THERMAL PHYSICS

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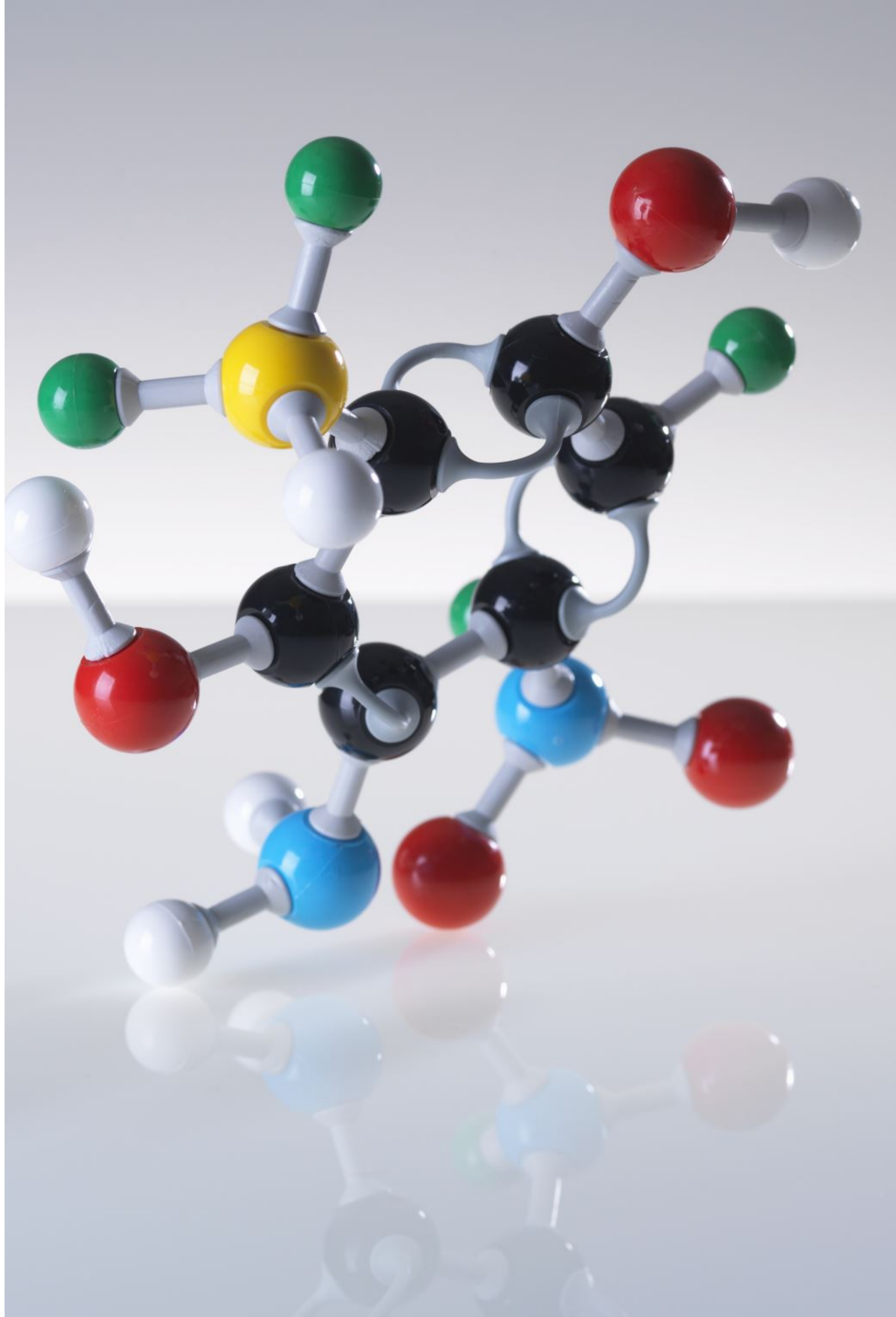
Thermal physics deals with the internal energy of objects due to the motion of the atoms and molecules comprising the objects, as well as the transfer of this energy from object to object, known as heat.

The internal energy of an object, known as its thermal energy, is related to the kinetic energy of all the particles comprising the object. The more kinetic energy the constituent particles have, the greater the object's thermal energy.



THERMAL PHYSICS PARAMETERS

1. MASS
2. WEIGHT
3. DENSITY
4. SPECIFIC VOLUME
5. SPECIFIC GRAVITY
6. TEMPERATURE
7. PRESSURE
8. HEAT

MASS AND WEIGHT

DEFINITION:

- Mass is the absolute quantity of matter in it.
- Weight is the force of gravity on the body.

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- <u>Weight</u> is the force of gravity on the body.

EXAMPLE:

If a man with a mass of 100 kg stands either on earth or on the moon, his mass remains constant. But regarding weight, his weight on earth will be different from his weight on the moon.

Why?

It's because weight depends on the gravity. So, if there is a change in gravity, there is also a change in weight.

SUMMARY OF FORMULA

FORMULA	NOTES
$W = \frac{mg}{k}$ where: W = weight m = mass g = gravity k = proportionality constant	$g = 9.8066 \frac{m}{s^2} \; (SI\,Unit)$ $g = 32.174 \frac{ft}{s^2} \; (English\,Unit)$ $k = 1 \frac{kg_m \cdot m}{N \cdot s^2} \; (SI\,Unit)$ $k = 32.174 \frac{lb_m \cdot ft}{lb_f \cdot s^2} \; (English\,Unit)$

COMPUTATION:

A ton of marble is shipped from Kantow where g = 9.8 m/s^2 to Bondok where g = 9.76 m/s^2.

1. What is its mass in Bondok in kg_m?
2. What is its weight in Kantow in N?
3. What is its weight in Bondok in N?

Solution:

1. The mass in Bondok,

$$m = 1 \text{ ton} \times \frac{1000\ kg_m}{1\ ton} = 1{,}000\ kg_m$$

2. The weight in Kantow,

$$W = \frac{mg}{k} = \frac{1{,}000\ kg_m\left(9.8\ \frac{m}{s^2}\right)}{1\ \frac{kg_m - m}{N - s^2}} = 9{,}800 \text{ N}$$

3. The weight in Bondok,

$$W = \frac{mg}{k} = \frac{1{,}000\ kg_m\left(9.76\ \frac{m}{s^2}\right)}{1\ \frac{kg_m - m}{N - s^2}} = 9{,}760 \text{ N}$$

DEFINITION:

- **Density** of any substance is its mass per unit volume.
- **Specific Volume** is the reciprocal of density.
- **Specific Weight** refers to the ratio of weight to the volume of a substance.
- **Specific Gravity** refers to the ratio of the density of a substance to the density of water.

SUMMARY OF FORMULA

FORMULA	NOTES
1. Density (ρ) $\rho = \frac{m}{V}$	$\rho_w = 1000\frac{kg_m}{m^3}\ (SI\ Unit)$ $\rho_w = 62.4\frac{lb_m}{ft^3}\ (English\ Unit)$ $\gamma_w = 9.8066\frac{kN}{m^3}\ (SI\ Unit)$ $\gamma_w = 62.4\frac{lb_f}{ft^3}\ (English\ Unit)$
2. Specific Volume (υ) $\upsilon = \frac{1}{\rho} = \frac{V}{m}$	
3. Specific Weight (ɣ) $\gamma = \frac{W}{V} = \frac{mg}{V} = \rho g$	
4. Specific Gravity (SG) $SG_s = \frac{\rho_s}{\rho_w}$	

COMPUTATION:

100 g of water is mixed with 150 g of alcohol (ρ = 790 kg_m/m^3). Determine the following:

a. The density of the mixture in kg_m/m^3.
b. The specific volume of the mixture in cm^3/g.
c. Specific Gravity of the mixture.

Solution

a. Density of the mixture, ρ_m

$$\rho_m = \frac{m_m}{v_m}$$

Solving for the mass of mixture, m_m

m_m = 100 g + 150 g = 250 g

Solving for the volume of the mixture, v_m

$v_m = v_{water} + v_{alcohol}$

$$v_{water} = \frac{m_w}{\rho_w} = \frac{100\ g\left(\frac{1\ kg}{1000\ g}\right)}{1000\ \frac{kg}{m^3}} = 1.0 \times 10^4\ m^3$$

$$v_{alcohol} = \frac{m_a}{\rho_a} = \frac{150\ g\left(\frac{1\ kg}{1000\ g}\right)}{790\ \frac{kg}{m^3}} = 1.9 \times 10^4\ m^3$$

$v_m = 1.0 \times 10^4\ m^3 + 1.9 \times 10^4\ m^3 = 2.90 \times 10^4\ m^3$

Therefore,

Therefore,

$$\rho_m = \frac{250\ g\left(\frac{1kg}{1000\ g}\right)}{2.90\ x\ 10^4\ m^3} = 862.45\ \text{kg/m}^3$$

b. Specific volume of the mixture

$$\nu = \frac{1}{\rho_m} = \frac{1}{862.45\ \frac{kg}{m^3}\ x\left(\frac{1\ m}{100\ cm}\right)^3\left(\frac{1000\ g}{1\ kg}\right)} = 1.16\ \text{cm}^3/\text{g}$$

c. Specific Gravity of the mixture,

$$SG = \frac{\rho_m}{\rho_w} = \frac{862.45}{1{,}000} = 0.86245$$

DEFINITION:

Pressure is the normal force acting on a unit area.

TYPES OF PRESSURE:

1. Atmospheric Pressure (P_{atm}) – is the pressure exerted by the atmosphere on any surface it comes in contact with. Standard atmospheric pressure at sea level is 1 atm.
2. Gauge Pressure (P_g) – is the intensity of pressure measured above or below atmospheric.
3. Absolute Pressure (P_{abs}) – is the intensity of pressure measured above the absolute zero pressure line.
4. Vacuum Pressure (P_v) – is the negative gauge pressure

Conversion of Units	
1 atm	101.325 kPa
	14.7 psi (lb_f/in^2)
	760 mm Hg
	29.92 in Hg
	1.0332 kg_f/cm^2
1 bar	100 kPa
1 torr	1 mm Hg

SUMMARY OF FORMULA

PRESSURE
1. **Absolute Pressure:** $$P_{abs} = P_{atm} + P_g$$
2. **Vacuum Pressure:** $$P_v = -P_g$$
3. Atmospheric Pressure" P = δh

COMPUTATION:

Sample Problem 1.2.3-1

Convert the following:

1. 150 kPaa to mm Hg_{gauge}
2. 12.5 psia to mm Hg_{vac}
3. 24 in Hg_{vac} to mm Hg_{abs} and kPaa
4. 6.5 psig to MPaa
5. 330 mm Hg_{gauge} to mm Hg_{abs} and kPag

Solution:

1. $P_{abs} = P_{atm} + P_g$

$150 \text{ kPaa} = 101.325 \text{ kPa} + P_g$

$P_g = 150 \text{ kPa} - 101.325 \text{ kPa} = 48.68 \text{ kPa}_g$

$Pg = 48.68 \text{ kPa}_g \times \dfrac{760 \ mm \ Hg}{101.325 \ kPa} = 365.09 \text{ mm Hg}_g$

2. $12.5 \text{ psia} = P_{atm} - P_{vac}$

$12.5 \text{ psia} = 14.7 \text{ psia} - P_{vac}$

$P_{vac} = 12.5 \text{ psia} - 14.7 \text{ psia} = -2.2 \text{ psi}_{vac}$

$P_{vac} = -2 \text{ psi} \times \frac{760\ mm\ Hg}{14.7\ psi} = 103.40 \text{ mm Hg}_{vac}$

3. $P_{abs} = P_{atm} - 24 \text{ in. Hg}_{vac}$

$P_{abs} = 29.92 \text{ in. Hg} - 24 \text{ in. Hg}$

$P_{abs} = 5.92 \text{ in. Hg}$

$P_{abs} = 5.92 \text{ in. Hg} \times \frac{101.325\ kPa}{29.92\ in\ Hg} = 20.05 \text{ in Hg}$

4. $P_{abs} = P_{atm} + 6.5$ psig

$P_{abs} = 14.7$ psi + 6.5 psig

$P_{abs} = 21.20$ psia

$P_{abs} = 21.20 \text{ psia} \times \frac{101.325\ kPa}{14.7\ psi} \times \frac{1\ MPa}{1000\ kPa} = 0.15$ MPaa

5. $P_{abs} = P_{atm} + 330$ mm Hg_g

$P_{abs} = 760$ mm Hg + 330 mm Hg_g

$P_{abs} = 1{,}090$ mm Hg

$P_{abs} = 1{,}090$ mm Hg

$P_g = 330 \text{ mm } Hg_g \times \frac{101.325\ kPa}{760\ mm\ Hg} = 44\ kPa_g$

DEFINITION:
TEMPERATURE IS THE DEGREE OF HOTNESS OR COLDNESS OF A BODY.

SUMMARY OF FORMULA

FORMULA	ABSOLUTE TEMPERATURE
$^\circ F = \frac{9}{5}{}^\circ C + 32$	$K = {}^\circ C + 273$
$^\circ C = \frac{5}{9}({}^\circ F - 32)$	$^\circ R = {}^\circ F + 460$

Convert the following:

1. $30^{\circ}C \longrightarrow {}^{\circ}R$
2. $90^{\circ}F \longrightarrow K$

Solution

1. t = 30 C, convert first to F,

$$F = \frac{9}{5}(30) + 32 = 86 \text{ F}$$

Then convert to R,

$$T = 86 + 460 = 546 \text{ R}$$

2. t = 90 F convert first to C,

$$t = \frac{5}{9}(90 - 32) = 32.22 \text{ C}$$

Then convert to K,

$$T = 273 + 32.22 = 305.22 \text{ K}$$

HEAT (Q)

HEAT is the energy transferred from one object to another due to their temperature difference.

Where:

- Q = Heat in Joule, Calorie
- m = mass in grams
- c = specific heat capacity, J/g-°C
- ΔT = Change in Temperature

1 cal = 4.184 Joule

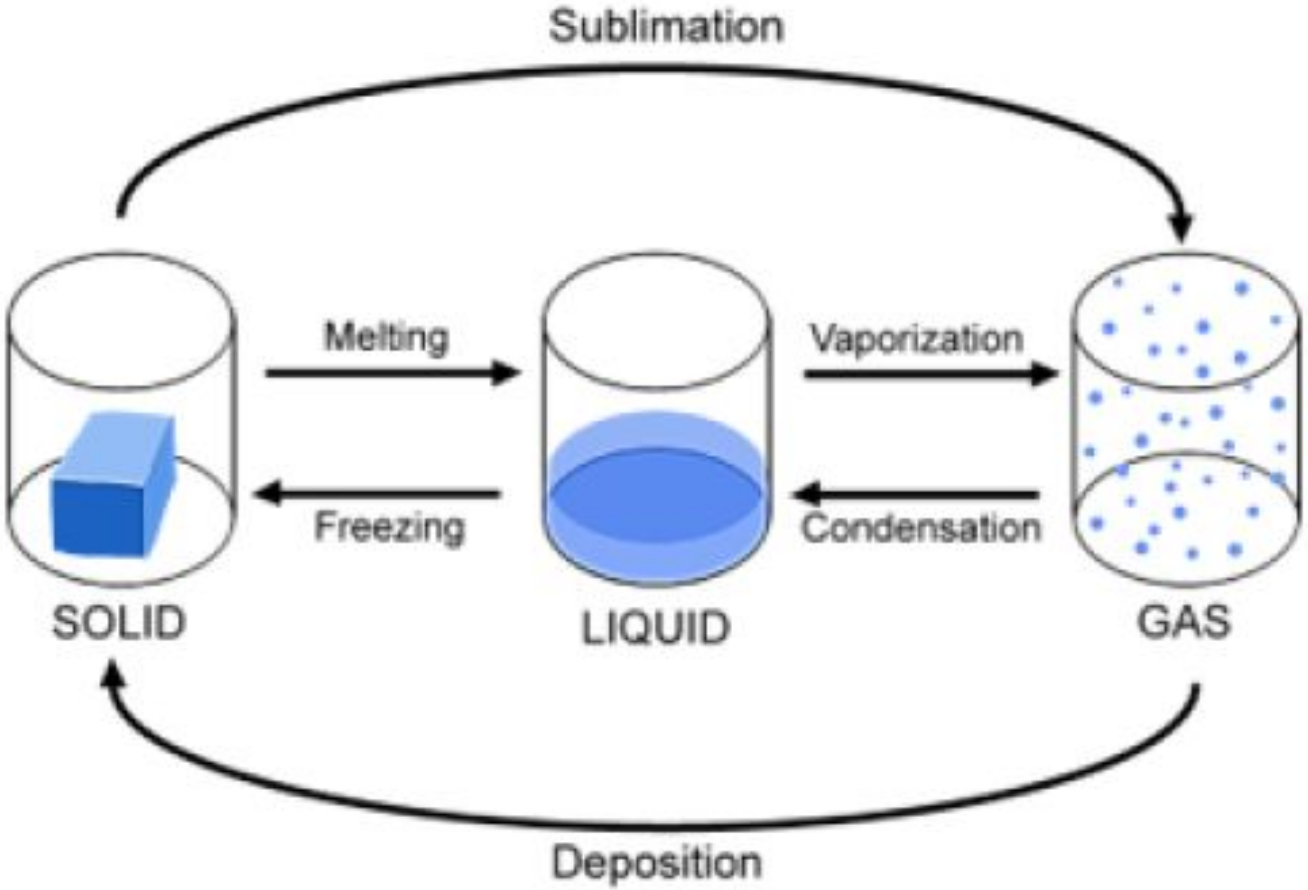
Heat in Thermodynamics

- Heat is a fundamental concept in thermodynamics, representing the transfer of thermal energy between systems due to a temperature difference. It plays a crucial role in various engineering applications, particularly in marine engineering, power plants, and refrigeration systems.

- Understanding heat transfer mechanisms and the different forms of heat—latent heat, sensible heat, and total heat—is essential for solving thermodynamic problems efficiently.

A **phase change** is when matter changes to from one state (solid, liquid, gas) to another. These changes occur when sufficient energy is supplied to the system and also occur when the pressure on the system is changed. The temperatures and pressures under which these changes happen differ depending on the chemical and physical properties of the system.

Phase changes are physical changes that take place when matter changes energy states, but chemical bonds are not broken or formed.



Methods of Phase Change

Melting - The transition from the solid to the liquid phase

Freezing or Solidifying - The transition from the liquid phase to the solid phase

Vaporization - The transition from the liquid phase to the gas phase

Condensation - The transition from the gas phase to the liquid phase

Sublimation - The transition from the solid phase to the gas phase

Deposition - The transition from the gas phase to the solid phase

During the melting or fusion process, the temperature on which the solid substance is about to change into liquid is called **melting point.**

The temperature at which liquid changes is **boiling point** on the process call **boiling.**

Freezing point is the temperature where liquid is about to solidify

Endothermic Process is when heat energy is added to or absorbed by a substance where at instance the increasing heat is causing the speed of molecules to move faster such as in melting, vaporization, and sublimation.

Exothermic Process is when heat energy is removed to or released by a substance where at instance the decreasing heat is causing the speed of molecules to move slower such as in freezing, condensation and deposition.

During the phase change, that heat energy that cause change in temperature is called **sensible heat** and the heat energy that cause change in phase is called **latent heat.**

Latent Heat of Fusion is involved when the change occurs between the solid and liquid phases in either direction.

Latent heat of vaporization is involved when the change occurs between the liquid and vapor phase.

Forms of Heat in Thermodynamics

1. Sensible Heat
2. Latent Heat
3. Total Heat

Forms of Heat in Thermodynamics

1. Sensible Heat

- Sensible heat is the heat energy added to or removed from a substance that results in a change in temperature but does not alter its phase (solid, liquid, or gas). This type of heat can be measured using a thermometer.

Forms of Heat in Thermodynamics

1. Sensible Heat

Mathematical Expression

$$Q = mc\Delta T$$

where:

- Q = Sensible heat (Joules or Calories)
- m = Mass of the substance (kg)
- c = Specific heat capacity ($J/kg \cdot K$)
- ΔT = Change in temperature ($T_f - T_i$)

Sensible Heat

Example Problem:

A 5 kg sample of water is heated from 20°C to 80°C. If the specific heat capacity of water is 4.186 kJ/kg·K, calculate the sensible heat required.

Solution:

$$Q = (5\ \mathrm{kg})(4.186\ \mathrm{kJ/kg}\backslash\mathrm{cdotpK})(80^\circ C - 20^\circ C)$$

$$Q = (5)(4.186)(60)$$

$$Q = 1255.8\ \mathrm{kJ}$$

Thus, **1255.8 kJ** of heat energy is required.

2. Latent Heat

- Latent heat is the heat absorbed or released by a substance during a phase change (e.g., melting, vaporization) without a change in temperature.

Latent Heat

Types of Latent Heat

Latent Heat of Fusion (L_f)

- Heat required to change a substance from solid to liquid at constant temperature.

Latent Heat of Vaporization (L_v)

- Heat required to change a substance from liquid to gas at constant temperature.

Latent Heat

Mathematical Expression: $$Q = mL$$

where:

- Q = Latent heat (Joules or Calories)
- m = Mass of the substance (kg)
- L = Latent heat of fusion or vaporization (J/kg)

Latent Heat

Example Problem:
How much heat is required to convert 2 kg of water at 100°C to steam at 100°C? The latent heat of vaporization of water is 2260 kJ/kg.

Solution:

$$Q = (2\ \mathrm{kg})(2260\ \mathrm{kJ/kg})$$

$$Q = 4520\ \mathrm{kJ}$$

Thus, **4520 kJ** of heat is required.

Sample Problem 1

How much heat is needed to liquefy 1.5 kg of solid aluminum if it has a specific heat of 399 KJ/Kg?

Given: $L_f = 399\ KJ/Kg$ $m = 1.5\ Kg$

Find: $Q_f = ?$

Solution:

$$Q_f = m \cdot L_f$$

$$= (1.5\ kg)(399\ KJ/Kg)$$

$$= 598.5\ KJ$$

Sample Problem 2

Determine the amount of heat absorbed by 2.6 kg water to change phase from liquid to vapor (steam). Specific heat of vaporization for water = 2260 KJ/Kg

Given: $L_v = 2260\ KJ/Kg$ $m = 2.6\ Kg$

Find: $Q_v = ?$

Solution: $Q_v = m \cdot L_v$

$= (2.6\ kg)(2260\ KJ/Kg)$

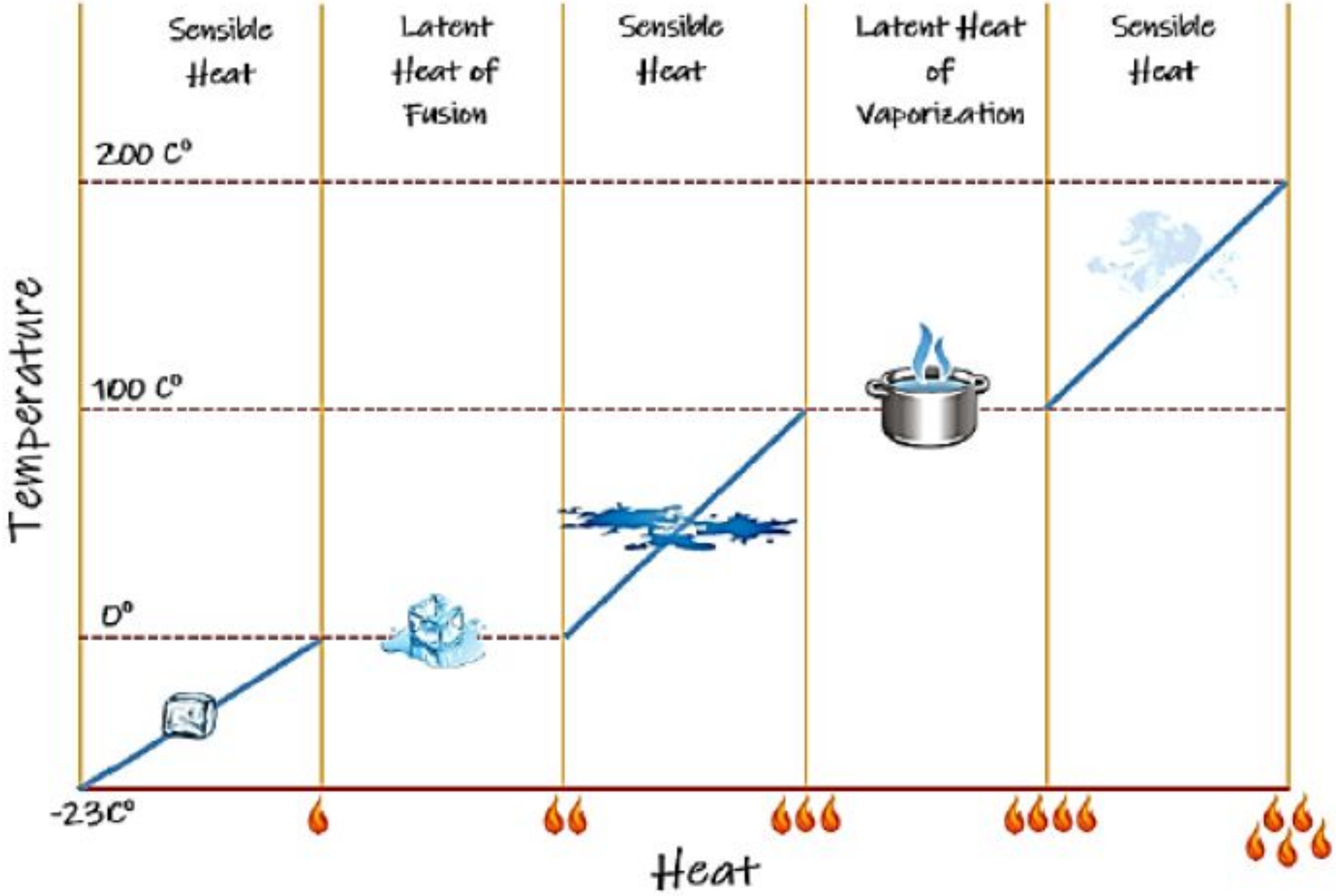
$= 5876\ KJ$

3. Total Heat (Enthalpy Change)

- Total heat is the sum of the sensible heat and latent heat required to change the temperature and phase of a substance.

Mathematical Expression: $$Q_{\text{total}} = mc\Delta T + mL$$

where the first term represents the sensible heat and the second term represents the latent heat.


Sensible Heat
Latent Heat of Fusion
Sensible Heat
Latent Heat of Vaporization
Sensible Heat
200 C°
100 C°
0°
-23C°
Temperature
Heat

Total Heat (Enthalpy Change)

Example Problem:

A 3 kg block of ice at -10°C is heated to steam at 100°C. The specific heat capacity of ice is 2.1 kJ/kg·K, of water is 4.186 kJ/kg·K, and the latent heat of fusion and vaporization are 334 kJ/kg and 2260 kJ/kg, respectively. Calculate the total heat required.

Solution:

1. Heat to raise temperature of ice (-10°C to 0°C):

$$Q_1 = (3)(2.1)(10) = 63 \text{ kJ}$$

2. **Heat to melt ice at 0°C:**

$$Q_2 = (3)(334) = 1002 \text{ kJ}$$

3. **Heat to raise temperature of water (0°C to 100°C):**

$$Q_3 = (3)(4.186)(100) = 1255.8 \text{ kJ}$$

4. **Heat to convert water to steam at 100°C:**

$$Q_4 = (3)(2260) = 6780 \text{ kJ}$$

Total Heat Required:

$$Q_{\text{total}} = Q_1 + Q_2 + Q_3 + Q_4$$

$$Q_{\text{total}} = 63 + 1002 + 1255.8 + 6780$$

$$Q_{\text{total}} = 9100.8 \text{ kJ}$$

Thus, **9100.8 kJ** of heat is required.

Thermal Expansion of Materials

LEARNING OUTCOME

Explain the effect of thermal expansion/ contraction on different materials due to change of temperature.

Thermal Expansion

What is thermal expansion?

- Thermal expansion is the increase in length, area, and volume of materials when they are subjected to an increase in temperature.

- It occurs because of the increase in particle-to-particle distances between its atoms and molecules as the result of an increase in their average kinetic energies.

How does thermal expansion of water work?

- Thermal expansion of water occurs when the temperature change from **4 degrees Celsius** to **0 degrees Celsius**. Instead of contracting like other substances, water expands and its density decreases, as demonstrated by ice floating on water.
- Above the temperature of 4 degrees Celsius, it behaves similarly to other substances/materials.

Why is Thermal Expansion Important?

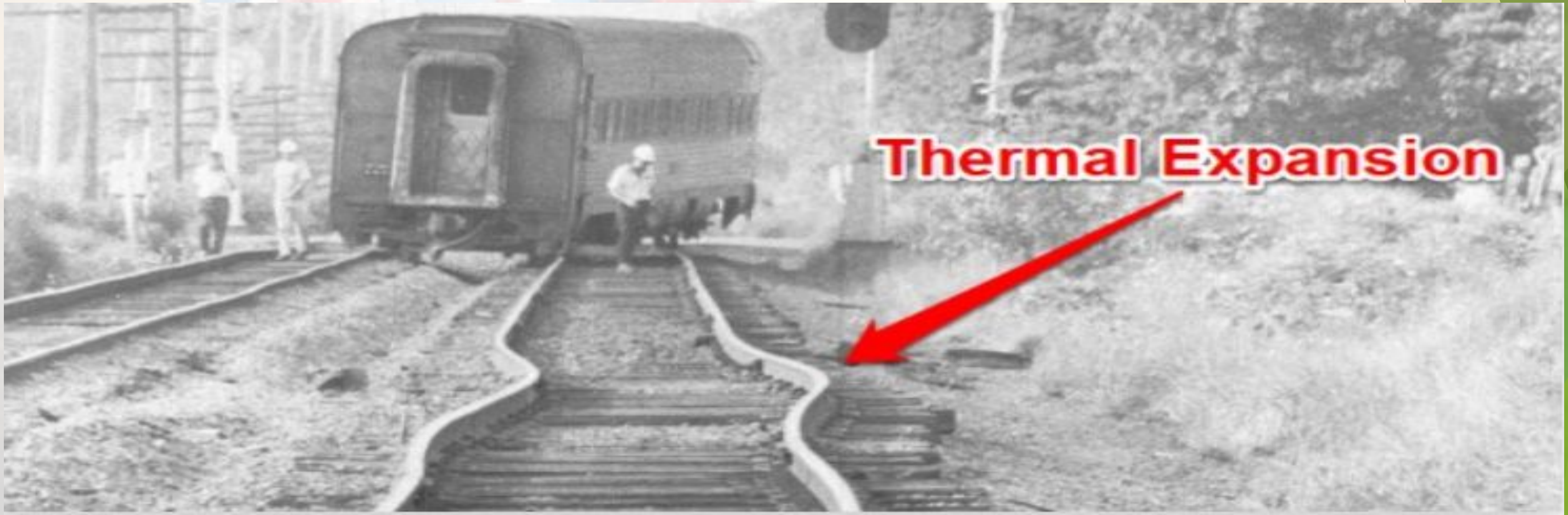
Thermal expansion is important because it can affect your measurement results. Furthermore, it can affect the quality of your customer's measurement results.

In a world where tighter tolerances are in demand, thermal expansion errors could have a significant effect on meeting specifications.

When you neglect to consider its effects, you provide your customers with bad measurement results that could affect the quality of their products and services. Additionally, disregarding these errors can increase your risk of encountering a false-accept or false-reject in your **conformance statements.**

Why is Thermal Expansion Important?

- Depending on your customer's business activities, bad measurement results could increase their risk of problems, damages, and unplanned downtime. Even worse, it could impact the health and safety of people.
- According to a recent study by Vanson Bourne, **23% of all unplanned downtime in manufacturing is the result of human error.**



Why is Thermal Expansion Important?

It can affect the following measurements:

- **Pressure** - changes in volume and area
- **Torque** - changes in radius
- **Flow** - changes in volume and area
- **Speed/Velocity** - changes in length/distance
- **Energy** - changes in length/distance
- **Volume** - changes in length, width, and height
- **Area** - changes in length and width

How to Reduce Thermal Expansion?

There are several ways to reduce the effect of thermal expansion. You can try to:

- Reduce contact with/exposure to heat sources,
- Control the environment,
- Allow thermal stabilization, and/or
- Correct for thermal expansion

Thermal Expansion of Solid

Applications of Thermal Expansion of Solids

1. **The gap between two consecutive rails:** There is expansion and contraction of rail tracks in summer and winter respectively.

2. **Removing Tight Lids of Glass jar to open the tight lids**, it is immersed in hot water for a minute, and then the metal cap expands and becomes loose.

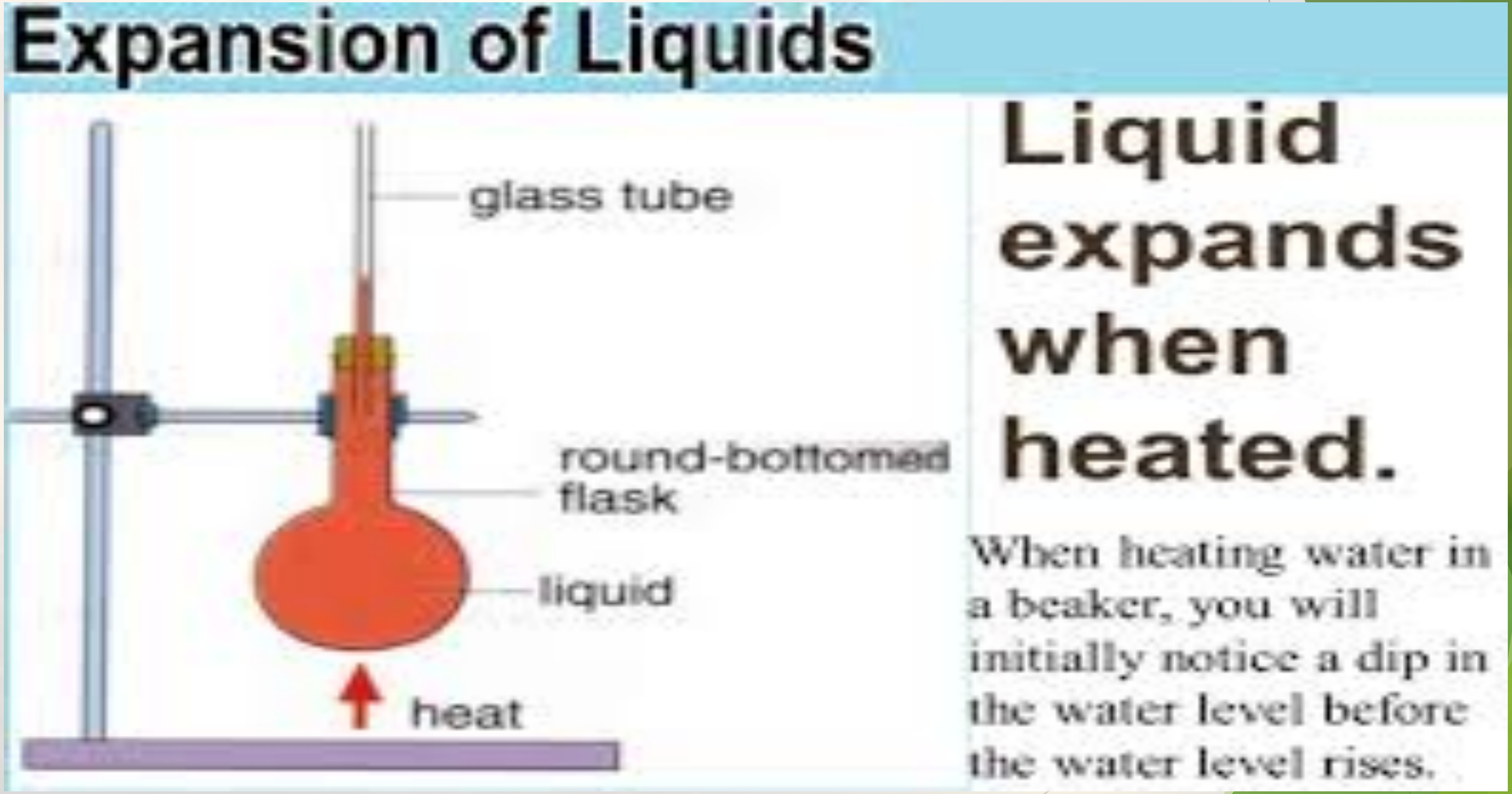
Applications of Thermal Expansion of Solids

3. **Hot milk is poured into a thick-walled glass vessel:** When the milk is poured into a thick-walled glass vessel at room temperature, the vessel's inner surface expands while the outer surface remains at room temperature.

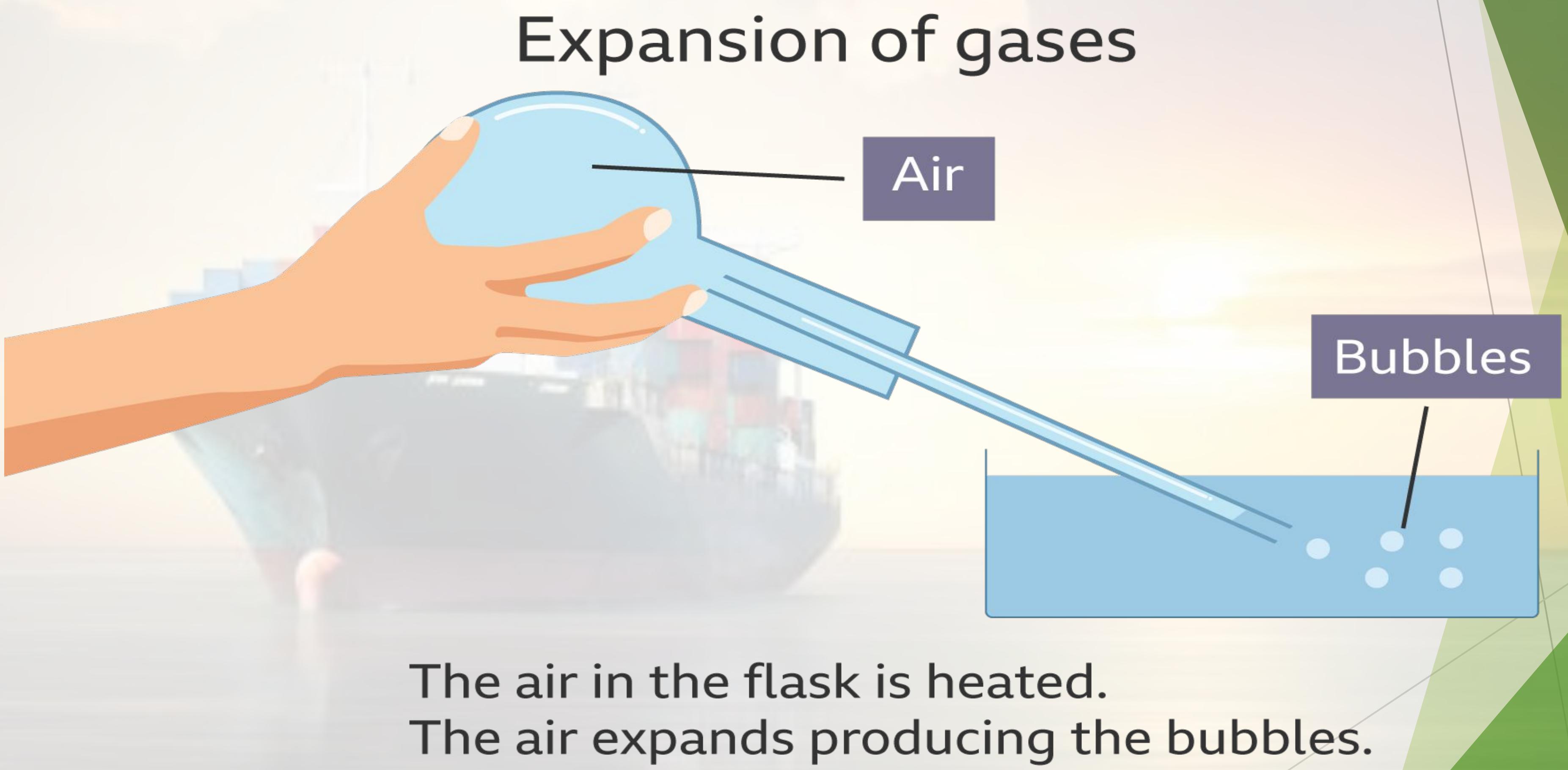
4. **Design of AirCraft:** The expansion in aircraft is 15-25 centimeters during its flight due to an increase in temperature.

5. **Thick bottles for soft drinks:** The walls of a bottle of soft drinks are made very thick to avoid bursting as the bottle contains gas.

Thermal Expansion of Liquid



Thermal Expansion of Gases



Types of Expansion

1. **Linear expansion** - Change in length.
2. **Area expansion** - Change in area.
3. **Volume expansion** - Change in volume.

Linear Expansion Formula

The formula for linear expansion is mathematically stated as.

$$\Delta L = L_o \alpha_L \Delta T$$

Where,

L_o = original length

α_L = length expansion coefficient

ΔT = temperature difference

ΔL = change in length

Coefficient of Linear Expansion Formula

It is defined as the change in length per unit length per degree Celsius of temperature change. The coefficient of linear expansion depends on initial length and change in temperature. The formula of coefficient of linear expansion formula can be written as

$$\alpha_L = \frac{\Delta L}{L_0 \Delta T}$$

The S.I. unit of coefficient of linear expansion is 1/°C or 1/K.

Area Expansion Formula

The formula for volume expansion is given as follows
:

$$\Delta A = A_o \alpha_A \Delta T$$

Where,

A_o = original area

α_A = area expansion coefficient

ΔT = temperature difference

ΔA = change in area

Coefficient of Area Expansion Formula

The formula of coefficient of area expansion formula can be written as

$$\alpha_A = \frac{\Delta A}{A_0 \Delta T}$$

Coefficient of volume expansion formula

The formula of coefficient of volume expansion formula can be written as

$$\alpha_V = \frac{\Delta V}{V_0 \Delta T}$$

Volume Expansion Formula

The formula for volume expansion is given as follows :

$$\Delta V = V_o \alpha_V \Delta T$$

Where,

V_o = original volume

α_V = volume expansion coefficient

ΔT = temperature difference

ΔV = change in volume

Thermal Expansion Formula Solved Examples

Example 1

The length of an object is 10 m, and it is heated to a temperature difference of 40°C. If the length expansion coefficient is 11×10^{-26}, find the change in length.

Thermal Expansion Formula Solved Examples

Example 2

The area of an object is $20m^2$ and it is heated to a temperature difference of 20°C. If the area expansion coefficient is 8×10^{-6}. Find the change in the area.

Thermal Expansion Formula Solved Examples

Example 3

The volume of an object is 10m^3 and it is heated to a temperature difference of 30°C. If the area expansion coefficient is 9×10^{-6} . Find the change in the volume.

Thermal contraction

- refers to the decrease in the **volume** or **size** of a material when its temperature is lowered.

- This phenomenon is the opposite of thermal expansion, where a material expands when heated.

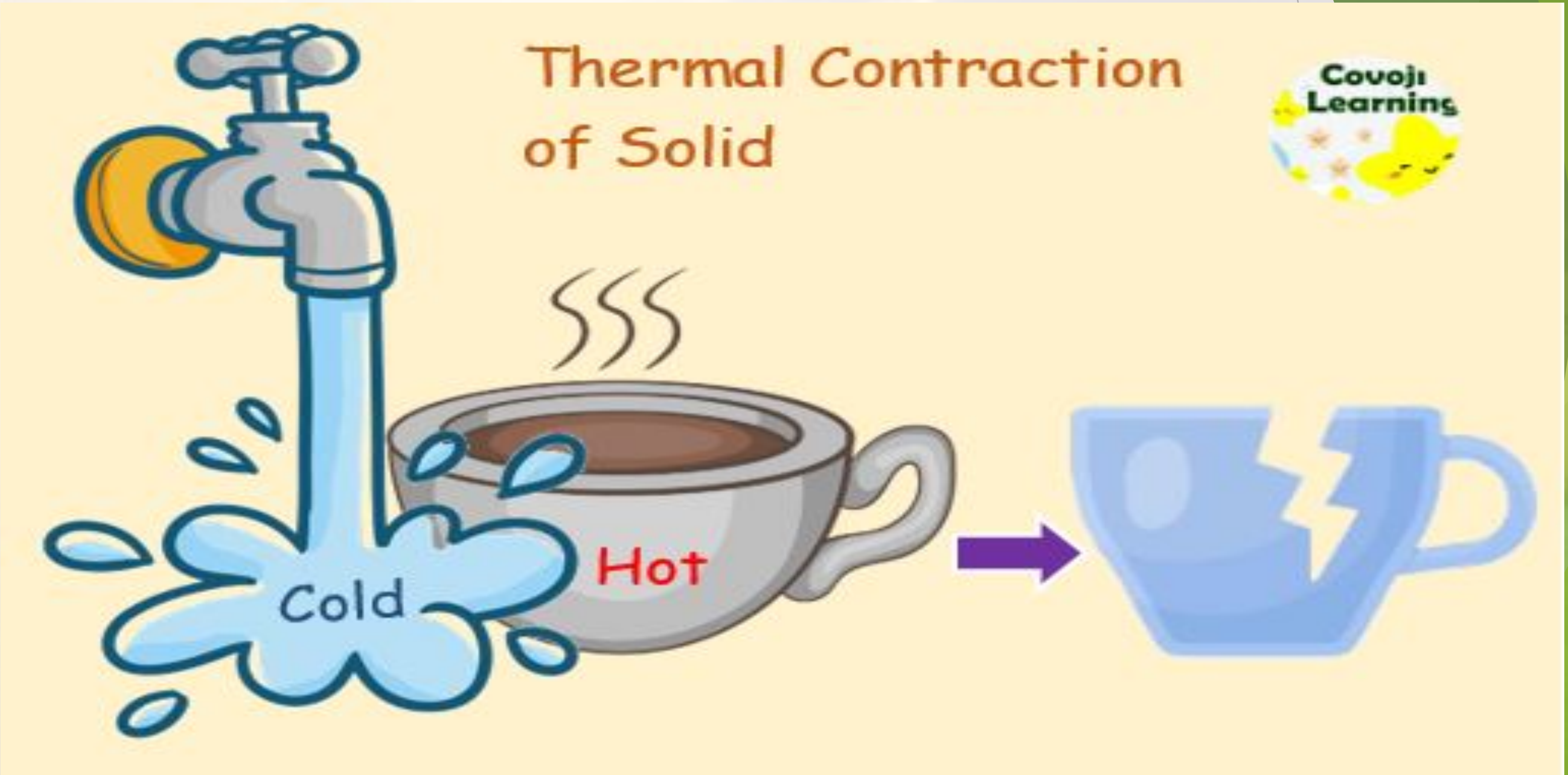
Thermal Contraction

- A balloon's volume will decrease when exposed to colder tempearatures

Example Thermal Contraction

- **Metals**: When metal objects cool, they shrink. For example, cooling steel contracts the metal, which must be taken into account when designing steel structures.
- **Water:** Water has a unique property—it expands when cooled from 0°C to 4°C, and only contracts when it freezes, which is why ice floats on water.

Thermal Contraction of Solid



Thermal Contraction of Liquid

Thermal Contraction of Gas

Thermal Expansion and Contraction

- Thermal expansion - the INCREASE in volume of a substance when its temperature is **raised.**
- Thermal contraction - the DECREASE in volume of a substance when its temperature is **lowered.**

Can you use the concepts of thermal expansion and contraction to explain how a thermometer works?

Thermal Expansion and Contraction

Expansion and Contraction

- When things heat up:
  - 1-The atoms speed up
  - 2- The atoms move further apart from each other
  - 3- The object expands (gets bigger)
  - 4- Diffusion happens faster.

Thermal Expansion and Contraction Examples

- Gasoline can drip or overflow from a freshly-filled metal tank on a hot day. As the temperature increases, both the tank and the gasoline expand, but the gasoline expands more than the metal tank (**e.g. steel)**. This causes the gasoline to overflow or drip from the container.

Thermal Expansion and Contraction Examples

- Power lines also sag during summer due to thermal expansion. It is also possible for them to break during winter if there is no allowance for them to contract.

Thermal Expansion and Contraction Examples

- Railroad tracks and metal bridges buckle during summer due to thermal expansion, especially if there is a lack of expansion joints to allow them to freely contract and expand.

An example of expansion joints in a bridge

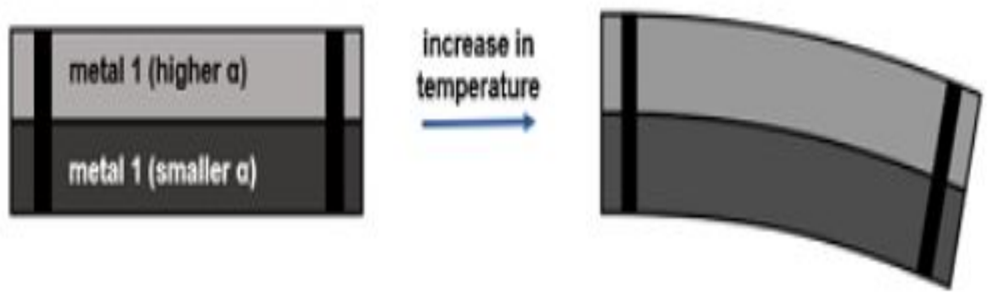
Thermal Expansion and Contraction Examples

- Glass materials used in cooking can also break if they are repeatedly subjected to hot and cold temperatures. Pyrex glass materials are commonly used in laboratories since they have a smaller thermal coefficient, allowing them to expand and contract at only a very small rate.

Pyrex glass is used in laboratory equipment and cookware because of its small coefficient of linear expansion.

Thermal Expansion and Contraction Examples

- **Bimetallic strips** which are commonly found in thermostats, contain two metals with different coefficients of linear expansion. One side of the strip expands more than the other one such that, when the temperature gets too high, the strip bends and cuts the circuit. The strip returns to its original position when the temperature slowly decreases.



Bimetallic strips are composed of two metals with different coefficients of linear expansion.

IDEAL GAS LAWS AND SPECIFIC HEAT

EXPLANATION:

This equation shows the relationship between the different properties of an ideal gas.

$$PV = mRT$$

where:

P = Pressure

V = Volume

m = mass

R = gas constant

T = Temperature

Gas Constants; Specific Heats at Low Pressure

Gas	c_p Btu/lb•R°	c_v Btu/lb•R°	c_p kJ/kg•K°	c_v kJ/kg•K°	k	R ft.lb/lb•°R	R J/kg•K
Argon (A)	0.1244	0.0747	0.5215	0.3152	1.666	38.68	208.17
Helium (He)	1.241	0.745	5.2028	3.1233	1.666	386.04	2077 67
Mercury (Hg)	0.0248	0.0148	0.1039	0.0624	1.666	7.703	41.45
Neon (Ne)	0.246	0.1476	1.0313	0.6188	1.666	76.57	412.10
Air	0.24	0.1714	1.0062	0.7186	1.4	53.342	287.08
Carbon monoxide (CO)	0.2487	0.1778	1.0426	0.7454	1.399	55.170	296.92
Hydrogen (H_2)	3.419	2.434	14.3338	10.2043	1.40	766.54	4125.52
Nitrogen (N_2)	0.2484	0.1775	1.0414	0.7442	1.399	55.158	296.86
Oxygen (O_2)	0.2194	0.1573	0.9198	0.6595	1.395	48.291	259.90
Carbon dioxide (CO_2)	0.2016	0.1565	0.8452	0.6561	1.288	35.11	188.96
Ammonia (NH_3)	0.499	0.382	2.0920	1.6015	1.304	90.73	488.31
Methane (CH_4)	0.5099	0.3861	2.1377	1.6187	1.321	96.33	518.45

SUMMARY OF FORMULA

FORMULA	NOTES
1. Ideal gas equation $PV = mRT$	$R_{air} = 0.28708 \frac{kJ}{kg_m \cdot K}$ $(SI\,Unit)$ $R_{air} = 53.34 \frac{lb_f \cdot ft}{lb_m \cdot {}^\circ R} (English Unit)$
2. Gas constant $R = \frac{\dot{R}}{MW}$	$\dot{R} = 8.314 \frac{kJ}{kg_{mol} \cdot K}$ $(SI\,Unit)$ $\dot{R} = 1545 \frac{lb_f \cdot ft}{lb_{mol} \cdot {}^\circ R}$ $(English\,Unit)$

Sample Problem 3.1-1:

Determine the mass of air in kg_m inside a room with a temperature of 22°C and a pressure of 101.325 kPa. The dimensions of the room are 12m x 14m x 3.5m.

Solution:

Using PV = mRT

$$m = \frac{PV}{RT}$$

R = 0.28708 kJ/kg - K

P = 101.325 + 101.325 = 202.65 KPaa

T = 273 + 22 = 295 K

V = 12 m x 14 m x 3.5 m = 588 m^3

Therefore,

$$m = \frac{\left(202.65\ \frac{kN}{m^2}\right)(588\ m^3)}{\left(0.28708\ \frac{kJ}{kg-K}\right)(295\ K)}$$

m = 1,407.016 kg

Sample Problem 3.1-2:

A tire contains 3730 in^3 of air at 32 psig and 80°F. Determine the mass of air in the tire in lb_m.

Solution:

Using PV = mRT

$$m = \frac{PV}{RT}$$

R = 53.342 lb_f-ft/lb_m-R

P = 32 + 14.7 = 46.7 psi

T = 460 + 80 = 540 R

V = 3730 in^3

Therefore,

$$m = \frac{\left(46.7\ \frac{lb_f}{in^2}\right)\left(\frac{144\ in^2}{1\ ft^2}\right)\left(3730\ in^3\right)\left(\frac{1\ ft}{12\ in}\right)^3}{\left(53.342\ \frac{lb_f-ft}{lb_m-R}\right)\left(540\ R\right)}$$

m = 0.504 lb

1. Boyle's Law

-If the temperature is constant, volume of gas varies inversely with the absolute pressure.

2. Charles' Law

-If the pressure is constant, volume varies directly with the absolute temperature.

3. Gay-Lussac's Law

-If the volume is constant, absolute pressure varies directly with the absolute temperature.

4. Combined Gas Law

- No constant variable.

<table>
<tr><th>FORMULA</th><th>NOTES</th></tr>
<tr><td>1. Boyle's Law

$P_1V_1 = P_2V_2$</td><td rowspan="4">where:

P = absolute pressure

V = volume

T = absolute temperature</td></tr>
<tr><td>2. Charles' Law

$\frac{V_1}{T_1} = \frac{V_2}{T_2}$</td></tr>
<tr><td>3. Gay-Lussac's Law

$\frac{P_1}{T_1} = \frac{P_2}{T_2}$</td></tr>
<tr><td>4. Combined Gas Law

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$</td></tr>
</table>

Sample Problem 3.2-1

An ideal gas undergoes a process where its initial pressure of 200 kPa gauge was decreased by 70 kPa gauge. Its temperature was decreased from 30°C to 18°C. Compute the resulting volume in m^3 if its initial volume is 2.5 m^3.

Solution:

$P_1 = 200\ kPa_g + 101.325 = 301.325 kPa$

$P_2 = 200 - 70 = 130\ kPa_g + 101.325 = 231.325\ kPa$

$T_1 = 30\ C + 273 = 303\ K$

$T_2 = 18\ C + 273 = 291\ K$

$V_1 = 2.5\ m^3$

$V_2 = ?$

Using the relationship,

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{(301.325\ kPa)(2.5\ m^3)}{303\ K} = \frac{(231.325\ kPa)(V_2)}{291\ K}$$

$V_2 =$ ___________ m^3

Sample Problem 3.2-2

A closed vessel contains air at a pressure of 140 kPag and a temperature of 20°C. Find the final gauge pressure in psi if the air is heated at constant volume to 100°C. The atmospheric pressure is 28 in. Hg.

Solution:

$$P_{atm} = 28 \text{ in. Hg} \left(\frac{101.325\ kPa}{29.92\ in\ Hg}\right) = 94.82 \text{ kPa}$$

$$P_1 = 140 \text{ kPa}_g + 94.82 \text{ kPa} = 234.82 \text{ kPa}$$

$$T_1 = 20 + 273 = 293 \text{ K}$$

$$P_2 = ?$$

$$T_2 = 100 + 273 = 373 \text{ K}$$

Since V = constant

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{234.82\ kPa}{293\ K} = \frac{P_2}{373\ K}$$

$$P_2 = 298.93 \text{ kPaa}$$

$$P_2 = 298.93 - 94.82 = 204.11 \text{ kPa}_g$$

- Specific heat (c)
- The **specific heat** is the amount of **heat** per unit mass required to raise the temperature by one degree Celsius.
- The relationship does not apply if a phase change is encountered- why

Names of Gases.	Specific Heat under Const. Press.	Specific Heat at Const. Vol.
Atmospheric Air, ...	1.000	0.700
Hydrogen Gas, ...	0.903	0.603
Carbonic Acid, ...	1.258	0.958
Oxygen, ...	0.976	0.676
Nitrogen, ...	1.000	0.700
Protoxide of Nitrogen, . . .	1.350	1.050
Olefiant Gas, ...	1.553	1.253
Oxide of Carbon, ...	1.034	0.734

$$Q = cm\Delta T$$

Q: heat added; c: specific heat; m: mass; ΔT: change in temperature

Substance	c/J kg^{-1} K^{-1}	Substance	c/J kg^{-1} K^{-1}
Aluminium	900	Ice	2100
Iron/steel	450	Wood	1700
Copper	390	Nylon	1700
Brass	380	Rubber	1700
Zinc	380	Marble	880
Silver	230	Concrete	850
Mercury	140	Granite	840
Tungsten	135	Sand	800
Platinum	130	Glass	670
Lead	130	Carbon	500
Hydrogen	14000	Ethanol	2400
Air	718	Paraffin	2100
Nitrogen	1040	Water	4186
Steam	2000	Sea water	3900

Specific Heat

- **Note**: It is easy to change the temperature of some things (e.g. air) and hard to change the temperature of others (e.g. water, block of steel)
- The amount of heat (Q) added into a body of mass m to change its temperature an amount is given by

$$Q = m.C.\Delta T = m.C.(T_f - T_i)$$

C is called the specific heat and depends on the material

Note: Temperature in either Kelvin or Celsius

The **heat capacity** C of an object is the proportionality constant between the heat Q that the object absorbs or loses and the resulting temperature change ΔT of the object

$$C = \frac{Q}{m\Delta T} = \left(\frac{cal}{g^oC}\right) = \left(\frac{J}{kg^oC}\right)$$

 # It is important to distinguish the heat transfer is done with constant volume or constant pressure
The specific heat is different for different processes, particular for gases

THANK YOU!!