1. Details of Module and its structure

Module Detail	
Subject Name	Physics
Course Name	Physics 02 (Physics Part 2,Class XI)
Module Name/Title	Unit 7, Module 12, Thermal Energy and Temperature Chapter11, Thermal Properties of Matter
Module Id	keph_201101_eContent
Pre-requisites	Heat energy, hot and cold, states of matter
Objectives	After going through this module the students will be able to: • Identify thermal properties of matter • Recognize that internal energy is 'the Heat energy' • Understand that temperature indicates the heat energy of a system • Know principles of working of thermometers
Keywords	Heat, temperature, thermometers

2. Development Team

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1. UNIT SYLLABUS

UNIT 7: PROPERTIES OF BULK MATTER: 24 periods

Chapter–9: Mechanical Properties of Solids:

Elastic behaviour, Stress-strain relationship, Hooke's law, Young's modulus, bulk modulus, shear, modulus of rigidity, Poisson's ratio, elastic energy.

Chapter–10: Mechanical Properties of Fluids:

Pressure due to a fluid column; Pascal's law and its applications (hydraulic lift and hydraulic brakes). Effect of gravity on fluid pressure. Viscosity, Stokes' law, terminal velocity, streamline and turbulent flow, critical velocity, Bernoulli's theorem and its applications. Surface energy and surface tension, angle of contact, excess of pressure across a curved surface, application of surface tension ideas to drops, bubbles and capillary rise.

Chapter–11: Thermal Properties of Matter:

Heat, temperature, thermal expansion; thermal expansion of solids, liquids and gases, anomalous expansion of water; specific heat capacity; Cp, Cv - calorimetry; change of state - latent heat capacity. Heat transfer-conduction, convection and radiation, thermal conductivity, qualitative ideas of Blackbody radiation, Wien's displacement Law, Stefan's law, Greenhouse effect.

2. MODULE-WISE DISTRIBUTION OF UNIT SYLLABUS 17 MODULES

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Module 3	• Searle's apparatus • Experiment to determine Young's modulus of the material of a wire in the laboratory • What do we learn from the experiment?
Module 4	• Volumetric strain • Volumetric stress • Hydraulic stress • Bulk modulus K • Fish, aquatic life on seabed, deep sea diver suits and submarines
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	clamped meter scale loaded at i) its ends ii) in the middle • Height of sand heaps, height of mountains
Module 6	• Fluids-liquids and gases • Stationary and flowing fluids • Pressure due to a fluid column • Pressure exerted by solids, liquids and gases • Direction of Pressure exerted by solids, liquids and gases
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Module 9	• Bernoulli's theorem • To observe the decrease in pressure with increase in velocity of a fluid • Magnus effect • Applications of Bernoulli's theorem • Examples • Doppler test for blockage in arteries
Module 10	• Liquid surface • Surface energy • Surface tension defined through force and through energy • Angle of contact • Measuring surface tension
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	• Determination of surface tension of water by capillary rise method in the laboratory • To study the effect of detergent on surface tension of water through observations on capillary rise.
Module 12	• Thermal properties of matter • Heat • Temperature • Thermometers
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Module 14	• Rise in temperature • Heat capacity of a body • Specific heat capacity of a material • Calorimetry • To determine specific heat capacity of a given solid material by the method of mixtures • Heat capacities of a gas have a large range • Specific heat at constant volume C_V • Specific heat capacity at constant pressure C_P
Module 15	• Change of state • To observe change of state and plot a cooling curve for molten wax. • Melting point, Regelation, Evaporation, boiling point, sublimation • Triple point of water • Latent heat of fusion • Latent heat of vaporisation • Calorimetry and determination of specific latent heat capacity
Module 16	• Heat Transfer • Conduction, convection, radiation • Coefficient of thermal conductivity • Convection

Module 17	• **Black body** • **Black body radiation** • **Wien's displacement law** • **Stefan's law** • **Newton's law of cooling,** • **To study the temperature, time relation for a hot body by plotting its cooling curve** • **To study the factors affecting the rate of loss of heat of a liquid** • **Greenhouse effect**

Module 12

3. WORDS YOU MUST KNOW

Kinetic energy: is the **energy** an object has due to its motion. As long as an object is moving at the same velocity, it will maintain the same **kinetic energy**.

Ice point: the freezing point of water of 0° Celsius or 273.15 kelvin at standard atmospheric pressure.

Freezing: The process of conversion of liquid to solid state. For water freezing means conversion to ice (its solid state)

Standard atmospheric pressure: The standard atmospheric pressure is the air pressure of 101325 pascals (Pa) or 101.325 kilopascals (kPa) (1013.25 millibars), exerted by a 760 millimeter (29.92 inches) column of mercury at sea level at a temperature of 0 degrees Celsius.

Steam point: the normal boiling point of pure water that is used as one of the fixed points of the international temperature scale.

Boiling is the rapid vaporization of a liquid, which occurs when a liquid is heated to its **boiling** point, the temperature at which the vapour pressure of the liquid is equal to the pressure exerted on the liquid by the surrounding atmosphere

Evaporation is a type of vaporization that occurs on the surface of a liquid as it changes into the gaseous phase. The surrounding gas must not be saturated with the evaporating substance.

Ideal gas: a hypothetical gas whose molecules occupy negligible space and have no interactions with each other, and which consequently obeys the gas laws exactly.

Gas parameters: A fixed mass of enclosed gas is described by its mass, volume, pressure and temperature. These are called gas parameters

Gas laws rules followed by gases at low pressure and low temperatures

Internal energy: The energy associated with the disordered, random motion of molecules is called Internal Energy. The total (internal) energy in a system includes potential and kinetic *energy*.

Thermal energy: is the internal **energy** of an object due to the kinetic **energy** of its atoms and/or molecules. The atoms and/or molecules of a hotter object have greater kinetic **energy** than those of a colder object. Heat is the flow of thermal energy.

Triple point a temperature at normal pressure where matter can exist in three states of matter (solid, liquid and gas) at triple point of water we will have ice water and water vapor. They would all be at the same temperature

4. INTRODUCTION

We all have common-sense notions of heat and temperature. Temperature is a measure of 'hotness' of a body. A kettle with boiling water is hotter than a box containing ice.

Hot **cold**

https://pixabay.com/no/illustrations/is-iskrem-dessert-sjokolade-brown-2221692/

http://maxpixel.freegreatpicture.com/Fire-The-Stake-Night-Night-Fire-Feast-Of-Fire-Camp-2541908.

In physics, we need to define the notion of **heat, temperature**, etc., more carefully.

In this module, you will learn

- **What is heat?**
- **What is the difference between heat and temperature?**
- **How is temperature measured?**
- **How is heat measured?**
- **Study the various processes by which heat flows from one body to another**.

In this course, you will find out why blacksmiths heat the iron ring before fitting on the rim of a wooden wheel of a bullock cart? and why the wind at the beach often reverses direction after the sun goes down.?

You will also learn what happens when water boils or freezes, and its temperature does not change during these processes even though a great deal of heat is flowing into or out of it.

5. TEMPERATURE AND HEAT

We can begin studying thermal properties of matter with definitions of temperature and heat.

Temperature is a relative measure, or indication of hotness or coldness. A hot utensil is said to have a higher temperature, and ice cube to have a lower temperature.

An object that has a higher temperature than another object is said to be hotter. Note that hot and cold are relative terms, like tall and short.

HOW IS HEAT DIFFERENT FROM TEMPERATURE?

Heat is a form of energy due to internal activity of its atoms/ molecules. The activity is mechanical.

The molecules in a crystalline solid have restricted activity of vibration about their mean positions, but the temperature of solid can be very high before it changes to liquid state.

So we cannot say temperature alone is the measure of heat energy. But it is certainly an indicator of heat energy of a body.

Also if you have two blocks of copper, one a 20 g piece and another 100 g. both may be at the same temperature. But they do not possess the same amount of heat energy. If you touch them they will give the same indication of being hot or cold.

So, we can say heat is the amount of internal energy of a body or system but temperature is an indicator of this energy.

Consider these definitions of temperature

i. **The degree of hotness or coldness of a body or an environment**.
ii. **A measure of the warmth or coldness of an object or substance with reference to some standard value**.
iii. **A measure of the average kinetic energy of the particles in a sample of matter, expressed in terms of units or degrees designated on a standard scale.**
iv. **A measure of the ability of a body, or more generally of any physical system, to transfer heat energy to another physical system.**

For certain, we are comfortable with the first two definitions - the degree or measure of how hot or cold an object is. But our understanding of temperature is not furthered by such definitions.

The third and the fourth definitions involve the kinetic energy of particles and the ability of a substance to transfer heat is scientifically accurate. However, these definitions are far too complex to serve as good starting points for a discussion of temperature.

So we will resign to a definition **temperature can be defined as the reading on a thermometer**. It serves as a great starting point for this module on heat and temperature.

Temperature is what the thermometer reads. Temperature is a measure of, 'heat energy' by the reading on a thermometer. So exactly how does a thermometer work?

WHAT IS TEMPERATURE?

No doubt you already have a good idea of what temperature is. ! Some body has fever because they feel hot.

You might say that it's how warm or cool something feels. In one sense, temperature is a relative measure of hotness or coldness.

Notice that the terms "hot" and "cold" are relative terms depending on who is taking the reading. Someone coming indoors on a winter day may feel as if the air inside the rooms in the house is warm while someone who has been in the house is wrapped in a blanket because she is cold. Because the temperature sense is relative to each individual it makes it unreliable as a good way to define temperature in physics.

At the Manali ski resort, the woolen clothing is used to shield oneself from the cold; this may not be needed in inside the covered areas as it may be hot there

https://upload.wikimedia.org/wikipedia/commons/7/72/Skiing_manali.jpg

For physicists, **temperature of an object is defined as the average kinetic energy of the particles of matter in the object, that is, the internal energy of the object.**

When particles of matter move more quickly, they have more kinetic energy, so their temperature is higher. With a higher temperature, matter feels warmer. When particles move more slowly, they have less kinetic energy on average, so their temperature is lower. With a lower temperature, matter feels cooler.

We can perceive temperature by touch. However, this temperature sense is somewhat unreliable and its range is too limited to be useful for scientific purposes. We know from experience that a glass tumbler containing ice-cold water left on a table on a hot summer day eventually warms up whereas a cup of hot tea on the same table cools down.

It means that when the temperature of body, ice-cold water or hot tea in this case, and its surrounding medium are different, heat transfer takes place between the system and the surrounding medium, until the body and the surrounding medium are at the same temperature.

We also know that in the case of glass tumbler of ice cold water, heat flows from the environment to the glass tumbler, whereas in the case of hot tea, it flows from the cup of hot tea to the environment. So, we can say that heat is the form of energy transferred between two (or more) systems or **a system and its surroundings by virtue of temperature difference.**

The SI unit of heat energy transferred is expressed in joule (J)

SI unit of temperature is kelvin (K), and ° C is also a commonly used unit of temperature.

When an object is heated or heat energy is supplied to it , many changes may take place.

- **Its temperature may rise,**
- **it may expand or,**
- **it may change state**

We will study the effect of supply or extraction of heat on different bodies in later modules

6. MEASUREMENT OF TEMPERATURE

A measure of temperature is obtained using a thermometer.

Many physical properties of materials change sufficiently with temperature to be used as the basis for constructing thermometers.

How do thermometers measure temperature?

Most materials have different coefficients of thermal expansion. This means that even though objects expand when heated and contract when cooled, different substances expand and contract by different amounts for the same temperature changes.

One example of how we can see this is by creating bi-metallic strip with two different metallic strips riveted together.

If the two metals have different expansion due to temperature changes, the duel strip will bend when heated as one of the metals expands more than the other as it is heated.

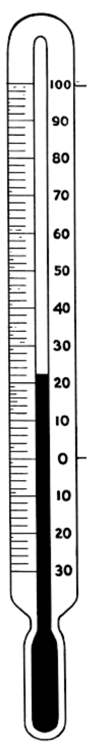
This property of metals is used in many temperature controlling devices.

Watch the bending of a bimetallic strip due to unequal expansion of different metals riveted at one end.

https://www.youtube.com/watch?v=9AWKkTPqrJE

If a heater is being used to warm a room. As the room gets warmer the bi-metallic strip in the thermostat will bend. If the room gets warm enough to bend the strip sufficiently it will shut off the heater. As the room cools the strip will bend back the other way. Then, turn the heater back on.

Many thermometers measure temperature with a **liquid that expands** when it gets warmer and contracts when it gets cooler



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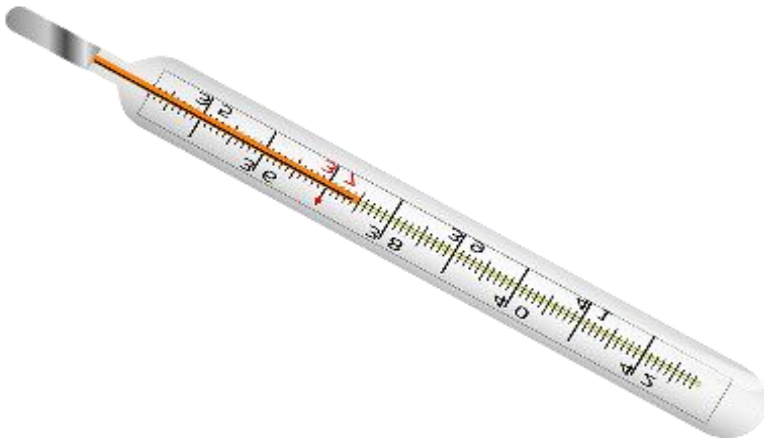
Picture of mercury thermometer.



Picture of clinical thermometer which tells us if the body temperature is above the normal or if we have fever

Look at the common thermometers shown. The red or silver liquid rises or falls in the glass tube as the temperature changes.

The increasing kinetic energy of the warmer liquid will cause the liquid to expand. Since the liquid is confined within the thermometer's glass tube it has nowhere else to go except up the thermometer's glass tube. Temperature is read off the scale at the height of the liquid in the tube. The warmer the fluid the more it expands and higher is the reading. **This means the expansion of liquid thread in the thermometer is proportional to temperature.**

As the temperature decreases, the average kinetic energy in the fluid decreases and the fluid contracts and it does not take up as much volume. This decrease in volume causes the top of the fluid line to drop down in the tube giving a lower reading.

In the above example, it is the volume of the confined liquid that changes and it uses the property of **variation of the volume of a liquid with temperature**.

For example, a common thermometer (the liquid-in-glass type) with which you are familiar. **Mercury and alcohol** are the liquids used in most liquid-in-glass thermometers. Thermometers are calibrated so that a numerical value may be assigned to a given temperature.

FIXED POINTS

For the definition of any standard scale, **two fixed reference points** are needed. Since all substances change dimensions with temperature, an absolute reference for expansion is not available.

However, the necessary fixed points may be correlated to physical phenomena that always occur at the same temperature.

The ice point and the steam point of water are two convenient fixed points and are known as the **freezing and boiling points of water** respectively.

These two points are the temperatures at which pure water freezes and boils under standard atmospheric pressure.

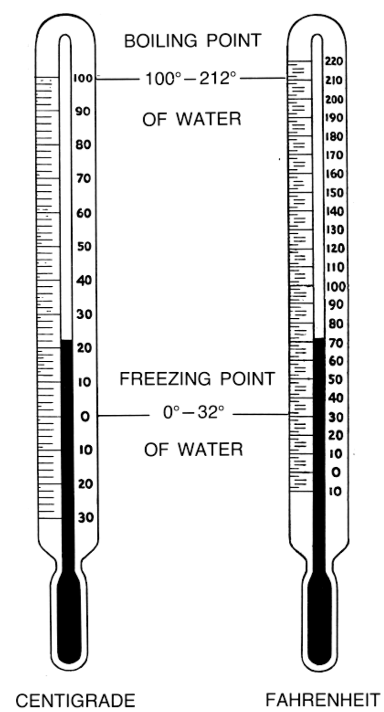
The expanded liquid column suggests the temperature from the calibrated scale marked on it.

Liquid-in-glass thermometers show different readings for temperatures other than the fixed points because of differing expansion properties of liquids.

SCALES OF TEMPERATURE

The **two familiar temperature scales** are the **Fahrenheit temperature scale** and the **Celsius temperature scale**.

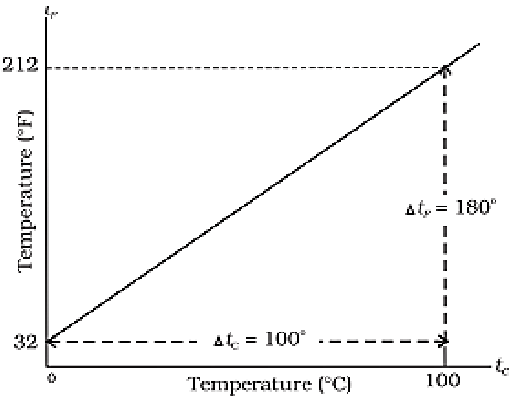
The ice and steam point have values 32 °F and 212 °F respectively, on the Fahrenheit scale, and 0 °C and 100 °C on the Celsius scale.



https://commons.wikimedia.org/wiki/File:Thermometer_(PSF).png

On the Fahrenheit scale, there are 180 equal intervals between two reference points, and on the Celsius scale, there are 100 equal intervals between these two reference points.

A plot of Fahrenheit temperature (t_F) versus Celsius temperature (t_C).



A relationship for converting the two scales from one to the other, may be obtained from a graph of Fahrenheit temperature (t_F) versus Celsius temperature (t_C) in a straight line whose equation is

$$\frac{t_F - 32}{180} = \frac{t_C}{100}$$

We normally use only the Celsius scale in daily routine, sometimes body temperatures are given in Fahrenheit as 100°F, 101°F temperature to indicate fever. normal body temperature $98.6\,^0$ F or $37\,^0$C.

THERMOMETERS BASED ON UNEQUAL EXPANSION OF SOLIDS

Thermostats in refrigerators, iron, geysers, toasters or MCB panels

Liquid-in-glass or bimetallic thermometers, thermometers show different readings for temperatures other than the fixed points (freezing point of water or melting point of ice, boiling point of water) because of dissimilar expansion properties of liquids and solids. The calibration between the fixed points helps us to measure temperatures between the two fixed points or temperatures.

THINK ABOUT THIS

- **How do we measure temperatures beyond the fixed point range that is beyond 100^0C or less than 0^0C?**
- **What possible disadvantages will you encounter?**

- **The bulb of the liquid glass thermometer should be placed inside the environment for which the temperature is to be determined, why is it not always possible?**

8. IDEAL-GAS EQUATION AND ABSOLUTE TEMPERATURE

Real and ideal gas

An ideal gas is one that follows the gas laws at all varying physical conditions of change in temperature and pressure.

To do so, the gas particles would need to occupy zero volume and they would need to exhibit no attractive forces what so ever toward each other. Since neither of those conditions can be true, there is no such thing as an ideal gas.

A **real gas** is a gas that does not behave as quoted above
However, at the conditions of temperature and pressure that are normally encountered in a laboratory or daily life , real gases tend to behave very much like ideal gases

A gas thermometer, gives the same readings regardless of which gas is used. They are very sensitive and hence are used when small accurate measurements are needed for scientific work.

Experiments show that all gases at low densities expand in the same way. **The variables that describe the behaviour of a given quantity (mass) of gas are pressure, volume, and temperature (P, V, and T). These are called gas parameters.**

When **temperature** is held **constant**,
the pressure and volume of a fixed mass of gas are related as
PV = constant.
This relationship is known as **Boyle's law,** after Robert Boyle (1627-1691) the English Chemist who discovered it.

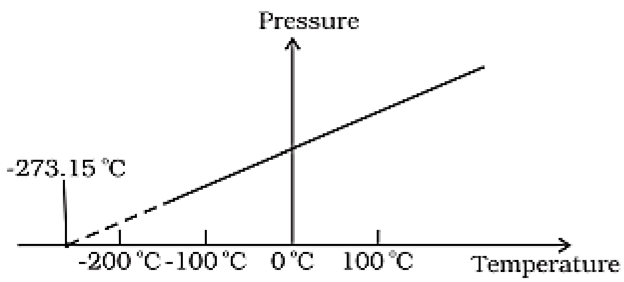
When the **pressure is held constant,**
The volume of a given quantity of the gas is related to the temperature as
V/T = constant.
This relationship is known as **Charles' law**, after the French scientist Jacques Charles (1747- 1823).
Low density gases obey these laws, which may be combined into a single relationship.

Notice that since PV = constant and V/T = constant for a given quantity of gas, then

PV/T should also be a constant.

This relationship is known as **ideal gas law**.

It can be written in a more general form that applies not just to a given quantity of a single gas but to any quantity of any dilute gas and is known as **ideal-gas equation:**



Pressure versus temperature of a low density gas kept at constant volume.

$$\frac{PV}{T} = nR$$

Or, **PV= nRT**

where, μ is the number of moles in the given sample of gas and **R is called universal gas constant:**

R = 8.31 J mol^{-1} K^{-1},

We have learnt that the product of pressure and volume are directly proportional to temperature:

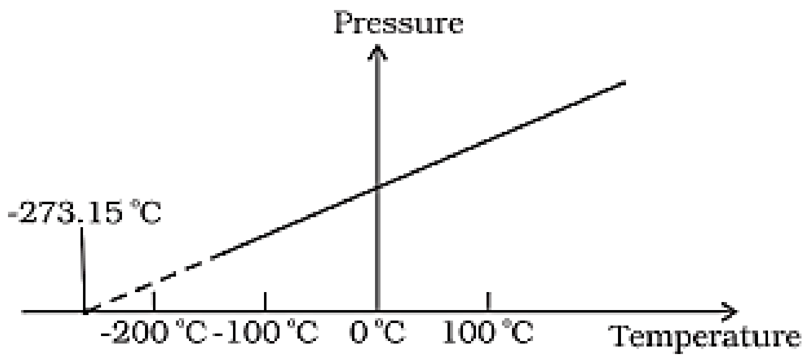
PV ∝ T.

This relationship allows a gas to be used to measure temperature in a **gas thermometer.**

GAS THERMOMETERS

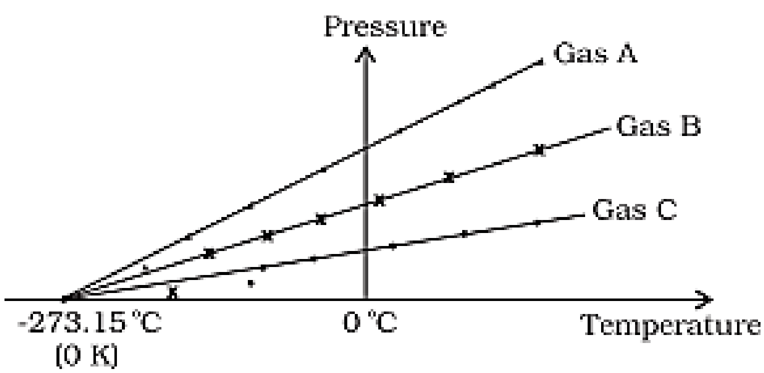
Holding the volume of a gas constant, it gives P ∝T. Thus, with a **constant-volume gas thermometer**, temperature is read in terms of pressure.

A plot of pressure versus temperature gives a straight line in this case, as shown in Fig.



However, measurements on real gases deviate from the values predicted by the ideal gas law at low temperature. But the relationship is linear over a large temperature range, and it looks as though the pressure might reach zero with decreasing temperature if the gas continued to be a gas. And does not convert to liquid

The absolute minimum temperature for an ideal gas is, therefore, inferred by extrapolating the straight line to the temperature axis, as in Fig.

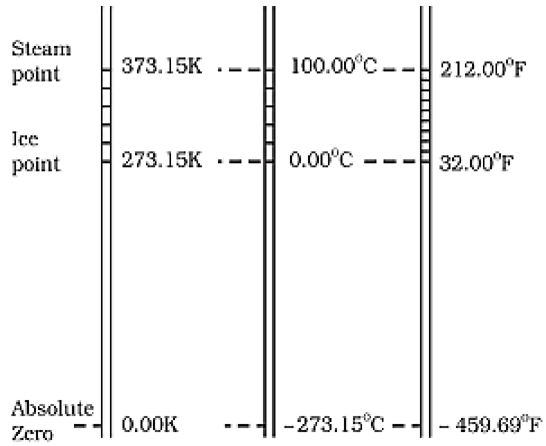


A plot of pressure versus temperature and extrapolation of lines for low density gases indicates the same absolute zero temperature.

This temperature is found **to be – 273.15 °C** and is designated as **absolute zero.**

Absolute zero is the foundation of the Kelvin temperature scale or absolute scale temperature named after the British Scientist Lord Kelvin.

On this scale, – 273.15 °C is taken as the zero point, that is 0 K



Comparison of the Kelvin, Celsius and Fahrenheit temperature scales.

The size of the unit for Kelvin temperature is the same Celsius degree, so temperature on these scales are related by

$T = t_C + 273.15$

How would you convert a temperature from Kelvin scale to Celsius scale?

You would subtract 273 from the Kelvin temperature.

For example, a temperature of 300 Kelvin equals 27 ºC.

Converting temperature between Celsius and Fahrenheit is more complicated.

The following conversion factors can be used:

Celsius → Fahrenheit: (ºC ×1.8) +32 =ºF

Fahrenheit → Celsius: (ºF −32)÷1.8 = ºC

EXAMPLE

What is a temperature of 20 ºC in Kelvin?

SOLUTION

$T = T_C + 273 = (20+273) = 293K$

EXAMPLE

What is the temperature of -300 ºC in Kelvin?

SOLUTION

$T = T_C + 273 \rightarrow T = -300 + 273 = -27K$

Mathematically, this answer is correct but it has no physical meaning as it is impossible. 0 K is the lowest possible temperature.

There can be no temperature lower than – 273 ºC.

EXAMPLE

The triple points of neon and carbon dioxide are 24.57 K and 216.55 K respectively.

Express these temperatures on the Celsius and Fahrenheit scales.

SOLUTION

Triple points of neon $T_{Ne} = 24.75K$

Triple points of carbon dioxide, $T_C = 216.55\ K$

On Celsius scale: C = T-273.15

Therefore, triple points of neon $C_{Ne} = 24.75 - 273.15 = -248.58\ °C$

Triple points of carbon dioxide, $C_C = 216.55 - 273.15 = -56.6\ °C$

On Fahrenheit scale:

$$F = \frac{9}{5}C + 32$$

Therefore,

Triple points of neon, $F_{Ne} = = \frac{9}{5} \times (-248.58) + 32 = -415.44°F$

Triple points of carbon dioxide, $F_C = \frac{9}{5} \times (-56.6) + 32 = -69.88\ °F$

EXAMPLE

Two absolute scales *A* and *B* have triple points of water defined to be 200 A and 350 B. What is the relation between T_A and T_B? Given: triple point of water = 273.16 K

(0^0C)

SOLUTION

Here, triple point of water on absolute scale A = 200 A

And triple point of water on absolute scale B = 350 B

Also, triple point of water on Kelvin scale = 273.16 K

It follows that temperature 200 A on absolute scale A and 350 B are equivalent to temperature 273.16 K on kelvin scale. Therefore, Size of one degree of Kelvin scale on absolute scale A = $\frac{273.16}{200}$

Therefore, value of temperature T_A on absolute scale A

$$= \frac{273.16}{200} \times T_A$$

Similarly, value of temperature T_B on absolute scale B

$$= \frac{273.16}{350} \times T_B$$

Since, T_A *and* T_B represent the same temperature,

$$\frac{273.16}{200} \times T_A = \frac{273.16}{350} \times T_B$$

Or

$$\mathbf{T_A = \frac{200}{350} T_B = \frac{4}{7} T_B}$$

Since the gas laws as we introduced them use Kelvins, they could not have been used before the Kelvin scale was around.

TRY THESE

- **Show how each of the gas laws and the combined law would be modified for Celsius units.**

- **Explain the above graph keeping in mind how and why the switch to Kelvins might have occurred in terms of your answer to the question above.**

The gas laws still hold in their general relationships; Boyle's law, being temperature-independent, remain unchanged. The other two laws are still linear relationships, but now there is an x -intercept.

The Kelvin scale can be explained as a way to eliminate the x-intercept found in various temperature-dependent phenomena, such as the gas laws.
Also, note that — as suggested by the discussion on scales above — converting between any two temperatures scales with zeroes calibrated to absolute zero will be as simple as converting between length or time scales.

9. OTHER THERMOMETERS

To fulfil our need to measure temperature of objects or environments, with a wide range of possible temperatures we need different thermometers. The principle of working of these thermometers depend upon the physical property which changes with temperature.

Type of thermometer	Lowest limit	Upper limit
Mercury thermometer	**-30 ^{0}C**	**300 ^{0}C**
Gas thermometer	**-268 ^{0}C**	**1500 ^{0}C**
Platinum resistance thermometer	**-200 ^{0}C**	**1200 ^{0}C**
Thermocouple thermometer	**-200 ^{0}C**	**1600 ^{0}C**
Radiation thermometers	**800 ^{0}C**	**No limit ~ 3000 ^{0}C to 4000 ^{0}C**
Disappearing filament thermometers	**600 ^{0}C**	**2700 ^{0}C**

10. SUMMARY

In this module we have learnt

- The thermal energy, or heat, of an object is obtained by adding up the kinetic energy of all the molecules within it.
- Temperature is related to the average kinetic energy of the molecules.
- All objects will be at some temperature depending upon their internal energy
- A thermometer is a devise which can indicate the internal energy with respect to freezing point or boiling point of water
- A thermometer may be designed on the basis of any physical changes a material may have due to increase or decrease of heat energy
- We can make thermometers using solid, liquid or gas, using a property which is heat dependant.
- The thermometers are made and calibrated to indicate the temperature and hence amount of heat of any system.
- Absolute zero is the temperature at which molecular motion stops and is the lowest possible temperature.
- Zero on the Celsius scale (ºC) is the freezing point of water and 100ºC is the boiling point of water.
- The relationship between Celsius and Kelvin temperature scales is given by
  K = ºC + 273.15.

- **We have a wide variety of thermometers to help us measure very low and very high temperatures.**