taking place under conditions of constant temperature and pressure

3-Thermal effects

- **Physiological effects**: such as feeling warm and alerting blood circulation and burns.
- **Chemical effects**: such as chemical reactions caused by heating. For example, the sulfur interacts with iron by heating and produces iron sulfate.

- **Physical effects**: expansion - changing the state from solid to liquid and from liquid to gas - increasing electrical resistance - increasing water vapor pressure - generating thermoelectric power when making thermocouples.

4- Temperature

Temperature is a physical quantity that expresses quantitatively the attribute of hotness or coldness. Temperature is measured with a thermometer. It reflects the kinetic energy of the vibrating and colliding atoms making up a substance.
Temperature is the measure of hotness or coldness expressed in terms of any of several scales, including Fahrenheit and Celsius. Temperature indicates the direction in which heat energy will spontaneously flow—i.e., from a hotter body (one at a higher temperature) to a colder body (one at a lower temperature). Temperature is not the equivalent of the energy of a thermodynamic system; e.g., a burning match is at a much higher temperature than an iceberg, but the total heat energy contained in an iceberg is much greater than the energy contained in a match.
Temperature, similar to pressure or density, is called an intensive property—one that is independent of the quantity of matter being considered—as distinguished from extensive properties, such as mass or volume.

5-Temperature Scale

When the state of the crystalline material changes from solidity to fluidity or from liquid to gaseous, this change occurs at constant temperatures - which can be considered as fixed points in temperature

The most important of these points are: the freezing point (or freezing point) and the boiling point of distilled water under pressure 76 cm / Hg (or the boiling point of water under pressure 76 cm/Hg)

Let us assume that the value of the physical property measured at freezing point is x0 and x100 at boiling point. n = the number of equal sections in between the two fixed points.

The change in the physical property of each section is:

$$\frac{X_{100} - X_0}{n}$$

Assuming that the value of the physical property x_t is at t temperature, then the change in the physical property corresponding to 1 ° C is:

$$\frac{x_t - x_0}{t} = \frac{x_{100} - x_0}{100}$$

$$x_t = x_0 + \left(\frac{x_{100} - x_0}{100}\right)t$$

$$= x_0\left(1 + (\frac{x_{100} - x_0}{100x_0})t\right)$$

$$= x_0(1 + \alpha t)$$

$$\alpha = \frac{x_{100} - x_0}{100x_0}$$

α is the coefficient of increasing in the physical property by high temperature, ie for example, increasing the length, volume or resistance. The temperature obtained by this method may vary depending on the calibration process for correction and it is agreed to make the thermometer the fixed-size hydrogen gas a standard thermometer. The most common temperature scales are summarized below:

a- Celsius Scale

The Celsius scale was invented in 1742 by the Swedish astronomer,

Anders Celsius. This scale divides the range of temperature between the freezing and boiling temperatures of water into 100 equal parts. You will sometimes find this scale identified as the centigrade scale. Temperatures on the Celsius scale are known as degree Celsius (°C).

b- Fahrenheit Scale

The **Fahrenheit** scale was established by the German-Dutch physicist, **Gabriel Daniel Fahrenheit**, in 1724. While many countries now use the Celsius scale, the Fahrenheit scale is widely used in the United States. It divides the difference between the melting and boiling points of water into 180 equal intervals. Temperatures on the Fahrenheit scale are known as degree Fahrenheit (^oF)

c- Kelvin Scale

The Kelvin scale is named after **William Thompson Kelvin**, a British physicist who devised it in 1848. It extends the Celsius scale down to absolute zero, a hypothetical temperature characterized by a complete absence of heat energy. Temperatures on this scale are called Kelvins (K)

Converting Temperatures It is sometimes necessary to convert temperature from one scale to another. Here is how to do this.

Temperature Conversion Formulas		
Example	**Formula**	**Conversion**
21oC = 294 K	K = C + 273	Celsius to Kelvin
313 K = 40 oC	C = K - 273	Kelvin to Celsius
89 oF = 31.7 oC	C = (F - 32) x 5/9	Fahrenheit to Celsius
50 oC = 122 oF	F = (C x 9/5) + 32	Celsius to Fahrenheit

Comparison of Temperature scales

Kelvin	**Celsius**	**Fahrenheit**	**Set Points**
373	100	212	water boils
310	37	98.6	body temperature
273	0	32	water freezes
0	-273	-460	absolute zero

6- Thermometers

What is the principle on which thermometers are made? There are many physical properties that are regularly altered by temperature changes, such as the volume of a certain amount of liquid, the pressure of a certain amount of stationary gas, the electric force at the point of contact of two different metals in a closed circuit.

Note some of the other physical properties that can change regularly by changing the temperature. If we choose one of these qualities those changes regularly by changing the temperature we can measure the temperature by the number that measures this variable.

A thermometer is a device that measures temperature or temperature gradient, using a variety of different principles. The word thermometer is derived from two smaller word fragments: thermo from the Greek for heat and meter from Greek, meaning to measure. A thermometer has two important elements, the temperature sensor (e.g. the bulb on a mercury thermometer) in which some physical change occurs with temperature, plus some means of converting this physical change into a value (e.g. the scale on a mercury thermometer). Industrial thermometers commonly use electronic means to provide a digital display or input to a computer.

7 -Types of Thermometers

a- The Liquid in Glass Thermometer

The Liquid in Glass thermometer utilizes the variation in volume of a liquid in temperature. They use the fact that most fluids expand on heating. The fluid is contained in a sealed glass bulb, and its expansion is measured using a scale etched in the stem of the thermometer If we consider that the thermometer does not expand then as physical property it utilizes the variation of length of liquid with temperature. Liquid in Glass thermometers have been used in science, medicine, metrology and industry for almost 300 years. Liquids commonly used include Mercury and Alcohol.

Structure:

Two basic parts:

a. The bulb: Acting as a reservoir holding the liquid whose volume changes with temperature. The Bulb also acts as a sensor or gauge which is inserted in the body whose temperature is to be measured.

b. The Stem: containing the scale that is measuring the temperature and a capillary through which the liquid can accordingly expand and contract.

C- General Properties

Advantages:

1. They are cheap to manufacture
2. Easy to carry and handle.

Disadvantages:

1. They tend to have high heat capacities. They are not sensitive enough, that is they cannot measure rapid temperature changes

General Equation for Temperature calculation using a liquid in glass thermometer:

$$t = \left(\frac{L_t - L_0}{L_{100} - -L_0} \right) \times 100$$

b- The Resistance thermometer

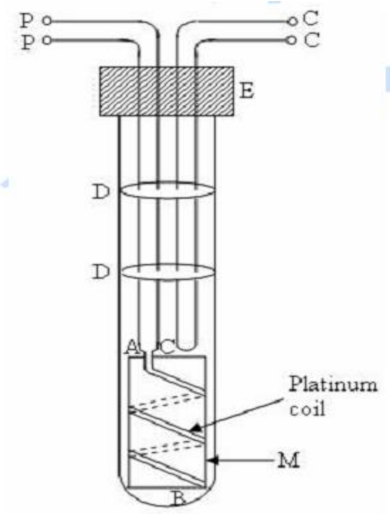
Platinum Resistance thermometer consists of a fine platinum wire (platinum coil) wound in a non-inductive way on a mica frame M (as shown in Figure). The ends of this wire are soldered to points A and C from which two thick leads run along the length of the glass tube (that encloses the set up) and are connected to two terminals (P, P) fixed on the cap of the tube.

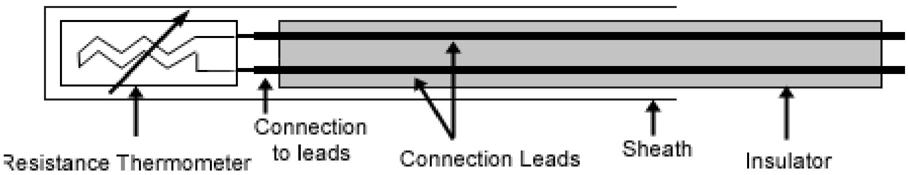
Also, by the side of these leads, another set of leads run parallel and are connected to the terminals (C, C) fixed on the cap of the tube. These are called compensating leads and are joined together inside the glass tube. The compensating leads and the platinum wire are separated from each other by mica or porcelain separators (D, D). The electrical resistance of the (P, P) leads is same as that of the (C, C) leads.

Resistance thermometers are slowly replacing thermocouples in many lower temperature industrial applications (below 600°C). Resistance thermometers come in a number of construction forms and offer greater stability, accuracy and repeatability. The resistance tends to be almost linear with temperature. A small power source is required.

No special extension cables or cold junction compensations are required. The resistance of a conductor is related to its temperature. Platinum is usually used due to its stability with temperature. The Platinum detecting wire needs to be kept free of contamination to remain stable. A Platinum wire or film is created and supported on a former in such a way that it gets minimal differential expansion or other strains from its former, yet is reasonably resistant to vibration.

Resistance thermometers require a small current to be passed through in order to determine the resistance. This can cause self heating and manufacturer's limits should always be followed along with heat path considerations in design. Care should also be taken to avoid any strains on the resistance thermometer in its application. Resistance thermometers elements are available in a number of forms. The most common are: Wire Wound in a ceramic insulator - High temperatures to 850 °C Wires encapsulated in glass - Resists the highest vibration and offers most protection to the Pt Thin film with Pt film on a ceramic substrate - Inexpensive mass production





Advantages

Depending on the metal being used resistance thermometers are able to cover extensive temperature ranges. Maximum values are generally related to the melting points of the metal used.

Variation of resistance with temperature is stable over an extensive temperature range.

Very accurate

Disadvantages

Compared to liquid in glass thermometers, they tend to be expensive.

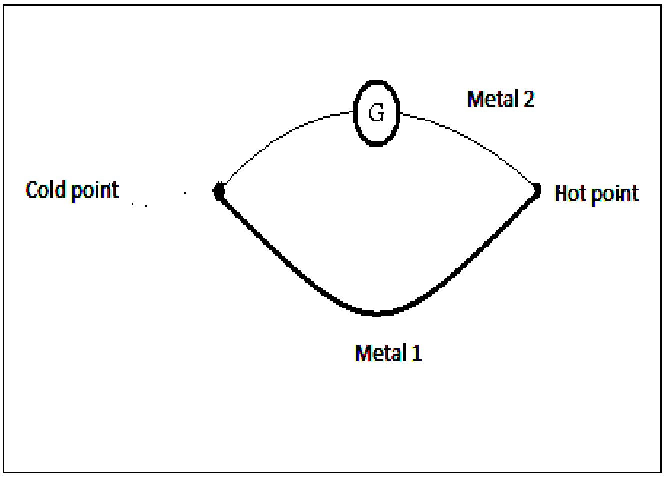
Require other equipment to measure temperature.

They exhibit high heat capacities thus they are not sensitive to temperature change meaning that they cannot be used to measure rapid temperature changes.

$$t = \left(\frac{R_t - R_0}{R_{100} - R_0} \right) \times 100$$

C- Thermocouples

As a Thermometric property thermocouples utilize the variation of EMF generated at a bimetallic junction with temperature. In1821, the German-Estonian physicist Thomas Johann Seebeck discovered that when any conductor (such as a metal) is subjected to a thermal gradient, it will generate a voltage. This is now known as the thermoelectric effect or Seebck effect



Unknown temperature is found according to the relation:

$$t = \left(\frac{E_t - E_0}{E_{100} - E_0} \right) \times 100$$

Many different thermocouple combinations have been used, but only 8 are standardized. These include 3 noble metal thermocouples using platinum and platinum-rhodium alloys, widely used for temperature measurement up to 1600 °C. The remaining 5 mainly use nickel-based alloys, which are cheaper and more suitable for industrial use up to about 1200 °C. Other refractory alloys can be used up to and beyond 2000 °C.

Advantages:

1. Cheap to manufacture.
2. The simplicity, ruggedness, low cost, small size and wide temperature range of thermocouples make them the most common type of temperature sensor in industrial use.
3. Low heat capacities making it capable of measuring rapid temperature changes.

Disadvantages:

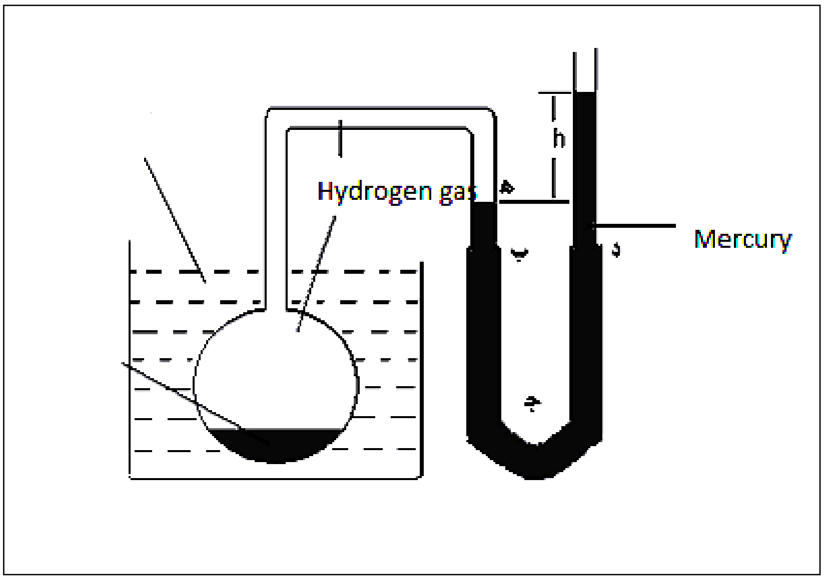
1. Sensitivity reduces accuracy

C -The Constant Volume Gas Thermometer

As a thermometric property it uses the variation of pressure of a gas with temperature. Usually air is used as a gas. For better accuracy other gases like helium that tend to have very low melting points close to absolute zero are used.

Advantages:

It is very accurate. In fact its accuracy allows it to be utilized to **calibrate other thermometers.**



Disadvantages:

1. It is not easy to handle and read.
2. It tends to be highly sensitive to temperature change, and mechanical vibrations. In fact to give a reading it usually entails a lot of time.
3. Expensive to manufacture and keep

Unknown temperature is found according to the relation:

$$t = \left(\frac{p_t - p_0}{p_{100} - p_0} \right) \times 100$$

Ex1 Calculate the temperature of an object where its value is measured by a Fahrenheit temperature equal to twice its value measured by a centimeter, Then calculate the temperature at which the readings are equal

Solution:

$C = ((F - 32) \times 5/9))$

And F=2C, then

C=1600 c

And F=C

F= -40 f

Ex2 Platinum thermometer Its resistance at the ice melting point is 6.5 ohm and at boiling point of water 11.5 ohm Find the temperature when the resistance is 14 ohm and then calculate the resistance of the thermometer at 60 ° C

Solution:

$$t = \left(\frac{R_t - R_0}{R_{100} - R_0} \right) \times 100$$

$$\left(\frac{14 - 6.5}{11.5 - 6.5} \right) . \times 100$$

$$= \; = 150$$

$$60 = \left(\frac{R_t - 6.5}{11.5 - 6.5} \right) \times 100$$

$$R_t = 9.5 \text{ ohm}$$

Ex3 Using the thermometer gas thermometer for the measurement of the temperature of the chamber, the gas pressures were 80cm, 109.3cm at temperature 0 C 0, 100C 0 ,respectively. If the pressure is 83cm at room temperature and 100cm in hot water. Find a hot degree both from the room and hot water

Solution

$$t = \left(\frac{p_t - p_0}{p_{100} - p_0} \right) \times 100$$

$$= \left(\frac{83 - 80}{109.3 - 80} \right) \times 100$$

$$= 10.239 \text{C}$$

$$= \left(\frac{100 - 80}{109.3 - 80} \right) \times 100$$

$$68.26 \text{C}$$

1- if the length of the mercury column in the thermometer's leg at freezing and boiling point, respectively is 15 and 25 cm, calculate the temperature at which the length of the column is equal to 22 cm.

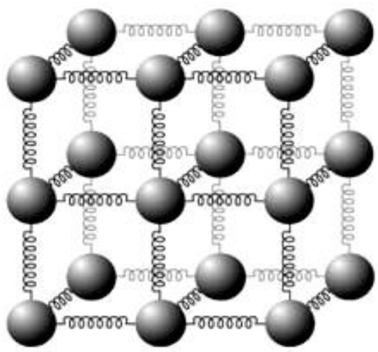
1. **Platinum thermometer** resistances at 0 ° C and water boiling point respectively are 200 and 400 ohm Calculate the temperature that makes it resist 300 ohm.

Chapter Two

Thermal Expansion

When the temperature of the material (solid, liquid or gaseous) is raised, the energy of its molecules increases and thus its vibration is increased around its position (see Figure). This increases the average distance between each molecule and neighboring molecules. The water shrinks when raising the temperature in the range 0: 4 degrees Celsius

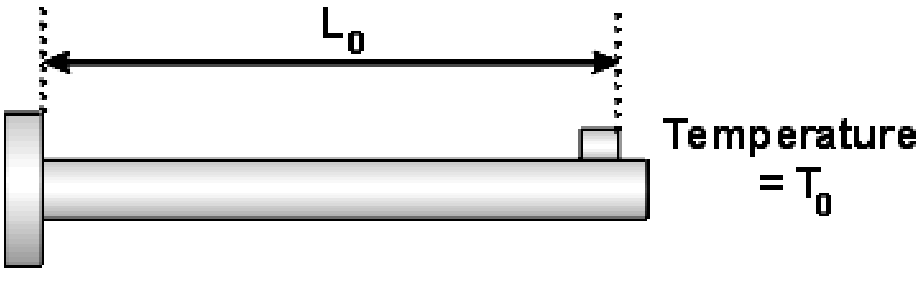
The thermal expansion of the material is a result of the change occurring to the distances between molecules and atoms of matter. To understand more precisely what we have to look at the figure below shows the crystalline structure of a solid state material that contains a matrix of ordered atoms connected to each other by electrical forces

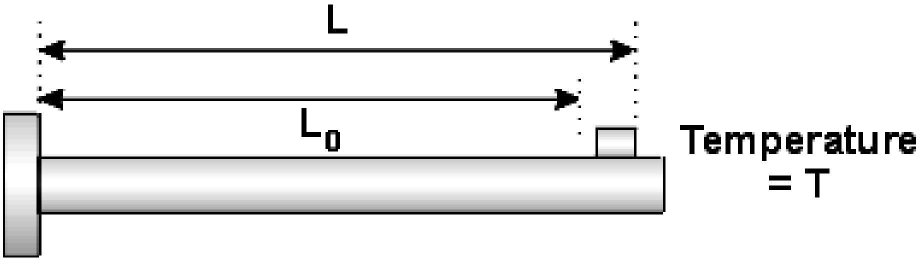


There are three types of expansion: Longitudinal (linear) expansion, surface expansion, and volumetric expansion. The following sections will be summarized them briefly:

1-Longitudinal expansion for solid material:

For a rod of solid copper, its length at zero C is Lo and by raising the temperature of Δt . The increase in length is ΔL is depend upon the temperature raising Δt and the initial length Lo





$$\Delta L \; \alpha \; L_o$$
$$\Delta L \; \alpha \; \Delta T$$
$$\Delta L \; \alpha \; \Delta T \; L_o$$
$$\Delta L = \sigma \; \Delta T \; L_o$$

Where σ is a fixed amount depends on the type of body material and called the coefficient of longitudinal expansion and thus be

$$\sigma = \frac{\Delta L / L_0}{\Delta T} \; :$$

According to the previous equation, we can know the coefficient of the longitudinal expansion of the material

As follows: The increase in the unit length of the material by raising the temperature of one degree Celsius. The unit according to the previous equation is / C°.

We can drive the law of longitudinal expansion in another way: Assuming that L0 L1 L2 is the length of a metal rod at zero temperatures, T1 and T2 temperature. Also, assuming that the coefficient of height increase by raising the temperature (longitudinal expansion coefficient) is constant and has the same value between the temperatures T1 and T2 and by applying Equation 1 (see chapter 1)

$$\boldsymbol{L_1 = L_0(1+\sigma T_1)} \qquad (3)$$

$$\boldsymbol{L_2 = L_0(1+\sigma T_2)} \qquad (4)$$

$$\frac{L_2}{L_1} = \frac{1+\sigma T_2}{1+\sigma T_1}$$

$$\boldsymbol{\frac{L_2}{L_1} = (1+\sigma T_2)(1+\sigma T_1)^{-1}} \qquad (5)$$

$$(1+\sigma T_1)^{-1} = (1-\sigma T_1 + \sigma^2 T^2{}_1 - \sigma^3 T^3{}_1) + ... + ...$$

Consider only the two second terms and neglect the other for simplification then,

$$L_2 = L_1(1+\sigma T_2)(1-\sigma T_1)$$

$$L_2 = L_1[1+\sigma(T_2 - T_1)]$$

$$\frac{L_2 - L_1}{L_1} = \sigma(T_2 - T_1)$$

Ex1

A length of lead piping is 50.0 m long at a temperature of 16°C. When hot water flows through it the temperature of the pipe rises to 80°C. Determine the length of the hot pipe if the coefficient of linear expansion of lead is 29×10^{-6} K^{-1}

Solution

Length L_1= 50.0 m, temperature T_1= 16°C, T_2 = 80°C and σ = 29 × 10^{-6} K^{-1}

Length of pipe at 80°C is given by:

$$L_2 = L_1[1+\sigma(T_2 - T_1)]$$

= 50.0[1 + (29 × 10-6)(80 - 16)]

= 50.0[1 + 0.001856]

= 50.0[1.001856] = 50.0928 m

i.e. an increase in length of 0.0928 m or 92.28 mm

Ex2

A rod of metal is measured at 285 K and is 3.521 m long. At 373 K the rod is 3.523 m long. Determine the value of the coefficient of linear expansion for the metal.

Length L_1= 3.521 m, L_2= 3.523 m, temperature T_1= 285 K and temperature T_2= 373 K 1212

$$L_2 = L_1[1+\sigma(T_2 - T_1)]$$

i.e. 3.523 = 3.521[1 + σ (373 - 285)]

3.523 = 3.521 + (3.521)(σ)(88)

i.e. 3.523 – 3.521 = (3.521)(σ)(88)

Hence, the coefficient of linear expansion = 0.00000645

Ex3

A copper overhead transmission line has a length of 40.0 m between its supports at 20°C. Determine the increase in length at 50°C if the coefficient of linear expansion of copper is 17 × 10^{-6} K^{-1}

Solution

$$L_2 = L_1[1+\sigma(T_2 - T_1)]$$

$$L_2 = L_1 + L_1\sigma(T_2 - T_1)$$

$$L_2 - L_1 = L_1\sigma(T_2 - T_1)$$

= (40.0)(17 × 10-6)(50 – 20) = (40.0)(17 × 10-6)(30)

= 0.0204 m or 20.4 mm

Ex4

A brass measuring tape measures 2.10 m at a temperature of 15°C. Determine :

(a) the increase in length when the temperature has increased to 40°C

(b) the percentage error in measurement at 40°C. Assume the coefficient of linear expansion of brass to be 18 × 10^{-6} K^{-1}

Solution

Length L1= 2.10 m, temperature T1= 15°C, T2= 40°C

and σ = 18 × 10^{-6} K^{-1}

$$L_2 = L_1[1+\sigma(T_2 - T_1)]$$

$$L_2 = L_1 + L_1\sigma(T_2 - T_1)$$

$$L_2 - L_1 = L_1\sigma(T_2 - T_1)$$

Hence, increase in length

= (2.10)(18 × 10-6)(40 – 15)

= (2.10)(18 × 10-6)(25)

= 0.000945 m or 0.945 mm

(b) Percentage error in measurement at 40°C = $\frac{\text{increase in length}}{\text{original length}}$

$$= \frac{0.000945}{2.1} \times 100\%$$

Ex 5

A pendulum of a 'grandfather' clock is 2.0 m long and made of steel. Determine the change in length of the pendulum if the temperature rises by 15 K. Assume the coefficient of linear expansion of steel to be 15×10^{-6} K^{-1}

Solution

Hence, increase in length = L1 σ $(T_2 - T_1)$

= (2.0)(15 × 10-6)(15)

= (2.0)(15 × 10-6)(15)

= 0.00045 m or 0.45 mm

Ex 6

A temperature control system is operated by the expansion of a zinc rod which is 200 mm long at 15°C. If the system is set so that the source of heat supply is cut off when the rod has expanded by 0.20 mm, determine the temperature to which the system is limited. Assume the coefficient of linear expansion of zinc to be 31 × 10^{-6} K^{-1}

Solution

Length L_1= 200 mm = 0.20 m, L_2= 200 + 0.20 mm = 200.2 mm = 0.2002, temperatureT1= 15°C

Hence, increase in length = $L_1 \sigma$ $(T_2 - T_1)$

0.2002 – 0.20 = (0.20)(31 × 10-6)(T_2- 15)

0.0002 = (0.20)(31 × 10-6)(T_2- 15)

$$T_2 - 15 = \frac{0.0002}{0.2 \times 31 \times 10^{-6}}$$

=32.26 0C

i.e. the temperature to which the system is limited,

$T_2 = 32.26 + 15 = 47.26°C$

Answer the following:

1-A length of steel railway line is 30.0 m long when the temperature is 288 K. Determine the increase in length of the line when the temperature is raised to 303 K. Assume the coefficient of linear expansion of steel to be $15 \times 10^{-6}\ K^{-1}$

2- A brass shaft is 15.02 mm in diameter and has to be inserted in a hole of diameter 15.0 mm. Determine by how much the shaft must be cooled to make this possible, without using force. Take the coefficient of linear expansion of brass as $18 \times 10^{-6}\ K^{-1}$

3-**Surface expansion**:

The surface expansion coefficient of the material is known as the increase in the unit area due to the increase of one degree Celsius.

We assume that a square metal plate with an area at 0 ° C is L02 and its temperature will expand in all directions then increase its area. If the increase in temperature is equal to T_1 ° the length of both sides is

$$L = L_0(1+\sigma T_1)$$

Then the area:

$$L^2 = L_0^{\ 2}(1+\sigma T_1)^2$$

$$L^2 = L_0^{\ 2}(1+2\sigma T_1 + \sigma^2 T_1)$$

$$L^2 = L_0(1+2\sigma T)$$

By neglecting the last term then the last equation becomes in the following picture:

$$S = S_0(1+\beta T_1)$$

Where S_0 represents the area at 0 ° C and S is the area at T1 and by comparing the equation of longitudinal and surface expansion we find that:

$$\beta = 2\sigma$$

i.e the coefficient of surface expansion is twice the value of the longitudinal expansion coefficient

By the same way, it can be shown that the volume expansion coefficient of Φ a solid body is three times the value of the longitudinal expansion coefficient

$$\Phi = 3\sigma$$

$$\Phi = \frac{V - V_0}{V_0 T_1}$$

V_o is the size at zero degrees Celsius and V is the size at T_1

In addition to the above effect of raising the temperature in the physical properties of the change in length, area and size, the changing of the density of materials as well as flexibility due to thermal effect will be discussed :

1-Density :

We know that the density is the mass of the volume unit of the material, ie the density of the material in the zero degree percent is :

$$\rho_0 = \frac{M}{V_0}$$

For temperature raising to T1 the density becomes ρ :

$$\rho = \frac{M}{V}$$

$$\frac{\rho_0}{\rho} = \frac{V}{V_0}$$

By substituting

$$V = V_0(1 + \Phi T_1)$$

$$\rho_0 = \rho(1 + \Phi T_1)$$

For two temperature T1 and T2 the density is

$$\rho_0 = \rho[(1 + \Phi(T_2 - T_1)]$$

2- Elasticity

The scientific experiments have shown that the Elasticity of objects changes with their high temperature. It was found that the young coefficient (Y) of the material is slightly less with high temperature and by more increasing of temperature, its value is missing at the melting point of the material.

For more understand of the effect of temperature on the elasticity of objects in a mathematical way, we assume that we have a hot metal rod L_2 at the temperature of T_2 and assume that we fixed the ends of this hot rod and let it cool until it reaches the temperature to room temperature T_1. The cold metal rod will tighten. If it is not fixed at the ends then reduce to to L_1

$$L_2 - L_1 = \sigma L_1 (T_2 - T_1)$$

The fixed metal rod which is hot and then cooled to room temperature, generates a state of tensile force to increases its length from L_1 to L_2. The definition of the Young coefficient, which expresses the elasticity of objects:

$$Y = \frac{\textit{Stress}}{\textit{Strain}}$$

$$Y = \frac{F / A}{(L_2 - L_1) / L_1}$$

From the mentioned equations we can deduced the following formula for Young coefficient

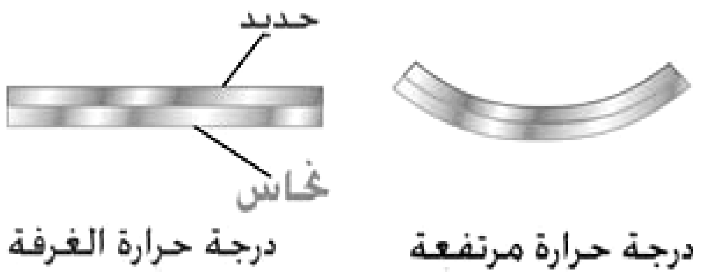
$$Y = \frac{F}{A} \frac{1}{\sigma (T_2 - T_1)}$$

This equation shows the effect of temperature on the elastic coefficient Y. Where it is clear that as the temperature increases the elastic coefficient decreased

Applications on the expansion of solid objects

1- **Bimetallic strip**

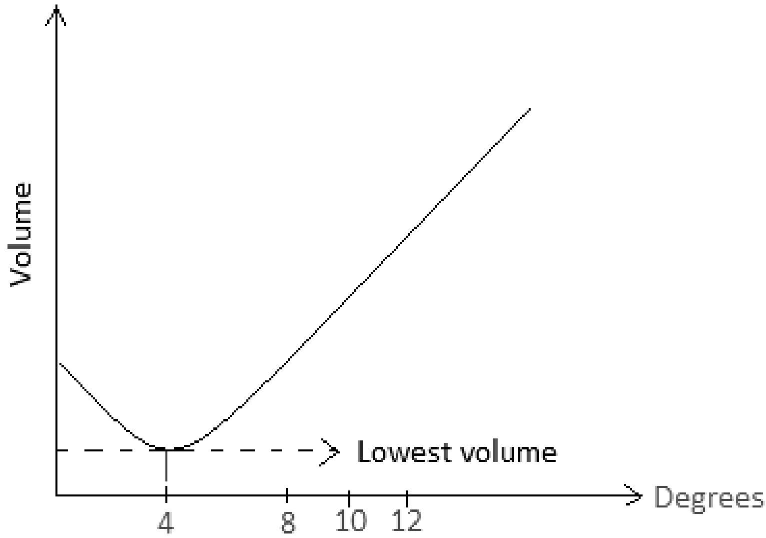
A bimetallic strip is used to convert a temperature change into mechanical displacement. The strip consists of two strips of different metals (see the figure) which expand at different rates as they are heated, usually steel and copper, or in some cases steel and brass. The strips are joined together throughout their length by riveting, brazing or welding. The different expansions force the flat strip to bend one way if heated, and in the opposite direction if cooled below its initial temperature. The metal with the higher coefficient of thermal expansion is on the outer side of the curve when the strip is heated and on the inner side when cooled



Liquid Expansion

The liquids expand and increase in size by increasing the temperature, and their volumetric expansion coefficient is large compared to the solids. Water is different from other liquids as the water density increases by increasing the temperature from 0 to 4 degrees Celsius.

The thermal expansion of water is different than most other liquids. With the exception of water, almost all liquids will expand with an increase in temperature. However take a look at the graph below to see how water behaves as the temperature increases from 0 degree to 4 degrees Celsius. Keep in mind that at zero degree, water is in its solid form.



As the temperature increases from 0 degree to 4 degrees, we notice that the volume is decreasing.

At 4 degrees Celsius, a given amount of water has the smallest volume. Since that amount of water has the smallest volume, it has the greatest density.

Liquids take the shape of the vessel which is contained. Therefore, when talking about the expansion of liquids, we must consider the expansion of the vessel Φc and the observed expansion of the fluid is not in fact the extension of the dilution of the liquid only between the real expansion of the fluid and the expansion of the vessel. That is, the liquid has a real expansion Φ_r and an apparent expansion Φa

$$\phi_r = \phi_a + \phi_c$$

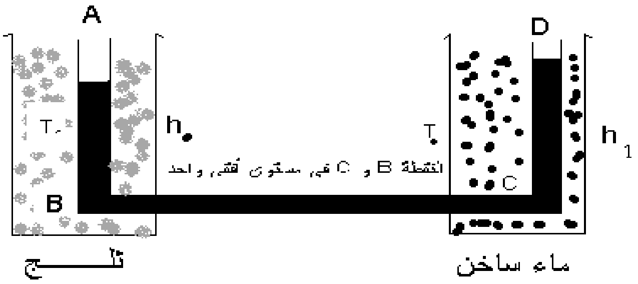
Real expansion of the liquid Φr: is the actual increase in the size of the volume unit of liquid if the temperature increased of one degree Celsius

Apparent expansion of the liquid Φa: is the apparent increase in the size of the volume unit of liquid if the temperature increased of one degree Celsius

Measurement of volumetric expansion coefficient of liquid Φ:

With out the need to take into account the expansion of the container containing the liquid, Dwing Dabti invented a simple method to measure the volumetric expansion coefficient of the liquid.

The device used (see the figure) as the form is composed of two vertical tubes AB DC connected to a horizontal tube with a small BC section and the AB tube is surrounded by fused ice. The CD tube is surrounded by a water bath that can be heated to different temperature



Assume that the water bath temperature is T and the temperature of the melting ice is To. When the liquid surface is stable in the two tubes, the liquid pressure at point B equals liquid pressure at point C.

Where T> To, the density of the liquid in the CD is less than the value in AB. This is resulting the rise of the liquid in the CD h1 becomes greater than the equivalent in AB h_o:

$$P_C = P_B$$

$$p + h_0 \rho_0 g = P + h_1 \rho g \qquad \frac{\rho_0}{\rho} = \frac{h_1}{h_0}$$

From the equation that shows the relationship between the two liquid densities at two different temperatures.

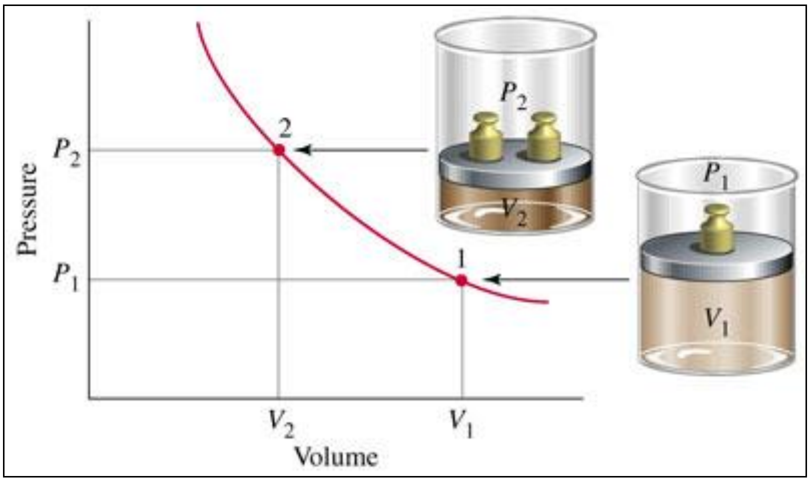
$$\rho_0 = \rho\left[(1 + \Phi(T - T_0)\right]$$

$$\frac{h_1}{h_0} = \left[(1 + \Phi(T - T_0)\right] \qquad \frac{h_1 - h_0}{h_0} = \left[\Phi(T - T_0)\right] \qquad \frac{h_1 - h_0}{h_0\left(T - T_0\right)} = \Phi$$

Gas expansion:

Gases are expanded when heated and raised temperature, and since the sizes depend upon the pressure, it is necessary to save pressure when studying the increase in size with temperature. On the other hand, if the objective is to study the increase of pressure with temperature, it proves the size.

Boyle's Law: When gas is kept at constant temperature its pressure is inversely proportional to the volume.



$$V \alpha \frac{1}{P}$$

$$PV = cons\tan$$

$$P_1V_1 = P_2V_2$$

Charle's Law

When the pressure of the gas kept constant the volume directly proportional to the temperature

$$V = V_0(1 + \Phi T) \qquad (1)$$

Φ is the Coefficient of increase in volume when pressure is confirmed .

Law of Pressure:

When the volume of the gas kept constant the pressure directly proportional to the temperature

$$P = P_0(1 + \beta T) \qquad (2)$$

Where β is the coefficient of pressure increase when the volume is confirmed

Prove that the : Φ = β :

Multiply the equation representing the coefficient of increase in size in P_o and multiply the equation which represents the coefficient of pressure increase in V_o

$$P_0V = P_0V_0(1+\Phi T)$$

$$V_0P = V_0P_0(1+\beta T)$$

$$\frac{P_0V}{PV_0} = \frac{(1+\Phi T}{(1+\beta T)})$$

From Boyle's Law

$$V = \frac{C}{P} \qquad V_0 = \frac{C}{P_0}$$

$$\frac{P_0{}^2}{P^2} = \frac{(1+\Phi T}{(1+\beta T)})$$

$$\frac{P_0{}^2}{P_0{}^2(1+\beta T)^2} = \frac{(1+\Phi T}{(1+\beta T)})$$

$$(1+\beta T)(1+\Phi T) = 1$$

By neglecting the amount of $\Phi\beta$ T2, and with the insignificance of the sign,

$$\boxed{\beta = \phi}$$

Ex1.

A silver plate has an area of 800 mm2 at 15°C. Determine the increase in the area of the plate when the temperature is raised to 100°C. Assume the coefficient of linear expansion of silver to be 19×10^{-6} K^{-1}

Solution

When the temperature change from T1 to T2, then

$$S_2 = S_1[1+\beta(T_2 - T_1)]$$
$$S_2 = S_1 + S_1\beta(T_2 - T_1)$$
$$S_2 - S_1 = S_1\beta(T_2 - T_1)$$

Then the area increase $S_2 - S_1 = S_1 2\sigma(T_2 - T_1)$

=800x10-6x2x19x10-6(100-15)

$=2.584 \times 10^{-6}$ m^2

Ex2

At 283 K a thermometer contains 4403 mm of alcohol. Determine the temperature at which the volume is 480 mm3 assuming that the coefficient of cubic expansion of the alcohol is 12×10^{-4} K^{-1}

Solution

$$V_2 = V_1[1 + \Phi(T_2 - T_1]$$

480x10-9 =440x10-9[1+12x10-4(T_2-283)]

T_2= 358.8 K

Ex3

A zinc sphere has a radius of 30.0 mm at a temperature of 20 C°. If the temperature of the sphere is raised to 420 C°, determine the increase in:

(a) the radius,

(b) the surface area,

(c) the volume of the sphere. Assume the coefficient of linear expansion for zinc to be 31×10^{-6} K^{-1}

Solution

(a) Initial radius, L1= 30.0 mm, initial temperature,

T1= 20 + 273 = 293 K

Final temperature,T2= 420 + 273 = 693 K and

σ = 31 × 10-6

New radius at 693 K is given by

$$L_2 = L_1[1 + \sigma(T_2 - T_1]$$

L2= 30.0[1 + (31 × 10-6)(693 - 293)]

= 30.372 mm

= Hence the increase in the radius is 0.372 mm

(b) Initial surface area of sphere, S1= 4πr2 = 4π(30)2 = 3600π mm2

New surface area at 693 K is given by

$S_2 = S_1[1 + 2\sigma(T_2 - T_1)]$

Since β = 2σ , to a very close approximation

= 3600π[1 + 2(31 × 10-6)(400)]

=3600π[1 + 0.0248] = 3600π + 3600π(0.0248)

Hence increase in surface area = 280.5 mm²

(c) Initial volume of sphere, V1 $\frac{4}{3}\pi r^3 = \frac{4}{3}\pi(30)^3 mm^3$

New volume at 693 K is given by:

$V_2 = V_1[1 + 3\sigma(T_2 - T_1]$

$V_2 = \frac{4}{3}\pi(30)^3[1 + 3x31x10^{-6}(400)]$ =4207 mm³

Ex4

A block of cast iron has dimensions of 50 mm by 30 mm by 10 mm at 15°C. Determine the increase in volume when the temperature of the block is raised to 75°C. Assume the coefficient of linear expansion of cast iron to be 11 × 10^{-6} K^{-1}

Solution

$V_2 = V_1[1 + \Phi(T_2 - T_1]$

$V_2 = V_1[1 + 3\sigma(T_2 - T_1]$

$V_2 = 15000[1 + 3 \times 11^{-6}(75 - 15)]$

$V_2 = 29.7\,\text{mm}^3$

Ex5

Two liters of water, initially at 20°C, is heated to 40°C. Determine the volume of water at 40°C if the coefficient of volumetric expansion of water within this range is 30 × 10^{-5} K^{-1}

Solution

$V_2 = V_1[1 + \Phi(T_2 - T_1]$

$V_2 = 2[1 + 30 \times 10^{-5}(40 - 20)]$

$= 2.012\,\text{litres}$

Ex6

Determine the increase in volume, in liters, of 3 m^3 of water when heated from 293 K to boiling point if the coefficient of cubic expansion is $2.1 \times 10^{-4} K^{-1}$ (1 litre ≈ $10m^3$)

Solution

Initial volume of sphere, $V1 = 3 \times 103 = 3000$ liters

New volume at boiling point (i.e. 373 K) is given by

$$V_2 = 3000\left[1 + 2.1 \times 10^{-4}(373 - 293)\right]$$

$$= 50.4 \,\text{litres}$$

Ex7

Determine the reduction in volume when the temperature of 0.5 liter of ethyl alcohol is reduced from 40°C to - 15°C. Take the coefficient of cubic expansion for ethyl alcohol as $1.1 \times 10^{-3} K^{-1}$

Solution

$$V_2 = V_1\left[1 + \Phi(T_2 - T_1\right]$$

$$V_2 = 0.5\left[1 + 1.1 \times 10^{-3}\left(-15 - 40\right)\right]$$

$$= 0.5\left[1 + .1.1 \times 10^{-3}(-55)\right]$$

$$= 0.5 - 0.5 \times 1.1 \times 10^{-3} \times 55$$

$$= 0.5 - 003025$$

V2 =0.46975 liter V1=0.5 liter

Hence, the reduction in volume =0.03025

Chapter Three

Heat Transfer

Heat transfer from the hot body to the cold body can be dne by one of three ways:

- Thermal Conduction
- Thermal convection
- Thermal Radiation

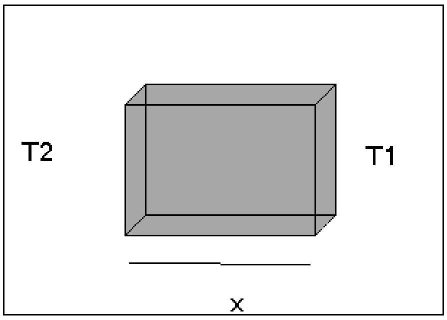
In this chapter we will discuss the above three methods of heat transfer and explanation with accompanied by equations and graphs.

1-Thermal Conduction;

Thermal conduction is the direct microscopic exchange of kinetic energy of particles through the boundary between two systems without bulk motion of the matter.

When an object is at a different temperature from another or its surroundings, heat flows so that the body and the surroundings reach the same temperature, at which point they are in thermal equilibrium. Such spontaneous heat transfer always occurs from a region of high temperature to another region of lower temperature.

Assume a cube with X length and its area of one of the sides is A. The temperature of the opposite sides is T_2 and T_1 where $T_2 > T_1$ so a connection occurs in the direction of the lower temperature.



The amount of heat transferred through the sides of the cube (H) is proportional to:

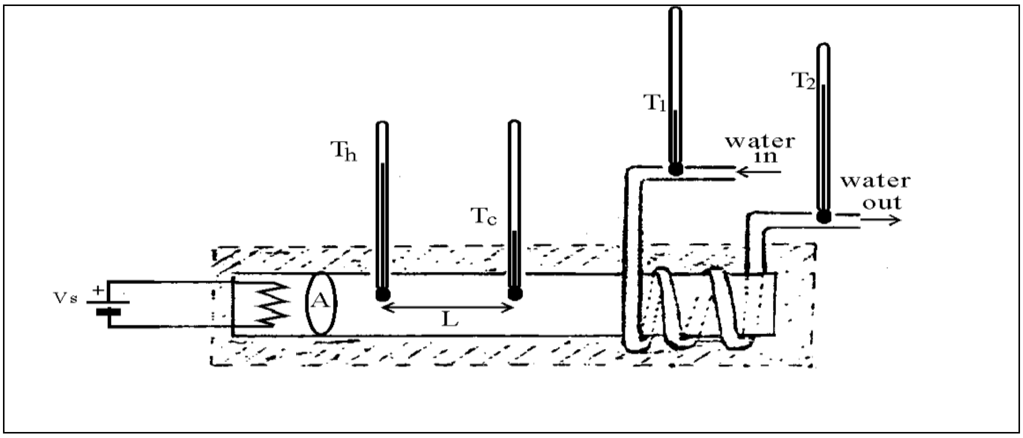
$$H \alpha T_2 - T_1$$
$$H \alpha A$$
$$H \alpha \frac{1}{x}$$
$$H \alpha t$$
$$H \alpha \frac{T_2 - T_1}{x} At$$
$$H = \lambda \frac{T_2 - T_1}{x} At$$
Then $$\frac{dH}{dt} = -\lambda A \frac{dT}{dx}$$

The proportionality coefficient (λ) is the thermal conductivity coefficient which is a characteristic of the material in terms of its thermal nature

$$\lambda = \frac{H}{A \frac{T_2 - T_1}{x} t}$$

Searle's method for thermal conductivity measurement:

Searle's apparatus are shown below to measure the thermal conductivity of copper. We input heat at one end of the bar by means of an electrical power supply. The other end of the bar we cool by wrapping tubing around it through which water flows at constant rate. The flowing water will carry off the heat reaching the cold end of the copper bar. In this way we eventually get a balance between the heat input on one end, and the heat carried away at the other end. As a result the temperature at each position of the bar becomes constant in time; we have reached what is called a dynamic equilibrium. The adjective "dynamic" is used since heating and cooling goes on continuously, and there is equilibrium because their net effect is to produce no change)



$$m\,(T_2 - T_1) = -\lambda \pi r^2 \left(\frac{T_h - T_c}{l}\right).t$$

Measurement of Thermal Conductivity by Lee's method

Aim: To determine thermal conductivity of a bad conductor (glass) in form of a disc using Lee's method.

Requisites:

(1) Lee's apparatus and the experimental specimen in the form of a disc.

(2) Two thermometers,

(3) Stop watch,

(4) Weighing balance,

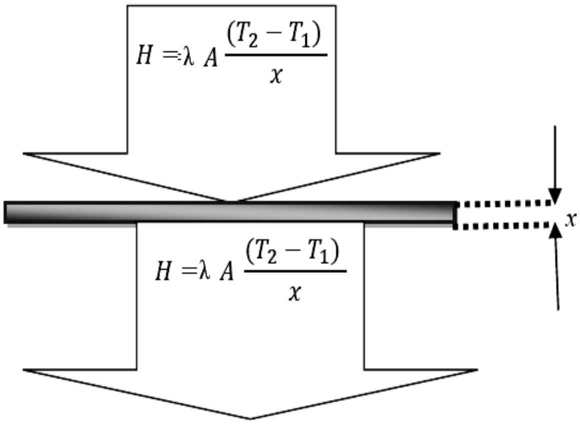
(5) Special clamp stand

(6) Boiler and Heater

Theory:

Thermal conductivity, λ, is the property of a material that indicates its ability to conduct heat. Conduction will take place if there exists a temperature gradient in a solid (or stationary fluid) medium. Energy is transferred from more energetic to less energetic molecules when neighboring molecules collide. Conductive heat flow occurs in direction of the decreasing temperature because higher temperature is associated with higher molecular energy. Fourier's Law expresses conductive heat transfer for one unit time as :

$$H = -\lambda A \frac{T_2 - T_1}{x}$$

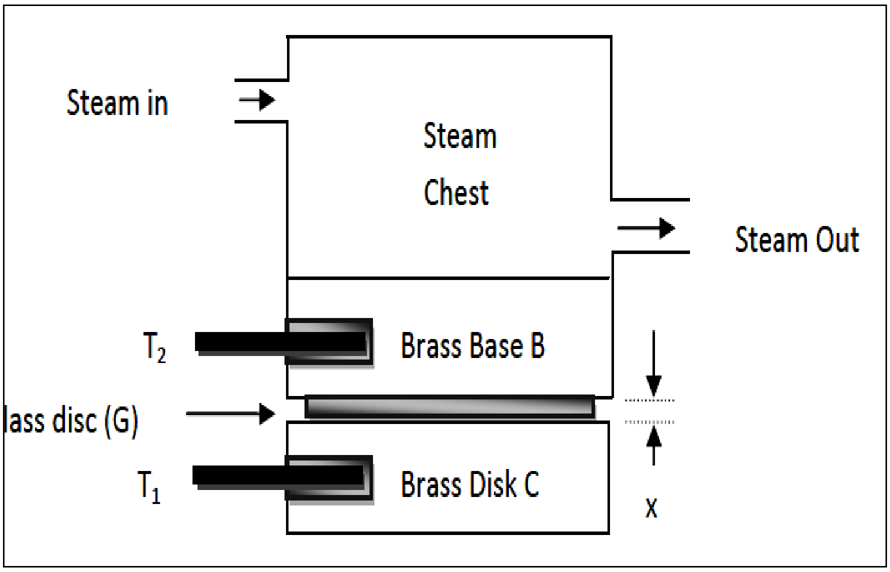


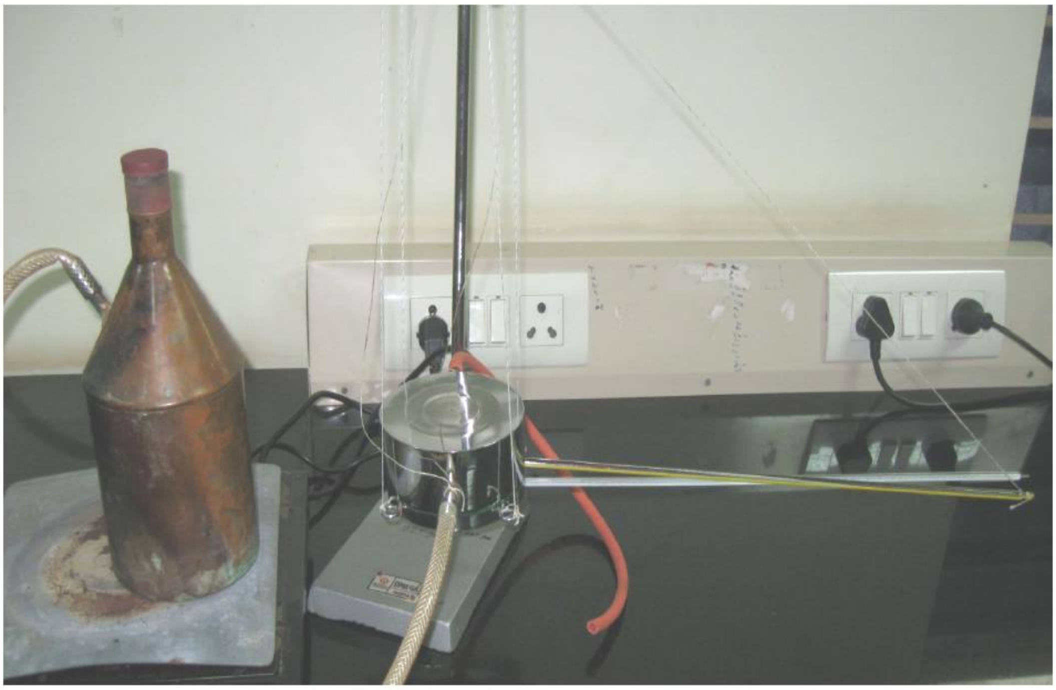
where H is the steady state rate of heat transfer, λ is the thermal conductivity of the sample, A is the cross sectional area and (T_2 – T_1) is the temperature difference across the sample thickness 'x' (see Figure), assuming that the heat loss from the sides of the sample is negligible. To keep the loss from the sides small, the sample is made in form of a thin disk with a large cross sectional area compared to the area exposed at the edge. Keeping 'A' large and 'x' small produces a large rate of energy transfer across the sample. Keeping x small also means that the apparatus reaches a steady state (when temperature T_1 and T_2 are constant) more quickly

Generally speaking, there are a number of possibilities to measure thermal conductivity, each of them being suitable for a limited range of materials, depending on the thermal properties and the medium temperature. The most commonly used methods are Searle's method and Lee's disc method, for good and bad conductors of heat, respectively. In the experiment, we will use Lee's disc method to determine the thermal conductivity of a bad conductor, e.g. Glass

Description of Lee's apparatus:

The apparatus shown in Figure consists of two parts. The lower part C is circular metal disc. The experimental specimen G, usually rubber, glass or ebonite (here it is glass) is placed on it. The diameter of G is equal to that of C and thickness is uniform throughout. A steam chamber is placed on C. The lower part of the steam chamber, B is made of a thick metal plate of the same diameter as of C. The upper part is a hollow chamber in which two side tubes are provided for inflow and outflow of steam. Two thermometers T_1 and T_2 are inserted into two holes in C and B, respectively. There are three hooks attached to C. The complete setup is suspended from a clamp stand by attaching threads to these hooks.





Photograph of thermal conductivity measurement setup

When steam flows for some time, the temperatures recorded (T1 and T2) gradually remain steady.

This is the steady state.

Let at the steady state, temperature of C = T1.

Temperature of B = T2.

Surface area of G = A

Conductivity of G = λ

Thickness of G = x

Hence amount of heat flowing through G per second, H is given by

$$H = -\lambda A \frac{T_2 - T_1}{x} \qquad (1)$$

When the apparatus is in steady state (temperatures T1 and T2 constant), the rate of heat conduction into the brass disc C is equal to the rate of heat loss from the bottom of it. The rate of heat loss can be determined by measuring how fast the disc C cools at the previous (steady state) temperature T1 (with the top of the brass disk covered with insulation). If the mass and specific heat of the lower disc are m and S, respectively and the rate of cooling at T1 is dT/dt then the amount of heat radiated per second is,

$$H = mS\frac{dT}{dt} \qquad (2)$$

Equating (1) and (2) and simplifying, k can be determined as,

$$\lambda = \frac{mS\left(\frac{dT}{dt}\right)x}{A(T_2 - T_1)}$$

Procedure:

1. Fill the boiler with water to nearly half and heat it to produce steam.
2. In the mean time, take weight of C by a weighing balance. Note its specific heat from a constant table. Measure the diameter of the specimen by a scale or slide calipers, if possible. Calculate the surface area, A = π r2.
3. Measure the thickness of the specimen by screw gauge. Take observations at 5 spots and take the mean value.
4. Put the specimen, steam chamber etc. in position and suspend it from the clamp stand. Insert the thermometers. Check if both of

them are displaying readings at room temperature. If not, note the difference θ, is to be added to ($T_2 - T_1$) later.

5. Now stem is ready. Connect the boiler outlet with the inlet of the steam chamber by a rubber tube.

6. Temperatures recorded in the thermometers will show a rise and finally will be steady at T_1 and T_2.

7. Wait for 10 minutes and note the steady temperature. Stop the inflow of steam.

8. Remove the steam chamber and the specimen G. C is still suspended. Heat C directly by the steam chamber till its temperature is about $T_1 + 7°$.

9. Remove the steam chamber and wait for 2 – 3 minutes so that heat is uniformly distributed over the disc C.

10. Place the insulating material on C. Start recording the temperature at ½ minute intervals. Continue till the temperature falls by 10 degree from T_1

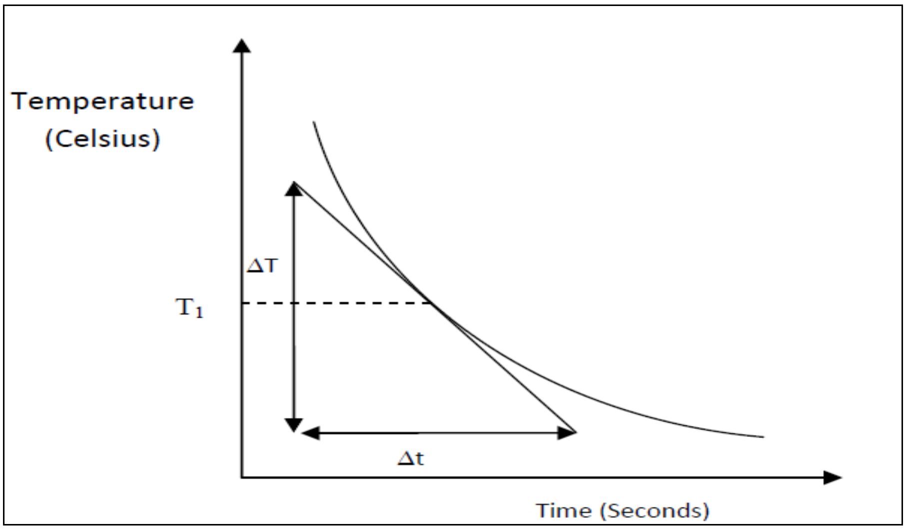
Graph:

Using the data according to step 10, plot the cooling curve (time versus Temperature) and determine the slope $dT/dt = \Delta T/\Delta t$ at the steady temperature T1 (see the figure below).

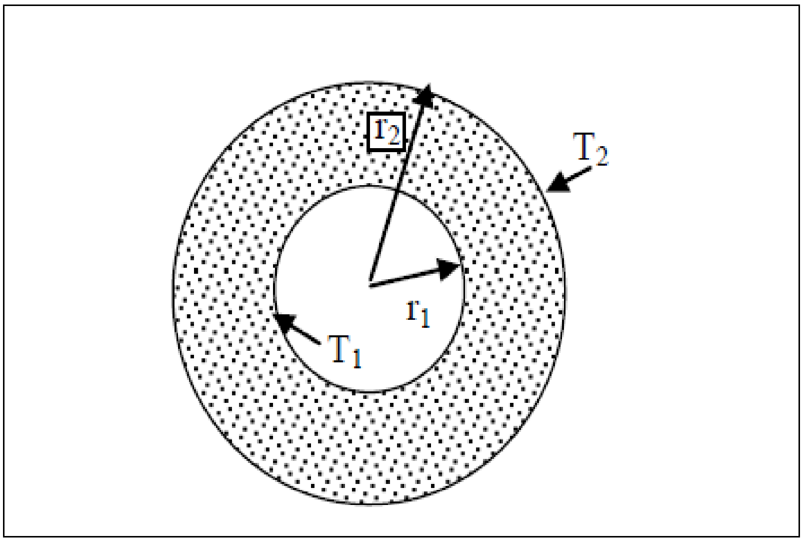
Probable errors and precautions

1. Don't record T1 and T2 unless they have remained steady for at least 10 minutes.

2. The tangent to the cooling curve should be done very carefully. An error in dT/dt will result in a wrong result for λ



1- Heat Conduction between two concentric balls:



Consider the above diagram we are interested in determining the rate of heat transfer through the peel. Heat flow, per unit time, is along radial direction outwards

$$H = -\lambda A \frac{dT}{dr}$$

$$A = 4\pi r^2$$

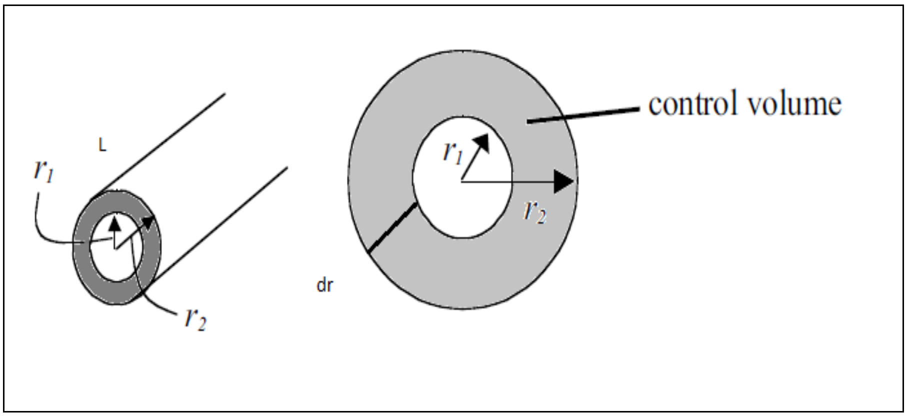
$$\frac{dr}{r^2} = -\frac{4\lambda\pi}{H} dT$$

$$\int_{r_1}^{r_2} \frac{dr}{r^2} = -\frac{4\lambda\pi}{H} \int_{T_1}^{T_2} dT$$

$$\left[\frac{1}{r}\right]_{r_1}^{r_2} = -\frac{4\lambda\pi}{H} [T]_{T_1}^{T_2}$$

$$H = \frac{4\pi\lambda r_1 r_2 (T_1 - T_2}{r_2 - r_1}$$

2- Heat conduction through hollow Cylinder:



We consider a hollow cylinder (see the figure) with inner and outer diameter are r_1, r_2 . The inner and outer temperature of the are T_2 and T_1 respectively where $T_1 > T_2$. Assume that cylinder length .

Let's take a small shell thickened dr. Since the crust is very small, we can consider that the crust is as if it is the same as the inner and outer surfaces.

Using the Fourier's equation

$$\frac{dH}{dt} = -\lambda A \frac{dT}{dx}$$

$$\boldsymbol{A = 2\pi r L}$$

$$\boldsymbol{\frac{dH}{dt} = -2\pi L r \lambda \frac{dT}{dr}}$$

For the steady state $\frac{dH}{dt}$ is constant then:

$$\boldsymbol{a = -r \frac{dT}{dr}}$$

$$\boldsymbol{a \int \frac{dr}{r} = \int dT}$$

$$\boldsymbol{b + a \log r = T}$$

By applying the boundary condition:

$T = T_1$ when $r = r_1$

$T = T_2$ when $r = r_2$

$$b + a \log r_1 = T_1$$

$$b + \log r_2 = T_2$$

$$T_1 - T_1 = a \log \frac{r_1}{r_2}$$

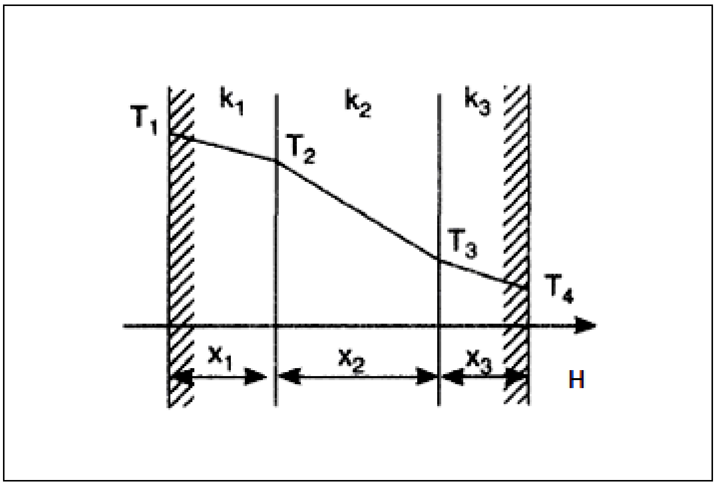
$$a = \frac{T_1 - T}{\log \frac{r_1}{r_2}}$$

$$\frac{dH}{dt} = -2\pi L\lambda \frac{T_1 - T_2}{\log (r_1 / r_2)}$$

$$H = -2\pi L\lambda \frac{T_1 - T_2}{\log (r_1 / r_2)} t$$

Heat conduction through composite wall:

Assume that a composite wall consist of three layers (x_1 x_2 x_3) and their thermal conductivity coefficients are k_1, k_2 and k_3, respectively and their surface area is A with temperatures of are $T_1 > T_2 > T_3 > T_4$



$$\frac{dH}{dt} = -\lambda_1 A \frac{T_1 - T_2}{x_1}$$

$$\frac{dH}{dt} = -\lambda_2 A \frac{T_2 - T_3}{x_2}$$

$$\frac{dH}{dt} = -\lambda_3 A \frac{T_3 - T_4}{x_3}$$

$$-\frac{dH}{dt}\frac{x_1}{\lambda_1 A} = T_1 - T_2$$

$$-\frac{dH}{dt}\frac{x_2}{\lambda_2 A} = T_2 - T_3$$

$$-\frac{dH}{dt}\frac{x_3}{\lambda_3 A} = T_3 - T_4$$

On addition

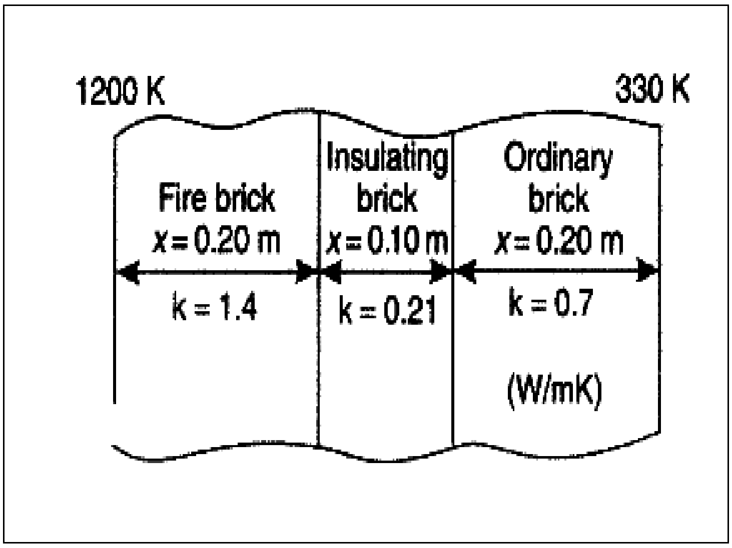
$$T_1 - T_4 = \frac{dH}{dt}\left[\frac{x_1}{\lambda_1 A} + \frac{x_2}{\lambda_2 A} + \frac{x_3}{\lambda_3 A}\right]$$

For one second:

$$T_1 - T_4 = H\left[\frac{x_1}{\lambda_1 A} + \frac{x_2}{\lambda_2 A} + \frac{x_3}{\lambda_3 A}\right]$$

Ex1

A furnace is constructed with 0.20 m of firebrick, 0.10 m of insulating brick, and 0.20 m of building brick. The inside temperature is 1200 K and the outside temperature is 330 K. If the thermal conductivities are as shown in Figure, estimate the heat loss per unit area and the temperature at the junction of the firebrick and the insulating brick



Solution

From equation 9.19:

$$Q = (1200 - 330) \Big/ \left[\left(\frac{0.20}{1.4 \times 1} \right) + \left(\frac{0.10}{0.21 \times 1} \right) + \left(\frac{0.20}{0.7 \times 1} \right) \right]$$

$$= \frac{870}{(0.143 + 0.476 + 0.286)} = \frac{870}{0.905}$$

$$= \underline{\underline{961 \text{ W/m}^2}}$$

The ratio (Temperature drop over firebrick)/(Total temperature drop) = (0.143/0.905)

$\therefore$ Temperature drop over firebrick $= \left(\frac{870 \times 0.143}{0.905} \right) = 137$ deg K

Hence the temperature at the firebrick-insulating brick interface = (1200 − 137) = $\underline{\underline{1063 \text{ K}}}$

Ex2

Wall of a room consist of three parallel layers of cement, bricks and wood their thickness are 2, 23 and 1 cm, respectively. If the air temperature is -5 ° C and the room temperature is 20 ° C. Calculate the amount of heat transmitted by conduction per minute of each square meter of the wall. The heat conduction coefficients for cement, bricks and wood are: 7×10^{-4} , 6×10^{-3} and 4×10^{-4} respectively.

Solution

$$T_1 - T_4 = \frac{H}{t} \left[\frac{x_1}{\lambda_1 A} + \frac{x_2}{\lambda_2 A} + \frac{x_3}{\lambda_3 A} \right]$$

$$20 + 5 = \frac{H}{60} \left[\frac{2}{0.0007 \times 10^4} + \frac{23}{0.006 \times 10^4} + \frac{1}{0.0004 \times 10^4} \right]$$

25 =H/60[0.286+0.383+0.250]

25 =(H/60)(0.919)

H =1632.2 cal

Ex3

Calculate the amount of heat transferred by the conduction per hour during the material between two balls united in the center. The inside and outside balls have diameters 4 and 6 cm , respectively . If the temperature of the surface of the two balls are 100 and 40 degrees Celsius, respectively, and the thermal conductivity of its material is equal to 3×10^{-4} .

Solution

The amount of heat transfer by conduction per second is :

$$H = 4\pi r r_2 r_1 \lambda \frac{T_2 - T_1}{(r_2 - r_1)}$$

The amount of heat transfer by conduction per one hour is

$$H = \left[4 \times 3.14 \times 2 \times 3 \times 0.0003 \times \frac{100 - 40}{(3 \ - 2)} \right] \times 60 \times 60$$

H=4885.8 cal.

Radiation Heat Transfer

Heat is transferred by radiation between the objects, surfaces and fluids that are different from each other and are different in their temperature in the form of electromagnetic waves. Electromagnetic waves are approximately equal to the speed of light (3 x 10 8 m s^{-1} . Therefore, the transfer of heat by radiation is the fastest method of heat transfer

When studying the process of heat transfer by radiation;

- The properties of Thermal Radiation should be studied
- Boltzmann Law for a Black Bodies

Finally, the process of heat transfer between different objects or surfaces at temperature depends on the shape of the surface or the radiant body and the distance between objects and some of them.

Also, we must know that the thermal radiation that is emitted from an object does not fully reach to the other body that exchanges with it. Heat, but loses part of it, all these factors are governed by a coefficient called Radiation Shape Factor

Properties of Thermal Radiation

When the thermal energy (thermal radiation) hits the surface of any object, a portion of this radiation is reflected (refracted radiation) and the a part is absorbed (absorbed radiation) . The last portion is transmitted radiation Therefore, the sum of the previous three parts equal to the correct.

$$\rho + \alpha + \tau = 1$$

where

Reflectivity factor is (ρ)

Absorptivity factor is (α)

Transmissivity factor is (τ)

However, most solid objects do not transmit heat radiation. Therefore, the Transmissivity factor of these objects is zero, so the previous equation becomes as follows

$$\rho + \alpha = 1$$

Stefan-Boltzmann Law For a Black Bodies

The total amount of energy emitted from the black surface because (this type of surface, as we know, absorbs the radiation at a very high rate and at the same time sends the radiation that absorbed it at a high rate also. This world found that the total energy emitted from the black surface of the unit of space is directly proportional to the absolute temperature of this body is raised to the fourth

$$\frac{q}{A} \alpha T^4 \qquad \frac{q}{A} = \eta T^4$$

η is Boltezman constant

What are some similarities between light and radiation?

Light and radiation are related phenomena, and there are similarities between them:

1. **Wave Nature:** Both light and radiation exhibit wave-like properties. Light, as electromagnetic waves, includes a range of wavelengths from radio waves to gamma rays. Radiation, in a broad sense, also encompasses electromagnetic waves and can refer to various types of waves such as radio waves, microwaves, and X-rays.
2. **Speed:** In a vacuum, both light and electromagnetic radiation travel at the speed of light, denoted as "c," which is approximately 3 x 10-8 meters per second.
3. **Energy Transfer:** Both light and certain types of radiation can transfer energy. For instance, sunlight (which is a form of electromagnetic radiation) carries energy from the Sun to the Earth.
4. **Electromagnetic Spectrum:** Both light and radiation are part of the electromagnetic spectrum, which is a continuum of all electromagnetic waves arranged by frequency or wavelength. The spectrum includes radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays.
5. **Particle Nature:** Light can also exhibit particle-like behavior, as described by the photon model. Similarly, certain types of radiation, such as X-rays and gamma rays, can be described as streams of particles called photons.
6. **Transverse Waves:** Both light and many forms of radiation are transverse waves, meaning that the oscillations occur perpendicular to the direction of wave propagation.
7. **Interaction with Matter:** Both light and radiation can interact with matter. For example, X-rays can penetrate soft tissues but are absorbed by denser materials like bones, leading to their use in medical imaging.

It's important to note that while there are similarities, there are also differences between various types of light and radiation, particularly in terms of their wavelengths, frequencies, and the ways they interact with matter.

What are some similarities between convection and radiation?

Convection and radiation are both modes of heat transfer, but they operate in different ways. Despite their differences, there are some similarities between the two:

1. **Transfer of Energy:** Both convection and radiation are mechanisms by which thermal energy is transferred from one place to another.
2. **No Medium Requirement:** Unlike conduction, which requires a material medium for heat transfer, both convection and radiation can occur in a vacuum or through a medium with low thermal conductivity.
3. **Natural Processes:** Both convection and radiation can occur naturally, without the need for external forces. For example, the sun emits heat through radiation, and the movement of fluids (liquids or gases) due to temperature differences is a natural convection process.
4. **Affected by Temperature Difference:** The rate of heat transfer in both convection and radiation is influenced by the temperature difference between the source and the surroundings. The greater the temperature difference, the more significant the heat transfer.
5. **Transport of Heat:** Both mechanisms involve the transport of heat from a region of higher temperature to a region of lower temperature, contributing to the equalization of temperatures over time.

It's important to note that while these similarities exist, the mechanisms and processes involved in convection and radiation are distinct:

- **Convection** involves the physical movement of a fluid (liquid or gas) to transfer heat. This movement can be natural (due to density differences caused by temperature variations) or forced (assisted by external means like a fan or pump).
- **Radiation** involves the transfer of energy through electromagnetic waves. This process doesn't require a material

medium for the transfer and can occur through a vacuum. Objects with a temperature above absolute zero emit thermal radiation.

Understanding these similarities and differences helps in comprehending how heat is transferred through different mechanisms in various situations.

What are some similarities between visible light and radiation?

Visible light and radiation both fall under the broader category of electromagnetic radiation, which is a form of energy that travels through space. Here are some similarities between visible light and other forms of electromagnetic radiation:

1. **Electromagnetic Nature:** Both visible light and other forms of radiation are manifestations of electromagnetic waves. They are composed of oscillating electric and magnetic fields that propagate through space.
2. **Speed of Light:** All electromagnetic waves, including visible light and other forms of radiation, travel at the speed of light in a vacuum, which is approximately 299,792 kilometers per second (186,282 miles per second).
3. **Wavelength and Frequency:** Electromagnetic waves vary in wavelength and frequency. Visible light consists of a specific range of wavelengths, roughly between 400 and 700 nanometers. Other forms of radiation, such as radio waves, microwaves, infrared radiation, ultraviolet radiation, X-rays, and gamma rays, have different ranges of wavelengths and frequencies.
4. **Energy Transfer:** Both visible light and other forms of radiation can transfer energy from one place to another. The amount of energy carried by an electromagnetic wave is directly proportional to its frequency.
5. **Travel through a Vacuum:** Both visible light and many other forms of electromagnetic radiation can propagate through a vacuum. This is because they do not require a medium (like air or water) for transmission; they can travel through empty space.
6. **Interaction with Matter:** Visible light and other forms of radiation can interact with matter. This interaction can include reflection, refraction, absorption, and transmission. Different materials may

exhibit different behaviors toward different wavelengths of electromagnetic radiation.

7. **Wave-Particle Duality**: Both visible light and other forms of radiation exhibit wave-particle duality. In certain experiments, they can behave as waves, while in others, they behave as particles (photons).

It's important to note that while there are similarities, there are also important differences between visible light and other forms of electromagnetic radiation, particularly in terms of their energy, effects on matter, and applications in various fields.

What is the nature of radiation?

Radiation refers to the emission or transmission of energy in the form of waves or particles through space or a material medium. There are several types of radiation, including electromagnetic radiation and particle radiation, each with its own characteristics.

1. **Electromagnetic Radiation:**
   - This type of radiation consists of oscillating electric and magnetic fields that travel through space at the speed of light.
   - The electromagnetic spectrum includes a wide range of frequencies and wavelengths, from low-frequency radio waves to high-frequency gamma rays.
   - Common examples of electromagnetic radiation include radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays.
2. **Particle Radiation:**
   - Particle radiation involves the emission of particles with mass from a radioactive source.
   - Common examples of particle radiation include alpha particles, beta particles, and neutrons.
   - Alpha particles consist of two protons and two neutrons and have a positive charge.
   - Beta particles can be either electrons (negatively charged) or positrons (positively charged).
   - Neutrons are neutral particles found in the nuclei of atoms.

Radiation can be categorized as ionizing or non-ionizing based on its ability to ionize atoms or molecules:

- **Ionizing Radiation:**
  - Has enough energy to remove tightly bound electrons from atoms, leading to the formation of ions.
  - Examples include X-rays, gamma rays, alpha particles, and beta particles.
  - Ionizing radiation is commonly used in medical imaging and cancer treatment but can be harmful in excessive doses.
- **Non-Ionizing Radiation:**
  - Lacks sufficient energy to ionize atoms or molecules.
  - Examples include radio waves, microwaves, and visible light.
  - Non-ionizing radiation is generally considered less harmful to living organisms, but prolonged exposure to high levels can still have biological effects.

It's important to note that while radiation has various applications, including medical diagnostics and treatments, industrial processes, and communication technologies, exposure to certain types of radiation, especially in high doses, can pose health risks and may require protective measures. Understanding the nature of different types of radiation is crucial for managing and mitigating potential risks.

What are phonons?

Phonons are quasiparticles or collective vibrational modes in a periodic crystal lattice. In simpler terms, they are the quantized units of vibrational energy associated with the lattice vibrations in a solid material, typically a crystal. These vibrations involve the motion of atoms or molecules within the crystal lattice.

In a crystal lattice, the constituent particles (atoms, ions, or molecules) are not static; they vibrate around their equilibrium positions. Phonons can be thought of as the quantized packets of these vibrational energy waves. They play a crucial role in understanding the thermal and mechanical properties of materials.

Here are some key points about phonons:

1. **Quantization of Vibrational Energy:** Phonons represent the quantization of vibrational energy in a crystal lattice. Just as photons are quantized units of light energy, phonons are quantized units of vibrational energy.
2. **Heat Conduction:** Phonons are closely associated with thermal conductivity in materials. The ability of a material to conduct heat is influenced by the movement of phonons through the lattice.
3. **Crystal Structure Influence:** The properties of phonons depend on the crystal structure of the material. Different crystal structures support different phonon modes.
4. **Dispersion Relations:** Phonons have dispersion relations, which describe how their energy and momentum depend on the wave vector. These relations help in understanding the behavior of phonons in a material.
5. **Role in Solid State Physics:** Phonons are a fundamental concept in solid-state physics and condensed matter physics. They are used to explain various phenomena, including thermal expansion, specific heat, and thermal conductivity in solids.

Understanding phonons is crucial for various areas of physics and materials science, including the design of materials for specific applications and the study of thermal and mechanical properties of solids.

Properties of radiation

Radiation refers to the emission or transmission of energy in the form of waves or particles. There are various types of radiation, including electromagnetic radiation and particle radiation, each with its own properties. Here are some general properties of radiation:

1. **Nature:**

- **Electromagnetic Radiation:** This includes visible light, radio waves, microwaves, infrared radiation, ultraviolet radiation, X-rays, and gamma rays. They all propagate through space at the speed of light.
- **Particle Radiation:** This involves the emission of subatomic particles such as alpha particles (helium nuclei), beta particles (electrons or positrons), and neutrons.

2. **Ionizing and Non-Ionizing:**

- **Ionizing Radiation:** This type of radiation has enough energy to remove tightly bound electrons from atoms, leading to the formation of ions. X-rays, gamma rays, and certain particles (alpha and beta particles) are ionizing.
- **Non-Ionizing Radiation:** This type of radiation does not have enough energy to ionize atoms. Examples include radio waves, microwaves, and visible light.

3. **Penetration:**

- **Penetrating Radiation:** Gamma rays and X-rays have high penetration abilities, capable of passing through materials like clothing and skin. This property makes them useful in medical imaging and industrial applications.
- **Less Penetrating Radiation:** Alpha particles, beta particles, and certain other forms of radiation have lower penetration abilities and can be stopped by materials like paper, plastic, or even human skin.

4. **Energy Levels:**

- **High Energy:** Gamma rays and X-rays have high energy levels and short wavelengths.
- **Low Energy:** Radio waves and microwaves have lower energy levels and longer wavelengths.

5. **Sources:**

- **Natural Sources:** Radiation is naturally present in the environment from sources like the sun, cosmic rays, and certain radioactive elements in the Earth's crust.
- **Man-Made Sources:** Activities such as nuclear power generation, medical procedures (X-rays, radiation therapy), and industrial processes can also contribute to radiation exposure.

6. **Health Effects:**

- Ionizing radiation can damage living tissues and cells, potentially leading to health issues such as radiation sickness, DNA damage, and an increased risk of cancer.
- Non-ionizing radiation is generally considered less harmful, with the main effects being thermal (heating) rather than direct ionization of atoms.

7. **Detection and Measurement:**

- **Geiger-Muller Counters:** Used to detect ionizing radiation.
- **Dosimeters:** Measure the absorbed dose of ionizing radiation.
- **Radiation Detectors:** Various devices are employed for different types of radiation, such as scintillation detectors for gamma rays.

Understanding the properties of radiation is crucial for managing its use in various fields and minimizing potential health risks

Detection of IR heat radiation

Infrared (IR) heat radiation detection is a technology commonly used in various applications, ranging from night vision and thermal imaging to industrial processes and medical diagnostics. There are several methods and devices for detecting IR heat radiation, each with its own principles and applications. Here are some common techniques:

1. **Thermal Imaging Cameras:**
- **Principle:** These cameras detect the infrared radiation emitted by an object due to its temperature. The higher the temperature, the more infrared radiation is emitted.
- **Application:** Used in various fields such as security, surveillance, firefighting, medical diagnostics, and industrial inspections.

2. **Infrared Sensors:**
- **Principle:** Infrared sensors, often based on pyroelectric or thermopile materials, detect changes in temperature and convert them into electrical signals.
- **Application:** Used in motion detectors, temperature sensors, and proximity sensors.

3. **Infrared Thermometers:**
- **Principle:** These devices measure the temperature of an object by detecting the infrared radiation it emits.
- **Application:** Commonly used in medical applications for non-contact temperature measurement, as well as in industrial processes and research.

4. **Infrared Gas Analyzers:**
- **Principle:** Used for measuring the concentration of certain gases that absorb infrared radiation. The amount of absorbed radiation is proportional to the gas concentration.
- **Application:** Environmental monitoring, industrial safety, and gas analysis.

5. **Infrared Pyrometers:**
- **Principle:** Measure the temperature of an object by detecting the infrared radiation emitted by the object's surface.
- **Application:** Used in industrial processes to measure the temperature of surfaces, such as molten metal or heated materials.

6. **Infrared Line Scanners:**

- **Principle:** These devices use infrared sensors to scan a line or area and create an image based on the infrared radiation emitted by objects.
- **Application:** Often used in industrial processes for quality control and monitoring.

7. **Infrared Detection for Security:**

- **Principle:** In security systems, infrared sensors can be used to detect the presence of people or objects based on their heat signatures.
- **Application:** Commonly used in burglar alarms, perimeter security, and motion detection systems.

These technologies leverage the fact that all objects with a temperature above absolute zero emit infrared radiation. The specific application will determine the type of device or sensor used for IR heat radiation detection.