THERMAL PROPERTIES OF MATTER (HEAT)

INTRODUCTION

Touch a piece of ice, how do you feel? Now touch a piece of heated iron, how do you feel? Have you ever wondered why you feel the way you feel!

The feeling of hot or cold results from the transfer of heat energy from one body to another. When we touch a hot body, we absorb heat from such a body and feel hotter. When we touch a cold body, we lose heat to such a body and feel colder.

HEAT AND TEMPERATURE

Heat

Heat is a form of energy that is transferred from point to another as a result of temperature difference between the points. The S.I unit of heat is a Joule denoted as J.

Heat has the following effects on a body;

- Increase in temperature of as body.
- Change in the physical state of matter of a body.
- Change in size of a body.
- Change in colour of a body.

Temperature

Temperature is the degree of hotness or coldness of a body.
A body becomes hot after absorbing heat and cold after losing heat.

NB: Temperature is the measure of how hot or cold a body is and should **not** be confused with the amount of heat the body contains.
Since heat is the sum of the kinetic energies of all the molecules in a body, then temperature can be defined as the measure of the body's kinetic energy.

Differences between heat and temperature

Heat	Temperature
• Is a form of energy that is transferred from point to another due to temperature difference between the points. • Depends on the kinetic energy of the molecules and their masses. • Is the cause of temperature. • Is measured in joules.	• Is the degree of hotness or coldness of a body. • Depends only on the kinetic energy of the molecules. • Is an effect of heat. • Is measured in Kelvin or ℃.

Measurement of temperature (Thermometry)
Temperature is measured using a device called a thermometer.
Definition: A thermometer is an instrument used to measure temperature of a body.

Examples of thermometers include the liquid-in-glass thermometer, constant volume gas thermometer, constant pressure gas thermometer, platinum resistance thermometer, thermocouple thermometer and the pyrometers.

Each of the thermometers above uses a specific thermometric property.
Definition: A thermometric property is a physical quantity that that varies continuously and uniformly with change in temperature but remains constant at a constant temperature.

Examples of thermometric properties
- Length of a liquid column for a liquid-in-glass thermometer.
- Pressure of a fixed mass of a gas for a constant volume gas thermometer.
- Volume of a fixed mass of a gas for a constant pressure gas thermometer.
- Electrical resistance of platinum wire for a platinum resistance thermometer.
- Electromotive force of a thermocouple for a thermocouple thermometer.
- Wavelength of the electromagnetic radiations emitted by a body for a pyrometer.

Qualities of a good thermometric property
- It should vary continuously and uniformly with change in temperature.
- It should vary considerably even for a very small change in temperature i.e it should be very sensitive to temperature change.
- It should vary over a wide temperature range.
- It should be accurately measurable using a simple apparatus.
- Each value of the thermometric property should correspond to one particular temperature.

TEMPERATURE SCALE
A temperature scale is that from which the degree of hotness or coldness of a body can be expressed.
There are three temperature scales i.e the Celsius(centigrade) scale which uses a degree Celsius as the standard, Fahrenheit scale which uses a degree Fahrenheit as the standard and the thermodynamic(kelvin) scale which uses a kelvin as the standard.

Conversion of scales

- To covert from the Celsius scale to the Fahrenheit scale, use $t = \frac{9}{5}\theta + 32$ or $5t = 9\theta + 160$.
- To convert from the Fahrenheit scale to the Celsius scale use $\theta = \frac{5}{9}(t - 32)$ or $5t = 9\theta + 160$.
- To convert from the Kelvin scale to the Celsius scale use $\theta = T - 273$.
- To convert from the Celsius scale to the Kelvin scale use $T = \theta + 273$.

Where - θ is the temperature on the Celsius scale.
- t is the temperature on the Fahrenheit scale.
- T is the temperature on the Kelvin scale.

NB: To convert from the kelvin scale to the Fahrenheit scale and vice versa, first convert the given scale to the Celsius scale and there after convert to the required scale.

EXAMPLES

1. Covert;
   (a) 127℃ to Kelvin. (b) -240℃ to Kelvin. (c) $233K$ to ℃ .
   (d) $1010K$ to °F. (e) 98°F to Kelvin. (f) 1098°F to Kelvin.

Solutions

(a) $T = \theta + 273$
= 127 + 273
= 400K
$\therefore 127℃ = 400K$

(b) $T = \theta + 273$
= -240 + 273
= 33K
$\therefore -240℃ = 33K$

(c) $\theta = T - 273$
$= 233 - 273$
= -40℃
$\therefore 233K = -40℃$

(d) $\theta = T - 273$
$= 1010 - 273$
$= 737℃$

$t = \frac{9}{5}\theta + 32$
$= \left(\frac{9}{5}x737\right) + 32$
$= 1358.6$°F

$\therefore 1010K = 1358.6$°F

(e) $\theta = \frac{5}{9}(t - 32)$
$= \frac{5}{9}(98 - 32)$
= 36.7℃

$T = \theta + 273$
$= 36.7 + 273$
= 309.7K

$\therefore 98°F = 309.7K$

ACTIVITY

(1) Convert:
   (a) $373K$ to ℃.

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   (b) 30℃ to Kelvin.

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(c) 454K to °F.

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(d) 32°F to Kelvin.

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FIXED POINTS OF A THERMOMETER

A fixed point is that constant temperature at which the physical state of water changes at standard atmospheric pressure of $760mmHg$.

Examples of fixed points include the upper fixed (steam) point, lower fixed (ice) point and the triple point of water.

The lower fixed point

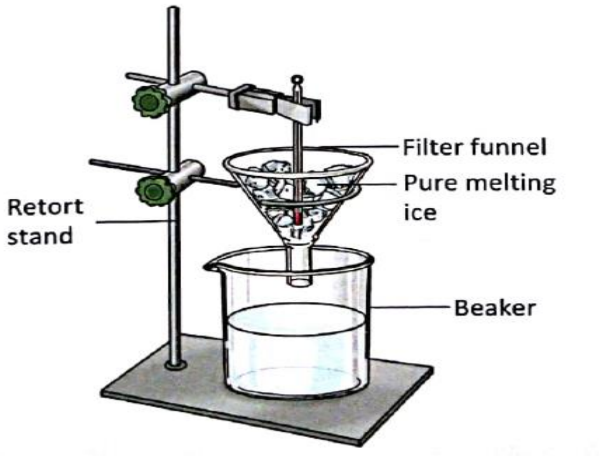
The lower fixed point is that constant temperature at which pure water and pure melting ice coexist in equilibrium at standard atmospheric pressure of $760mmHg$.

OR

The lower fixed point is the that constant temperature at which pure water turns to ice at standard atmospheric pressure of $760mmHg$.

The lower fixed point is taken to be $0℃$ on the Celsius scale and $273K$ on the Kelvin scale.

Determination of the lower fixed point



- Support a filter funnel vertically using a retort stand.
- Place lumps of pure ice, obtained by freezing distilled water, in the funnel.
- Fix the thermometer vertically into the ice and adjust its position so that its bulb is completely covered by the ice and the liquid thread is clearly visible.
- Observe the level of the liquid thread as it reduces until when it remains constant for a considerable amount of time.
- Note the temperature at this point and it is the lower fixed point.

NB: The ice must be pure because impurities lower the freezing point of ice.

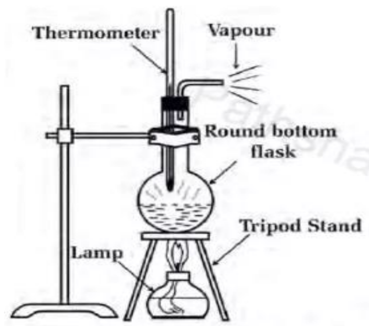
The upper fixed point
The upper fixed point is that constant temperature at which pure water and its own vapour coexist in equilibrium at standard atmospheric pressure of 760mmHg.

OR

The upper fixed point is that constant temperature at which pure water turns to steam at standard atmospheric pressure of 760mmHg.

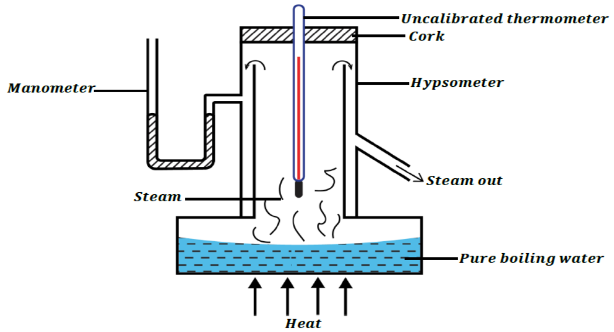
The upper fixed point is taken to be 100°C on the Celsius scale and 373K on the Kelvin scale.

Determination of the lower fixed point



- Support a round bottomed flask vertically using a retort stand.
- Pour some water into the flask.
- Pass the thermometer through a hole in cork and fix it vertically in the flask so that its bulb is just above the water and the liquid thread is clearly visible.
- Heat the water and observe the level of the liquid thread until when it remains constant for a considerable amount of time.
- Note the temperature at this point and it is the upper fixed point.

Alternatively, a hypsometer (a double walled copper can) may be used.



- Pour some water into the hypsometer.
- Pass the thermometer through a hole in cork and fix it vertically in the hypsometer so that its bulb is just above the water and the liquid thread is clearly visible.
- Heat the water and observe the level of the liquid thread until when it remains constant for a considerable amount of time.
- Note the temperature at this point and it is the upper fixed point.

NB: - The level of the liquid in the manometer should be the same to ensure that the pressure of the steam is equal to the atmospheric pressure.
- The double walls minimise heat loss to ensure that the temperature of steam remains constant.
- The bulb of the thermometer should not be placed in the water because the water may be impure and therefore may be boiling at a temperature higher than that of steam.
- The difference between the upper fixed point and the lower fixed point is called the fundamental interval.

The triple point of water

The triple point is that unique temperature at which pure water, pure ice and pure water vapour coexist in equilibrium at standard atmospheric pressure of 760mmHg.

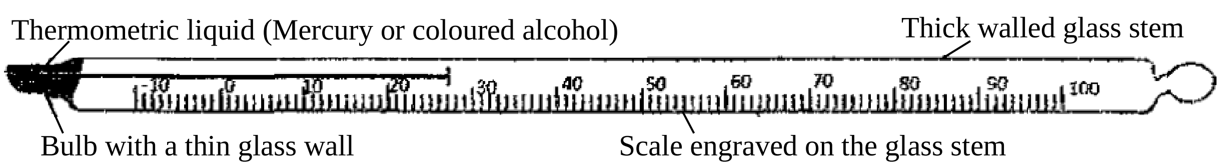
The upper fixed point is taken to be $100℃$ on the Celsius scale and 373K on the Kelvin scale.

THE LIQUID-IN-GLASS THERMOMETER

A liquid in glass thermometer is a thermometer that uses length of a liquid column inside a narrow glass tube to measure temperature.

Examples of liquid-in-glass thermometers include the clinical thermometer commonly used by doctors and nurses in hospitals to measure temperature of patients and the six’s (maximum and minimum) thermometer commonly used at weather stations to measure the maximum and minimum temperature reached over a period of time, say 24 hours.

Structure of a liquid-in-glass thermometer



It consists of thin walled bulb at the end of a capillary tube of fine bore that provides passage of the thermometric liquid as it expands or contracts. The capillary tube is housed in thick calibrated glass stem. The space above the thermometric liquid is usually evacuated to minimize build up of excess pressure when the liquid expands.

Operation of a liquid-in-glass thermometer

- The bulb of the thermometer is placed in direct contact with the body whose temperature is to be measured.
- Sufficient time is allowed for the thermometric liquid to expand or contract until the length of the liquid thread remains constant.

- The reading on the scale at this point is noted and it gives the temperature of the body.

Sensitivity of a liquid in glass thermometer

Sensitivity of a thermometer is the measure of the ability of the thermometer to detect any small change in temperature.

The sensitivity of a liquid-in-glass thermometer depends on the size of the bulb, the extent to which the bulb of the thermometer is immersed in the body whose temperature is being measured and the reversible thermal expansion of the liquid compared to glass.

How to increase sensitivity of a liquid-in-glass thermometer

- Make the bulb of the thermometer large. If the bulb is large, then it will contain a larger amount of the thermometric liquid and so there will be a greater expansion per degree rise in temperature.
- Make the bore of the capillary tube very narrow. If the bore of the capillary tube is narrow, then a small volume of the thermometric liquid will spread over a larger length of the capillary tube.
- Ensure that the bulb is completely immersed. If the bulb is completely immersed, then the thermometric liquid will be easily heated.

Precautions taken when designing a liquid -in-glass thermometer

- The walls of the bulb should be very thin to ensure that the thermometric liquid is easily cooled or heated.
- The amount of liquid in the bulb should be so small to ensure that it takes a short time to get cooled or heated.
- The glass stem should be thick and strong to ensure that the inner parts of the thermometer are well protected from mechanical damage.
- The bore of the capillary to tube should have a uniform cross section area to ensure uniform expansion of the thermometric liquid.
- The capillary tube should have a fine bore to ensure that it is sensitive to even a slight change in temperature.
- The thermometric liquid used should have a higher coefficient of thermal expansion (linear expansivity).

THERMOMETRIC LIQUIDS

A thermometric liquid is a liquid that can be used to measure temperature in a liquid in glass thermometer.

Examples of thermometric liquids include mercury and alcohol.

Choice of a thermometric liquid

The choice of the thermometric liquid largely depends on the range of temperature to be measured e.g

- mercury which freezes at -39℃ and boils at 357℃ is suitable for measuring very high temperature but not very low temperatures.
- alcohol which freezes at -115℃ and boils at 78℃ is suitable for measuring very low temperatures but not very high temperatures.

Qualities of a good thermometric liquid

- It should be opaque so that it is clearly visible.
- It should have a regular expansion.
- It should not wet the glass of the thermometer.
- It should be a good conductor of heat so that it quickly responds to any temperature change.
- It should have a high linear expansivity so that it responds to even slight changes in temperature.
- It should have a very low melting point and a very high boiling point so that it can be used to measure temperature over a wide range.

Advantages of mercury over alcohol as a thermometric liquid

- It is a better conductor of heat than alcohol.
- It is opaque and so can easily be seen unlike alcohol which needs to coloured to be easily seen.
- It does not wet the glass unlike alcohol which tends to wet the glass of the thermometer.
- It has a uniform expansion than alcohol since it is a metal.
- It boils at higher temperature than alcohol and so can be used to measure very high temperatures.

Advantages of alcohol over mercury as a thermometric liquid

- It melts at a lower temperature than mercury and so can be used to measure very low temperatures.
- It has a higher linear expansivity than alcohol and so expands more for a small change in temperature.

Why water is not used as a thermometric liquid

- It is transparent and so not clearly visible.
- It has an anomalous expansion.
- It sticks to and wets the glass of the thermometer.
- Its meniscus is difficult to read.
- It is a poor conductor of heat.
- It has a narrow temperature range i.e it boils at $100℃$ and freezes at $0℃$.

CALIBRATION OF A THERMOMETER LIQUID-IN-GLASS THERMOMETER

Calibration of the thermometer is the process of engraving a temperature scale on the glass stem of the thermometer.

Steps taken to calibrate a liquid-in-glass thermometer

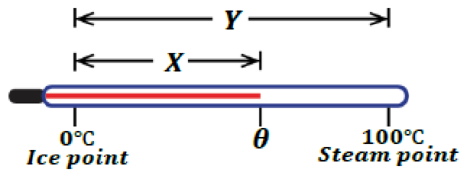
- Determine the lower fixed point of the thermometer to be calibrated.
- Determine the upper fixed point of the thermometer to be calibrated.
- Determine the fundamental interval.
- Divide the fundamental interval into 100 equal divisions. Each division will be equal to $1℃$ and so the thermometer will be able to measure temperature directly.

Determination of temperature from an uncalibrated liquid-in-thermometer

The unknown temperature θ is obtained from the expression;

$$\theta = (\frac{Length\ of\ the\ liquid\ thread\ above\ the\ lower\ fixed\ point}{Fundamental\ interval}\text{x}100)°\text{C}$$

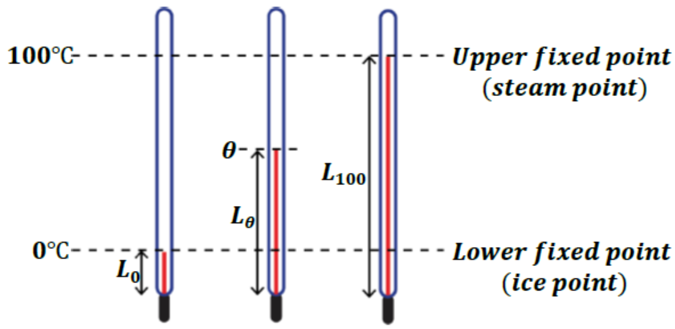
Method 1



If X is the length of the liquid thread above the lower fixed point and Y is the fundamental interval, then the unknown temperature θ is obtained from the expression;

$$\theta = (\frac{X}{Y}\text{x}100)°\text{C}$$

Method 2



If l_o is the length of the liquid thread at the lower fixed point, l_{100} is the length of the liquid thread at the upper fixed point and l_θ is the length of the liquid thread at the unknown temperature θ, then the unknown temperature is obtained from the expression;

$$\theta = (\frac{l_{\theta -}l_o}{l_{100 -}l_o}\text{x } 100)°\text{C}$$

Examples

1. At a certain temperature θ, the length of the liquid thread above the lower fixed point of an uncalibrated thermometer is 12.4cm. If the fundamental interval is 20.0cm, what is the value of θ?

Solution

$$\theta = (\frac{X}{Y}\text{x}100)°\text{C}$$
$$= (\frac{12.4}{20.0}\text{x}100)$$
$$= 62°\text{C}$$

2. A newly made thermometer has its lower fixed point 10cm away from the bulb and upper fixed point 60cm away from the bulb. What is the temperature if the length of the mercury thread of such a thermometer is 30cm away from the bulb?

Solution

$$\theta = (\frac{l_{\theta -}l_o}{l_{100 -}l_o}\text{x } 100)°\text{C}$$
$$= (\frac{30 - 10}{60 - 10}\text{x } 100)°\text{C}$$
$$= 40°\text{C}$$

3. The fundamental interval of the thermometer is 50mm. How far above the ice point will the mercury level be when the bulb is placed in a liquid at a temperature of 90°C?

Solution

$$\theta = (\frac{X}{Y}\text{x}100)°\text{C}$$

$$90 = \frac{X}{50}\text{x}100$$

$$X = \frac{90\text{x}50}{100}$$

$$= 45\text{mm}$$

∴ The mercury level will be 45mm above the ice point

Activity

1. When a thermometer is placed in a boiling liquid , the mercury thread rises above the lower fixed point by 18.5cm. Find the temperature of the liquid if the fundamental interval is 20cm.

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2. The length of the mercury-in-glass thermometer between the lower fixed point and the upper fixed point is 18cm. When the bulb is dipped in a hot liquid, the mercury level is found to be 10cm above the ice point. Calculate the temperature of the liquid.

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3. The length of the mercury thread of a thermometer at ice point is 22cm and that at steam point is 62cm. Calculate the reading of the thermometer when the mercury thread is 42cm long.

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4. In an uncalibrated thermometer, the length of the mercury above the bulb is 38mm at the lower fixed point and 138 at the upper fixed point. When the thermometer is placed in a hot liquid, the length of the mercury thread above the bulb is 78mm. Calculate the temperature of the hot liquid.

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5. The resistance of a platinum resistance thermometer is 5.2Ω at ice point, 5.7Ω at steam point and 5.5Ω at an unknown temperature. Determine the unknown temperature.

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6. The length of the mercury thread in a thermometer is 80mm at steam point and 50mm at a temperature of 50°C. Determine the length of the mercury thread at ice point.

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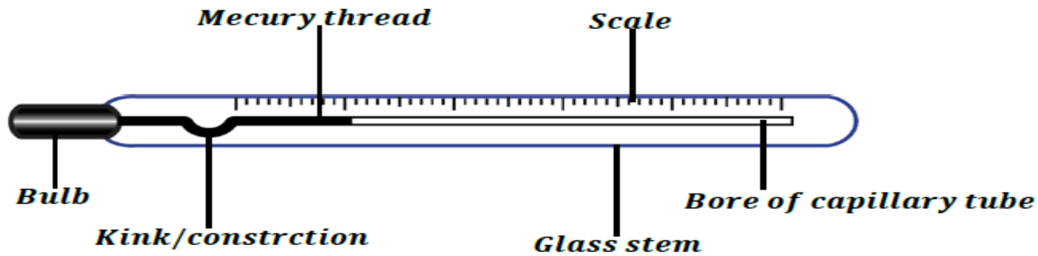
THE CLINICAL THERMOMETER



The clinical thermometer is a special liquid-in-glass thermometer designed to be used by doctors and nurses in clinics and hospitals to measure temperatures of human beings. The clinical thermometer has a very narrow temperature range i.e 35°C to 42°C since the human body temperature is not expected to fall outside that range.

How to measure temperature using a clinical thermometer

- Place the clinical thermometer in the arm pit, under the tongue or anus of the person whose body temperature is to be measured.
- After about two minutes, remove the thermometer and read off the temperature of the person.
- Shake the thermometer to ensure that the mercury returns to the bulb.

NB: -The kink prevents the back flow of mercury before the temperature is read.

-The thermometer should be shaken well so that mercury returns back to the bulb before the thermometer can be used on another person.

- The thermometer should not be sterilized in boiling water. This is because boiling water causes mercury to expand far beyond the space of the bore thus exerting pressure on the stem and causing it to burst.

ATMOSPHERIC TEMPERATURE

Atmospheric temperature is the measure of the degree of hotness or coldness at different layers of the earth’s atmosphere.

The earth’s atmosphere refers to a thin layer(blanket) of air (mixture of gases) that surrounds planet earth. The layers of air are retained by the earth’s gravitational pull and are useful because they protect us from harmful ultraviolet radiations from the sun, warm the earth keeping the temperatures habitable and create a pressure without which liquid water wouldn’t exist on earth.

Factors that affect atmospheric temperature

Time of the day

The atmospheric is hotter during day and cooler during the night. The difference in temperature from day to night is brought about by the rotation of the earth.

During day, the earth faces the sun and receives solar radiant energy at rate higher than its surface loses heat by surface radiation thereby becoming warmer. During the night, the earth faces away from the sun and receives no solar radiant energy but continues to lose heat by surface radiation thereby becoming cooler.

The difference between the highest temperature observed during day and lowest temperature observed during the night is called **diurnal temperature range**.

Cloud cover

Thin cloud cover result into warmer days and cooler nights whereas thick cloud cover results into cooler days and warmer nights.

During day, the earth is heated up by the sun, If the skies are clear, more heat reaches the earth’s surface resulting in warmer temperature. If the skies are cloudy, some of the solar radiant energy is reflected back by cloud droplets so less heat reaches the earth’s surface resulting into cooler temperatures.

During the night, the earth loses heat by surface radiation. If the skies are clear, more heat is lost from the earth’s surface resulting in cooler temperatures. If the skies are cloudy, some of the surface radiant energy is reflected back by cloud droplets so less heat is lost from the earth’s surface resulting into warmer temperatures.

This explains why deserts experience extremely high temperatures during day and extremely high temperatures during the night.

Altitude

The temperatures are high at low altitude and lower at low altitude.

As altitude increases, air pressure drops and the air molecules spread further apart resulting into cooler temperatures.

NB: Beyond a certain height however, the temperature begins to rise as altitude increases.

Latitude
Atmospheric temperatures drop with increase in distance from the equator due to the curvature of the earth.

In areas closer to the poles, solar radiant energy has a larger area of the atmosphere to pass through and the sun is at a lower angle in the sky. This results into more heat loss and hence cooler temperatures.

Distance from the sea
Oceans heat up and cool down much more slowly than land resulting into breezes that moderate the local coastal regions. This means that coastal areas experience cooler temperatures in the hot season and warmer temperatures in the wet season than inland areas at the same altitude and altitude.

Prevailing winds
Prevailing winds are winds that blow consistently in a given direction over a particular region of the earth. The direction of prevailing winds determines which type of air mass usually moves over an area e.g a west wind might carry warm moist air from over an ocean resulting in warmer local temperatures while an east wind might carry cold dry air from over a mountain range resulting in cooler local temperatures.

Activity

Describe the changes in atmospheric pressure effect our lives.

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ACTIVITY OF INTEGRATION

There is an out break of a disease in your village whose major symptom is high temperature. Your village mates are poor and can not afford to buy thermometers to monitor their body temperature. As a Physicist, use your knowledge of thermometry write down a detailed procedure your village mates may follow to make thermometers from locally available materials.