Colloidal Systems In Food

- Sols
- Gels
- Emulsion
- Foams

1) Classification & Functions of Colloidal systems in food.
2) Types of colloidal system in Food.
3) Stability.

1) Classification & Functions of Colloidal systems in food :-

→ A colloid is a type of chemical mixture where one substance is dispersed evenly throughout another. Colloids are formed when one substance is dispersed through another, but does not combine to form a solution.

A colloidal systems consists of two separate phases : a dispersed phase (internal phase) and continuous phase (dispersion phase / medium). A colloidal system may be solids, liquid, gas--eous.

Colloidal dispersion is a two phase system in which the particles in the dispersed phase are btw 1-100 nm in diameter. For this, reason most manufactured food can be considered as food colloids and many contains hydrocolloids that are added to control stability and rheological properties.

Food hydrocolloids are high molecular weight hydrophillic biopolymers used in food products to control their texture, flavor and shelf life. Colloidal system in foods can be classified into different groups based on the states of matter constituting the two phases. They are sols, gels, emulsion & foams.

Functions of colloidal systems in Food products.

Colloidal systems give structure, texture and mouth feel to many different food products, for example - jam, ice-cream, mayonnaise. Food colloid contains hydrocolloids that gives stability and rheological properties of food components. An emulsifying agents may be used to help the oil and water phases to mix permanently.

⇒ Types

a) Sols & Gels : A sol can be defind as a colloi-dal dispersion in which a solid is the dispersed phase and liquid is the continuous phase and liquid is the continuous phase. Gravy stirred custard and other thick sauces are some of the example of sols.

When a jelly is made, gelatin is dispersed into a liquid and heated to form a sol. As the solution cools, protein molecules unwind forming a network that traps water and forms a gel.

If corn flour is mixed with water and heated, the starch granules absorb water until they rupture, the starch then disperses in the water and the mixture becomes more viscous and forms a gel on cooling. Other types of gels are formed with pectin and agar. Pectin, a form of carbohydrate found in fruits is used in the production of jam to help it set. Agar is a polysaccharide extracted from seaweed which is capable of forming gels, If a gel is allowed to stand for a time, it starts to "weep". This loss of liquid is known as syneresis.

b) Emulsions:

An emulsion is a mixture of two or more immiscible liquids. One liquid is dispersed in the other. that is material that keep fat globules in water droplet or water droplet in fat are emulsifiers. When water and oil are shaken together, they form an emulsion. This emulsion is unstable. An emulsion may be oil-in water (o/w) in which case small oil droplet are dispersed through water eg, milk or water-in oil (w/o) in which case small water droplets are dispersed through oil eg:- butter.

An emulsifying agent is made up of two parts. One is hydrophillic and other is hydrophobic. The emulsifier holds the disperse phase within the continuous phase. This results in the emulsion becoming stable.

Mayonnaise is an example of a stable emulsion of oil and vinegar, when egg yolk may be used as an emulsifying agent. Stabilisers are often added to emulsions to increase the viscosity of emulsion to increase the viscosity of the product. These help improve the stability of the emulsion, as over the time emulsion may separate.

c) Foams:

Foams are composed of small bubbles of gas dispersed in a liquid eg:- egg white foam. As liquid egg white is whisked, air bubbles are incorporated. The mechanical action causes albumen proteins to unfold and form a network, trapping the air. If egg white is heated, protein coagulates and moisture is driven off. This forms solid foam, eg:- a meringue. Ice cream, bread and cake are other examples of solid foams.

Foam stability is measured as the times required to lose with 50% of the liquid or 50% of the volume from the foam. Generally, heating a globular protein to achieve partial denaturation will increase foaming properties.

Colloidal Systems in Food: Functions, Types and Stability

Classification and Function of Colloidal Systems in Food:
A colloid is a type of chemical mixture where one substance is dispersed evenly throughout another. Colloids are formed when one substance is dispersed through another, but does not combine to form a solution. There are many types of colloidal systems depending on the state of the two substances mixed together.

The colloidal systems can be classified into two **general classes** on the basis of their affinity for liquids:

- **Lyophilic Systems**: The system in which dispersed phase and liquid dispersion medium attract each other is called lyophlic systems.
- **Lyophobic Systems**: The systems in which the dispersed phase and liquid dispersion phase repel each other is called lyophobic systems.**Properties of Colloidal Systems**
- **The** colloidal system shows following properties
  1. **Adsorption: The tendency of molecules and ions to adhere to the surface of certain** solids **or liquids is called adsorption.** Colloidal particles show a high tendency of adsorption. Thus, colloidal systems provide a large surface area for adsorption of molecules and ions.
  2. **Brownian Movements:** Robert Brown in 1927 observed that colloidal particles show random dancing movements. These movements were named Brownian movements.
  3. Tyndall **Effect:** The colloidal particles scatter light. This is called Tyndall effect. **The** path of light appears **as** a cone. It is known **as Tyndall cone.** This property helps to detect the presence of colloidal particles.
  4. **Precipitation: The** additions of an electrolyte remove the electrical double layer present around the colloidal particles. As a result the dispersed particles **of** a colloidal suspension will aggregate and precipitate.
  5. **Electrical Properties:** All colloidal particles carry same electric charge. This charge may be positive or negative.

There **is** a adsorption of free ions in the dispersion medium. It produces an electrical double layer around the colloidal particles. The electric charges on the colloidal particles stabilize the colloidal systems.

6. **Filtration:** The colloidal particles cannot pass through a parchment membrane. This property of colloidal dispersions is used to separate them from true solution by a process called **dialysis.**
7. **Phase Reversal: The sol and gel form** of colloidal system can be interchanged due to change in certain conditions. Certain lyophilic sols form gels under certain conditions. For example, aqueous agar sols are cooled. It forms a jelly-like gel. The conversion of a sol to a gel is called **gelation. If** a gel of gelatin or agar is heated, it will convert back to a sol. This process is known as solation. The property of colloidal dispersions is called phase reversal.

A colloidal system consists of two separate phases: a dispersed phase (or internal phase) and a continuous phase (or dispersion medium). A colloidal system may be solid, liquid, or gaseous. The substance which is dispersed is known as the disperse phase and is suspended in the continuous phase. Egg white foam is an example of this. Air bubbles (disperse phase) are trapped in the egg white (continuous phase) resulting in a foam.
Colloidal dispersion is a two phase system in which the particles in the dispersed phase are between 1 and 100 nm in diameter. For this reason, most manufactured foods can be considered as food colloids and many contain hydrocolloids that are added to control stability and rheological properties.

Food hydrocolloids are high molecular weight hydrophilic biopolymers used in food products to control their texture, flavor and shelf life. Colloidal systems in foods can be classified into different groups based on the states of matter constituting the two phases. They are sols, gels, emulsion and foam. Emulsion and foam again can be categorised into solid emulsion/foam and liquid emulsion/foam.

Colloids are formed when one substance is dispersed through another, e.g., sols (a solid is dispersed in a liquid), gels (a liquid held in a solid network, e.g., jam or jelly), emulsions (oily and watery liquids mixed together, e.g., milk and butter), foams (bubbles of gas trapped in a liquid, e.g., whisked egg white or whipped cream), solid foam (bubbles of gas trapped in a solid, e.g., meringue, cake, bread).

Types of Colloids

Examples	Dispersing Medium	Dispersed Substance	Colloid Type
Fog, aerosol sprays	Gas	Liquid	Aerosol
Smoke, airborne bacteria	Gas	Solid	Aerosol
Whipped cream, soap suds	Liquid	Gas	Foam
Milk, mayonnaise	Liquid	Liquid	Emulsion
Paint, clays, gelatin	Liquid	Solid	Sol
Marshmallow, Styrofoam	Solid	Gas	Solid foam
Butter, cheese	Solid	Liquid	Solid emulsion
Ruby glass	Solid	Solid	Solid sol

Most colloids are stable, but the two phases may separate over a period of time because of an increase in temperature or by physical force. They may also become unstable when frozen or heated, especially if they contain an emulsion of fat and water.

Functions of Colloidal Systems in Food Products:

Colloidal systems give structure; texture and mouth-feel to many different food products, for example – Jam, ice cream, mayonnaise. Food colloid contains hydrocolloid that gives stability and rheological properties of food components. An emulsifying agent may be used to help the oil and water phases to mix permanently.

Types of Colloidal System in Food:

(i) Sols and Gels: A sol can be defined as a colloidal dispersion in which a solid is the dispersed phase and liquid is the continuous phase. Gravy, stirred custard and other thick sauces are some of the examples of sols. When a jelly is made, gelatin is dispersed into a liquid and heated to form a sol. As

the solution cools, protein molecules unwind forming a network that traps water and forms a gel.
If corn flour is mixed with water and heated, the starch granules absorb water until they rupture, the starch then disperses in the water and the mixture becomes more viscous and forms a gel on cooling. Other types of gel are formed with pectin and agar. Pectin, a form of carbohydrate found in fruits, is used in the production of jam to help it set.

However, for it to gel there must be at least 50% sugar and conditions should be acidic. Agar is a polysaccharide extracted from seaweed which is capable of forming gels. If a gel is allowed to stand for a time, it starts to 'weep'. This loss of liquid is known as syneresis.

(ii) Emulsions:

An emulsion is a mixture of two or more immiscible (they will not mix together) liquids. One liquid (the dispersed phase) is dispersed in the other (the continuous phase), i.e., material that keep fat globules in water droplet or water droplet in fat are emulsifiers. When water and oil are shaken together, they form an emulsion. This emulsion is unstable.

If left to stand, the oil will form a separate layer on top of the water, e.g., traditional French dressing. A stable emulsion is formed when two immiscible liquids are held stable by a third substance, called an emulsifying agent. An emulsion may be oil-in-water (o/w) in which case small oil droplets are dispersed through water, e.g., milk, or water-in-oil (w/o) in which case small water droplets are dispersed through oil, e.g., butter.

(iii) Foams:

Foams are composed of small bubbles of gas (usually air) dispersed in a liquid, e.g., egg white foam. As liquid egg white is whisked, air bubbles are incorporated. The mechanical action causes albumen proteins to unfold and form a network, trapping the air. If egg white is heated, protein coagulates and moisture is driven off. This forms solid foam, e.g., a meringue. Ice cream, bread and cake are other examples of solid foams.

Stability of Colloidal Systems: All colloidal systems have two phases a continuous phase and discontinuous or dispersed phase. The particles of the dispersed substance are suspended in the mixture and do not completely dissolved within. The substance which is dispersed is known as the disperse phase and is suspended in the continuous phase. Most colloids are stable. The stability depends on the interaction between the two phases. But the two phases may separate over a period of time because of an increase in the temperature or by physical force.

Stability of Sols and Gel in Food:

A sol is a colloidal system in which a solid is dispersed phase and liquid is the continuous phase. The proper ratio of the ingredients is necessary to achieve the desired viscosity of the sols at a certain temperature. Pectin is hydrophilic and attracts a layer of water that is bound tightly to the molecules by hydrogen bonds. So water forms an insulating shield for the pectin providing layers that inhibit bonding between the molecules of the colloidal substances.

Sols can be transformed into gels as a result of reduction in temperature. In pectin gel, the pectin molecules are the continuous phase and the liquid is the dispersed phase while in pectin sol, the pectin molecules are the dispersed phase and the liquid is continuous phase. Sols may be formed as a preliminary step in making a gel. Jams and jellies made with pectin are common examples that form a sol prior to the desired structure.

Stability of Emulsion in Food:

An emulsion is a mixture of two or more immiscible (they will not mix together) liquids. One liquid (the dispersed phase) is dispersed in the other (the continuous phase), i.e., material that keep fat globules in water droplet or water droplet in fat are emulsifiers. An emulsion may be oil-in-water (o/w) in which case small oil droplets are dispersed through water, e.g., milk, or water-in-oil (w/o) in which case small water droplets are dispersed through oil, e.g., butter.

An emulsifying agent is made up of two parts. One is hydrophilic (water loving) and the other is hydrophobic (water hating). The emulsifier holds the disperse phase within the continuous phase. This results in the emulsion becoming stable.

Mayonnaise is an example of a stable emulsion of oil and vinegar, when egg yolk (lecithin) may be used as an emulsifying agent. Stabilisers are often added to emulsions to increase the viscosity of the product. These help improve the stability of the emulsion, as over time the emulsion may separate. Stabilisers also increase shelf life, E461 methylcellulose, used in low fat spreads.

UNIT 5 WATER

Structure

5.0 OBJECTIVES

After studying this Unit we shall be able to:

- state the significance and role of water in food processing;
- describe the structure and properties of water;
- differentiate between water content and water activity in foods;
- explain the significance of water activity in controlling the physical, chemical and biological properties of foods;
- explain the effect of water in food spoilage; and
- describe the water quality and standards used in the food industry for different purposes.

5.1 INTRODUCTION

We all know that water is essential for the sustenance of all forms of life on the planet Earth. Its enormous usability and utility makes it a wonder liquid. It not only occupies about 70% of our planet but also constitutes a good component of the living systems like the plants, animals, and the human body. All the food products contain varying amount of water in their tissues; in many cases to the extent of more than 90 per cent. Various quality and processing attributes like deterioration, dehydration, spoilage etc., in raw as well as processed foods, are influenced by the water content.

It is very important to understand the nature and properties of water to relate these with various processes related to the food quality and its maintenance in food industry. Water activity and sorption isotherms are two important concepts which help in understanding the role of water in drying, packaging and preservation etc. The physical, chemical and microbiological quality of water used in food processing operations should conform to certain standards. Therefore, knowledge of the quality parameters and standards of water is also very important.

In this first Unit of the Block let us look at some important aspects of water. We begin with explaining the structure of water, its association in liquid and the solid state and the effect of the structure on physical and chemical properties of liquid water. The ways in which the water is present in foods, related concept of water activity and its effect on food spoilage has been discussed in detail. Lastly, a section in the Unit is dedicated to the aspects of water quality and standards.

Since the unique properties of water are a consequence of its structure, we shall first examine the structure of water in the following section.

5.2 WATER: STRUCTURE AND PROPERTIES

Hydrological cycle is defined as the cyclic process of evaporation, cloud formation, rainfall snowfall and refilling of water bodies.

You know that water exists in three forms: found as solid (ice) below 0°C in liquid form as water between 0°C and 100°C and as gas above 100°C at the atmospheric pressure. All the three states exist as part of the hydrological cycle. Water is indispensable and unique in many ways. In its liquid form, it is considered a universal solvent due to the ease with which many substances dissolve in it. Its being liquid is striking in contrast to the hydrides of elements close to oxygen in the periodic table (e.g. NH_3, H_2S etc.), which are gases at room temperature. Similarly the solid form of water i.e. ice has lower density than its liquid form. It is another unique feature of water. The lower density of ice helps it to float on the surface of water bodies in cold regions and thus facilitates in the sustenance of aquatic life during very cold seasons. The gaseous form of water i.e. water vapour is an essential constituent of atmosphere responsible for the humidity and a number of phenomena like precipitation (rain) etc. The uniqueness of water can be attributed to its structure. Let us try to look into it.

5.2.1 Structure of Water

A molecule of water containing deuterium- an isotope of hydrogen is called heavy water and has a molecular formula of D_2O

The molecular formula of water is H_2O. You know that oxygen has six valence electrons and hydrogen has one valence electron. According to Lewis formulation, in order to complete the octet, oxygen shares one electron each with the two hydrogen atoms. In the process, the hydrogen atoms also acquire two electrons thus completing their duplet as shown in Fig 5.1(a).

The **dipole moment, μ,** is a measure of polarity of the bond. A pair of opposite charge, *q*, separated by a distance, *d*, has a dipole moment of $\mu = d\, q$ with the direction pointing towards the positive charge.

(a) Lewis structure **(b) Tetrahedral structure**

Fig. 5.1: Structure of water molecule as per Lewis and hybridisation concepts

Water is a bent molecule with a bond angle of 104.5° and its shape may be explained in terms of hybridisation of the valence orbitals of oxygen to give tetrahedrally oriented sp^3 hybridised orbitals. Two of these hybridised orbitals form bonds with hydrogen atoms by overlapping with their 1*s* orbitals while the other two accommodate the non-bonding electron pairs. You would recall that a tetrahedral structure has a bond angle of 109.5^o.However, due to differential interaction between the bonded and non bonded pairs of electrons as shown in the structure of H_2O molecule 5.1(b), the tetrahedral gets slightly distorted and the H-O-H bond angle becomes 104.5°

The unshared pair of electrons on oxygen atom makes it slightly negative while the two H atoms become slightly positive. The charge separation in water molecule gives rise to two dipoles in the molecule. These dipoles are responsible for causing strong interactions with the other water molecules forming hydrogen bonds as shown in Fig. 5.2. It is due to these intermolecular hydrogen bonds that the water remains in liquid form at room temperature.

This charge distribution around a water molecule is very important in terms of its microscopic and macroscopic, chemical and physical properties (subsection 5.2.2.).

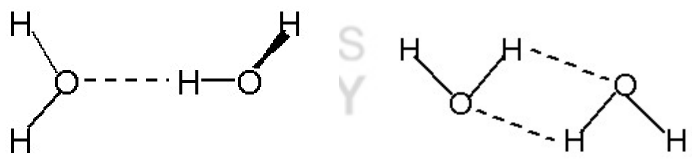

Fig. 5.2: Hydrogen bonded water molecules

Water molecules not only form hydrogen bonds among themselves, they form hydrogen bonds with any molecule that contains N–H, O–H or F–H bonds i.e. a bond between a hydrogen atom and an electronegative element. Many foodstuffs like starch, cellulose, sugars, proteins, DNA, and alkaloids etc., contain a number of such bonds which are both H-donors as well as H-acceptors in the formation of hydrogen bonds.

Before reading how the structure of water molecule affects its properties, try to answer the following Questions.

Check Your Progress Exercise 1

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

Tick (√) mark on the correct answer for the statement given below.

1) The bond angle in the tetrahedral structure of water is 104.5^o instead of 109.5^o because:

a) the water molecule has a triangular structure.

b) the oxygen atom is not sp^3 hybridized.

c) the lone pair-lone pair repulsion is more than the lone pair- bond pair repulsion.

d) there is charge separation between oxygen and hydrogen atom.

5.2.2 Properties of Water

It was mentioned earlier that water is called a wonder liquid due to some of its unique properties not common to other liquids. It is mainly due to the structure of water molecule and its ability to form hydrogen bonds. Let us take up some of the unique properties of water and understand their correlation with the structure.

The hydrogen bond is quite weak (2 – 10 k cal/mol) as compared to covalent bond (~100 k cal/mol)

- **Melting and boiling points:** Water has high melting and boiling points as compared to the substances of similar molecular weight. This is attributed to hydrogen bonding that leads to the association of a large number of water molecules. Though hydrogen bonds are weak, they are present in large number. Therefore, lot of energy is required to break these leading to increased the melting and boiling points.

The high heat capacity of water means that large quantities of energy are absorbed or released when its temperatures changes.

- **Specific heat/Heat capacity:** The heat capacity of a substance is defined as the energy required in changing the temperature of the substance by 1°C. It is actually a measure of the amount of heat a substance can store. Liquid water has the largest heat capacity per unit mass of all substances. It is due to slow hydrogen bond breaking. It implies that high energy consumption would be required for processing the food containing water. However, the high heat capacity is advantageous for humans in buffering the rapid temperature changes with alterations in the environment.

- **Heat of fusion, Latent heat vapourisation and Heat of sublimation:** Water has high heat of fusion, vapourisation and sublimation. **Heat of fusion** is defined as the energy required in changing 1 g of ice at 0°C to liquid whereas the **latent heat of vapourisation** refers to the heat required to change liquid water to the gaseous state. Similarly, **heat of sublimation** is concerned with the sublimation process i.e., direct conversion of solid (ice) to gas (water vapour). This is done at pressures below 4.58 mm Hg and forms the basis of freeze drying.

Freeze drying is one of the ways of food preservation.

In solid state of water (ice) the hydrogen bonds hold the individual molecules together in a regular three-dimensional lattice having an infinite array of the tetrahedral water molecules. Fig. 5.3

- **Density:** The liquid water has a hexagonal lattice structure. When the temperature of liquid water at room temperature is lowered, its density increases like that of any other substance and reaches a maximum value of 1.00 at around 4^{o}C. However, on further decreasing the temperature it starts decreasing. This unusual decrease is due to the organization of water molecules in such a way that each of the oxygen atoms is surrounded in tetrahedral fashion by four additional oxygen atoms. A lot of empty space is created in this open structure which is stabilized by extensive hydrogen bonding. This gives rise to a cage structure of water in solid state i.e. ice, Fig. 5.3.

  Since the ice is lighter than water, it floats at the surface and the aquatic animals are able to survive beneath the layers of a frozen water body like lake or river.

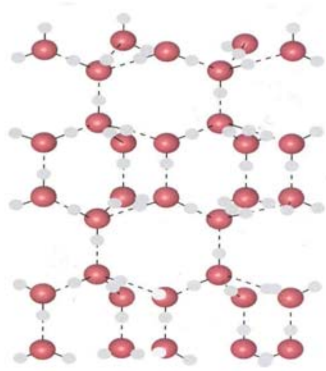

Fig. 5.3: Cage structure of ice

- **Dielectric Constant:** Water has high dielectric constant. Dielectric constant is a measure of the relative effect of the medium or the force with which two oppositely charged poles attract each other. The high dielectric constant of water is due to the polarity in the molecule. It enables water to separate ions of electrolytes by reducing the electrostatic attraction between them. The dielectric behaviour of water is made use of in designing sensors for measuring water activity (subsection 5.3.2) an important parameter.

  The dipolar nature and polarity of water molecule affect its interaction with various biomolecules constituting the food. If the biomolecule has polar groups in structure then it will have a stronger dipole-dipole interaction with the water molecule. Such molecules are said to be **hydrophilic** (water loving) in nature, i.e. glycerin group in mono or diglycerides. The molecules which do not possess polar groups interact or dissolve in water with difficulty. These are called to be **hydrophobic** in nature, e.g., the side chains of some amino acids like valine, leucine etc., constituting a protein.

- **Supercooling:** Another property of water which is important in the preservation and deterioration of food products is its supercooling. It refers to cooling the pure water to below 0°C down to about -40°C to -50°C. Supercooling finds application in the storage of food products like fruits and vegetables and also the prepared products.

Now check your understanding regarding the properties of water by answering the following Questions.

Check Your Progress Exercise 2

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1) Fill in the blanks spaces with appropriate words.

a) The molecules which have a binding affinity for water molecule are said to be……………………. in nature.

b) The property of water made use in the freeze drying preservation of food is …………………….

c) Water can absorb a lot of heat before it begins to get hot due to its high …………………….

d) The dielectric constant of water is high due……………………in the molecule.

5.3 WATER IN FOODS

We consume food in its raw as well as in the cooked form. You must have observed that all the food products contain certain amount of water. This is very obvious in the case of vegetables and fruits like spinach, cucumbers, watermelons etc. The water contained in raw foods is referred to as the **moisture content** of those foods. The moisture content of certain foods depends on the temperature and partial vapor pressure of water in the surrounding. These are called **hygroscopic foods**. On the other hand, the foods in which the moisture content does not get affected by these factors are called **non-hygroscopic.** The hygroscopic foods can absorb water in a number of ways. This is referred to as **sorption** and can occur by formation of a hydrate, binding to surface, diffusion in the food, capillary condensation, formation of a solution etc. Let us first learn about the forms/ types in which water is present in food products.

5.3.1 Types of Water in Foods

The water content or the moisture content of a food influences its appearance, texture and flavour. It varies a great deal in different food items. The green leafy vegetables contain more than 90 per cent of water while it may be negligible in oils and fats like ghee, butter, oil etc. Table 5.1 enlists the water content of some common food materials.

The water content of a food is generally defined in terms of its moisture content which can be determined accurately by measuring the weight of water present in a known weight of sample.

Table 5.1: Water Content of Some Common Foods

Products	Water (%)
Green leaves	95
Tomato	95
Water melon	93
Orange	87
Potato	78
Banana	75
Butter	16
Rice	12
Legumes (dry)	9-11

Water in foods can be either in free or bound form, depending on its interaction with the surrounding molecules. The **'bound water'** refers to water that is physically or chemically bound to other food components Many compounds like starch, proteins and some salts have water bound to them in the form of hydrates.

The **free water** is the bulk water free from any other constituents. It is held in narrow channels between certain food components due to capillary forces and is held trapped within the spaces in food. It is surrounded by physical barrier e.g., biological cell that prevents it from escaping. As you will read in the next subsection, the free water is actually responsible for the microbial growth and deterioration of food. This form of water is also called the **available water**.

Another form of water in food is called **imbibed water.** This water is found in hydrophilic gums like gelatin which is a type of protein with ability to absorb a large amount of water. Gelatin forms a jelly like mass on absorbing or imbibing water. Imbibed water is more or less like the hydrate formation and involves hydrogen bonding. A yet another form of water in food is **adsorbed water**. Some solid foods have the ability or tendency to adsorb water on surface. The powdered forms of the solids adsorb more water because of a larger surface area.

5.3.2 Moisture Content

The moisture content of a food item is defined as the amount of water lost per gram of the food product at about 100^o C. Mathematically it can be represented as follows.

$$\% \text{ Moisture} = (m_w/m_{sample}) \times 100$$

where, m_w = mass of water

m_{sample} = mass of sample

Mass of water can be related to the number of water molecules in the following manner:

$$m_w = n_w M_w/N_A$$

n_w = no. of water molecules

M_w = molecular weight of H_2O (18g mol^{-1})

N_A=Avogadro number = 6.022×10^{23} mol^{-1}

Avogadro Number is defined as the number of atoms, molecules or ions in one mole of a substance. It equals 6.022×10^{23} mol^{-1}

It is important to find out the moisture content of a food as it helps to know:

- the probability of microbial growth;
- the food quality as the water content determines the texture, taste, appearance and stability of foods; and
- the behaviour of foods during and post processing e.g. mixing, drying, packaging, storage etc.

A number of analytical techniques have been used to measure the moisture content of foods and their advantages and disadvantages. The loss on drying, infrared, NMR or Karl Fisher titration are commonly employed tools. Such moisture determination is essential in terms of product quality, composition, shelf life, package determination etc.

Though important, water content or per cent moisture is not a reliable predictor of microbial responses and chemical reactions in food products. The water content of a safe product varies from product to product and from formulation to formulation. One safe, stable product might have a water content of 15 per cent while another with a water content of just 8 per cent is susceptible to microbial growth. This is so because the microbial stability or physico-chemical properties of food are often determined by amount of free water present rather than the total amount of water. It is the free water, not the bound one, that supports the growth of bacteria, yeasts and molds (fungi). This unbound or **available water** is expressed in terms of **water activity.** This is a crucial parameter and is often ill understood. In the next subsection we shall try to understand the term water activity and its significance. Before moving on to the next subsection, assess your understanding about the moisture content by answering the following exercise.

Check Your Progress Exercise 3

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1) Put a (√) mark in front of the correct statements and (x) mark in front of the wrong statements.

a) The amount of water present in some foods can change with a change in the amount of water vapours in the surrounding atmosphere.

b) The bound water is responsible for the microbial growth in food and hence deterioration of that particular food.

c) A food with a large amount of water/moisture content is always more liable to be attacked by microbes.

2) The percentage of the moisture content in cucumber is 90 %. How many water molecules will be there in 1g of this vegetable?

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

5.4 WATER ACTIVITY

The water present in foods interacts with major hydrophilic nutrients such as carbohydrates, proteins, water-soluble vitamins, and minerals etc. by means of polar hydrogen-bonding interactions. The alkyl chains of fats and proteins, on the other hand, are hydrophobic in nature, and therefore do not tend to interact with water. In other words the hydrophilic molecules cause the water molecules to bind while hydrophobic do not. We may categorize the water within food into bound water, affected water, and free water in the order of their decreasing strength of interaction. Depending upon the strength of interaction the water may escape with varying degree of tendency. Since the structure and properties of the bound water get altered due to the interactions we can say that the properties of water in food are different from those of pure water.

The water activity is related to moisture content which is not bound to the food component and can be exchanged between the product and its environment.

Though we have used the terms like 'bound' and 'free' but we should be clear of the fact that these refer to the *relative strength* of the interaction between different food constituents and water. Different molecules of bound water may be free to different extents and similarly the free water molecules are bound to some extent.

As mentioned earlier, the microbial and chemical stability of a food product is directly related to how much water is available in a food item, for biological or chemical reactions. This is measured in terms of **water activity** which describes the escaping tendency of the water in a sample. Let us read in the following subsections what is meant by water activity, the factors it depends upon and its determination

5.4.1 Definition of Water Activity

Generally speaking, water activity in foods is impacted mostly by either sugar or salt. We use this to preserve food.

Water activity is defined as the ratio of the vapour pressure of water in a food item (p) to the vapour pressure of pure water (p_O) at the same temperature. You know that the relative humidity of air is defined as the ratio of the vapour pressure of air to its saturation vapour pressure. Therefore, when a sample in a sealed chamber comes to equilibrium with the water vapour in the surrounding, the water activity of the sample can be equated to the relative humidity of surrounding air. Mathematically, it can be written as follows.

$$a_w = p/p_o$$

Where a_w = water activity

p = partial pressure of water in food material

p_0 = vapour pressure of pure water at the same temperature

Multiplication of a_w by 100 gives the equilibrium relative humidity (ERH) in per cent. Thus a food with an a_w of 0.65 would produce an ERH of 65 per cent.

$$a_w \times 100 = p/p_o \times 100 = \%\ ERH$$

Alternatively, the water activity may defined as

$$a_w = \text{\% Equilibrium relative humidity}/100$$

Since water activity is a ratio of vapour pressures; it has no units. Its value ranges from 0.0 (bone dry) to 1.0 (pure water) but most food products have a_w value in the range of 0.2 for very dry fruits to 0.99 for moist fresh foods. Water activity of some food products is given in Table 5.2.

Bone dry: without a trace of moisture

Table 5.2: Water Activity of Some Food Products

S. No.	Products	Water Activity
1.	Highly perishable vegetables, meat, fish, milk, bread	0.95
2.	Cheese, fruit juice	0.91
3.	Dry cheese, sponge cakes	0.87
4.	Fruit juice concentrates, flour, rice, pulses	0.80
5.	Jam, marmalade	0.75
6.	Dried fruits, nuts	0.65
7.	Noodles, spaghetti, etc.	0.50

5.4.2 Measurement of Water Activity

Water activity is not a directly measurable quantity and can be measured only with an indirect method. A devise called water activity meter is used to measure the water activity of a food product. It measures the water activity of a sample based on its vapour pressure. The a_w of a food stuff can be determined from the relative humidity of the air surrounding the food sample when the air and sample are at equilibrium. For the purpose of a_w measurement the food sample is placed in a small closed chamber and when equilibrium is established between the sample and the air surrounding it, the relative humidity of the air is measured. Smaller the chamber volume, faster is the equilibration at constant temperature.

Since water activity is a thermodynamic concept and is an equilibrium property at a given temperature and moisture content, the following requirements must be met in its measurement and reporting:

- The system should be in equilibrium
- The temperature must be specified
- The system should have a specific standard

You have learnt the concepts of water (or moisture) content and water activity of a food product in terms of their definitions, method of measurement and also their significance. You would agree that both the water content as well as the water activity are important and both of these must be specified for a state sample to fully describe its. However, water activity is the most relevant property for quality and safety issues.

Isotherms are the graphical curves obtained at constant temperature

The relationship between water content and water activity of food stuff can be expressed in terms of a plot, between the two at a given temperature, called sorption isotherm. Let us see how this is done in the next subsection. Before that, check your understanding of what you have read about water activity by answering the following exercise.

Check Your Progress Exercise 4

Note: a) Use the space below for your answer.

b) Compare your answers with those given at the end of the unit.

1) Match the statements given in column A with the terms given in column B.

	Column A		**Column B**
a)	Ratio of partial pressure of water in foods to vapour pressure of pure water multiplied by 100	i)	Water activity
b)	Water in foods responsible for microbial growth in water activity due to	ii)	Equilibrium relative humidity
c)	Percent equilibrium relative humidity divided by hundred is defined as	iii)	Available water

5.5 SORPTION ISOTHERMS

You are now familiar with two important water related terms i.e., water content or the moisture content and the water activity in the context of foods. These are interrelated; higher moisture content normally means a larger water activity. The relationship, however, is not linear. In fact, the variation in a_w with an increase in water content generally shows **a sigmoid (S-shaped) curve.** Such a curve at a given temperature is called the **moisture sorption isotherm**.

These isotherms are obtained by placing completely dry food samples in the atmospheres of increasing relative humidity at a given temperature and measuring the increase in the weight of the sample due to absorption of water. The data so obtained is then plotted to get the sorption isotherm. Thus a sorption isotherm is a plot of the amount of water absorbed (moisture content) as a function of relative humidity (or water activity). A schematic representation of a sorption isotherm is given in Fig.5.5.

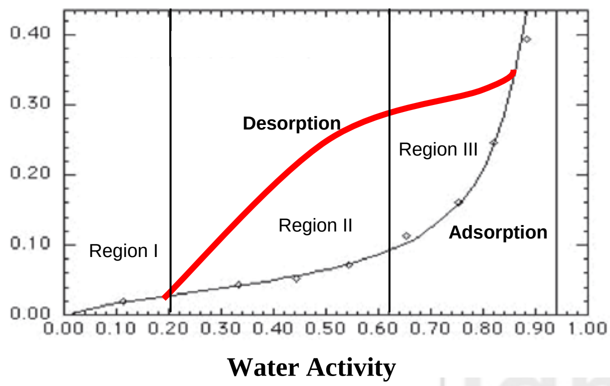

Fig 5.5: Schematic representation of adsorption and desorption isotherms

A typical sorption isotherm may be divided into three different regions depending on the state of water present in the food. The initial increase in the moisture content with an increase in the relative humidity corresponds to the formation of a **monolayer film** of water due to adsorption on food constituents. This **region I** is followed by **region II** that is due to the adsorption of additional layers of water over the monolayer. The **region III** is a result of the condensation of water, in the pores of the food material that dissolves the soluble components of the food. A simple equation called the **Brunauer Emmet Teller (BET)** equation can be used to calculate the monolayer moisture value from the a_w versus moisture content data of an isotherm. This value is an important determinant of the shelf life of the food.

Similar to the sorption curves, the **desorption isotherms** can be obtained by placing the wet food samples in the atmospheres of same relative humidity as in case of sorption isotherms at a given temperature and measuring the decrease in the weight of the sample due to desorption of water. The data so obtained is then plotted to get the desorption isotherm. A look at the sorption and desorption curves of a given food item reveals that the amount of water (moisture content) at any a_w may be different in the two types of isotherms. This difference between desorption and adsorption is called **hysteresis** and is generally observed in most of the hygroscopic products.

Significance of Sorption-Desorption Isotherms

The sorption isotherms drawn for different food products are quite significant in a number of ways. Some of these are listed below:

- These provide useful information for processing and packaging the dehydrated food items.
- A study of these graphs will be helpful in deciding about the food products that may be packed together.
- These help in determining the water content at certain critical a_w values related to stability and safety of the food items.
- These can be used in the selection of suitable ingredient to make a safe formulation at high moisture content.

Attempt the following exercise before proceeding further.

Check Your Progress Exercise 5

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1) Complete the blank spaces in the following statements with appropriate words.

The ………….. isotherms may be obtained for ..……..foods while the …………… isotherms are obtained with …….foods. There is a ………of weight in the first case and ………..of weight in the latter.

5.6 FOOD SPOILAGE

Most natural foods have a limited shelf life. You must have observed that fresh food items such as meat, fish, pepper, mangoes or oranges if kept in open for a few days, their appearance, smell and taste changes. These get covered with whitish or orange substances or start smelling bad. Some foods can be kept for a considerably longer time. No doubt, eventually these also get decomposed. This is known as decay and leads to food spoilage i.e., the food becomes unfit for consumption.

Spoilage can be defined as alterations in foods or the physiological, chemical and biological changes in a food that make it inedible or hazardous to eat. Certain organisms and chemicals present in the food and outside it are responsible for the gradual changes causing the spoilage of foods. The two main ways by which food can spoil are given below:

Natural decay: It is a result of moisture loss through respiration or evaporation of water and the action of enzymes present in the food by oxidation, browning and ripening processes.

Contamination by microorganisms: The enzymes present in the food facilitate its contamination by micro-organisms, (like bacteria, moulds and yeasts) and cause food spoilage. These microorganisms multiply rapidly in favourable conditions of moisture and temperature.

The effect of contamination is different on different components of food. For example, the proteins get putrified and produce foul smell while the fats and oils get rancid i.e., they begin to smell and taste bad. On the other hand cooked cereals containing carbohydrates become marshy and slimy on contamination and are called stale.

You have read that the microbial action on foods depends mainly on the water activity Let us understand their relationship.

5.6.1 Role of Water Activity

You have read that the chemical reactions and the microbial growth in a food product depend upon the water or moisture content and water activity or availability of water besides optimum temperature and other conditions. On the basis of moisture content, the food products can be broadly put into three categories as:

Low moisture foods e.g., dried or freeze dried foods having a moisture content of 5-15 per cent **intermediate moisture foods** e.g., cakes and dates with a moisture content of 20-40 per cent and **high moisture** foods e.g. fresh fruits and vegetables of greater than 40 per cent of moisture. Though moisture content is important, it is the water activity (a_w) that is critical factor for the shelf life of a food item. It may be used to predict stability with respect to physical properties like texture and caking, rates of deteriorative reactions and microbial growth. The critical a_w values with the effect on shelf life of foods, important in food industry are given in Table 5.3

The potentially hazardous foods or the food prone to spoilage are those that have a_w of greater than 0.85.

Table 5.3: Some Water Activity Values and their Effect on Shelf Life

S. No.	Water Activity Value	Effect on Food
1.	0.2–0.3	A monolayer of moisture is formed. It represents the optimal moisture content for the maximum shelf life of the dehydrated foods.

S. No.	Water Activity Value	Effect on Food
2.	0.35–0.45	The water is available outside the monolayer and the water phase requiring chemical reactions begin to occur. This may cause changes in physical state, e.g., loss of crispness, stickiness, and re-crystallization of amorphous state sugars.
3.	0.4–0.5	The soft materials like raisins etc., become hard due to drying out.
4.	0.6	Considered a critical point where there is high potential for growth of microbes if the moisture content increases.
5.	0.6–0.8	The rates of chemical reactions that require an aqueous phase increase and cause deterioration of foods, reaching a maximum. The rates however fall at higher moisture content.
6.	0.85	Another critical point, above which bacterial spoilage occurs and pathogens begin to grow.

Thus we realize that if we want to prevent the food spoilage or the action of microbes and maintain food quality, the water activity of the food product needs to be lowered. Conventionally, the water activity in foods has been controlled by drying, addition of sugar or salt, and by freezing.

The added salt or sugar dissolves in the free water and makes it bound or unavailable. In other words, it decreases the water activity and makes the food less prone to spoilage. Lowering the temperature checks the activity of the enzymes in the food and also makes conditions unfavorable for the growth of microorganisms. Drying of the product acts as a means of preserving the food by lowering the water activity.

After answering the following exercise you can proceed on to reading another important aspect of water i.e. the water quality and standards

Check Your Progress Exercise 6

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1) Arrange the following foods in the increasing order of their water activity.

Spinach, Almonds, Orange juice, dried peas.

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

5.7 WATER QUALITY AND STANDARDS

You know that water as used by us comes from various sources. We get fresh water from natural sources like rivers, lakes, streams etc. and ground water which in most of the cases is drawn by a hand pump for the household purposes or by tube wells and dug wells for use in irrigation of crops. As you might have noticed, water used for cooking / drinking is different from the one used for washing dishes or clothes. The two are of different quality. In order to understand the quality and standards of water used for various purposes it is important to be aware of the various parameters of water quality. The water quality parameters can be broadly put into two categories:

- Physicochemical Parameters
- Biological Parameters

5.7.1 Physicochemical Parameters of Water Quality

As the name suggests, the physicochemical parameters depend on the physical and chemical characteristics of water. The physical characteristics of water are given briefly in Table 5.4.

Table 5.4: Some Physical Characteristics of Water

S.No.	Physical Property	Explanation
1.	Turbidity	It is mainly caused by the presence of insoluble materials in suspended or colloidal forms.
2.	Colour	Fine water is colourless. The colour of water sample depends upon the light penetration in water. It gives the visible evidence of contamination in water, and its acceptability for any use.
3.	Odour	It is usually the results of volatile inorganic and organic compounds such as hydrogen sulphide, ammonia, mercaptans etc. Odour is the first test for checking the suitability of drinking water, since the human sense of smell is far more sensitive than human taste.
4.	Taste	It is generally associated with odour. Hence, the inference drawn during study of odour holds good for taste also.
5.	Temperature	It decides to a large extent the biological activities of water. Cooler water has a wider diversity of biological species. At still lower temperature, the biological activities become slower. Most chemical reactions involving dissolution of solids are accelerated by increased temperature.
6.	Electrical conductivity	It is related to its total dissolved solids. Since it is an easily measurable parameter, it is a useful indicator to judge the water quality.

Chemical Characteristics of Water

The chemical characteristics of water are determined by the presence of chemical constituents like, total dissolved solids, various ions (OH^-, CO_3^{2-} and HCO_3^-), sulphates, chlorides, fluorides, nitrates and metal ions. These are expressed in terms of total dissolved solids (TDS), the alkali content etc. The presence of all the inorganic and organic constituents affects the quality of water. It is worthwhile to read how the inorganic substances affect the quality.

Hardness of Water

You must have observed that while using bathing or washing soap, sometimes you get good lather other times we complain of a poor lather formation with soap. This is due to the presence of salts in water especially the ground water. These salts are the chlorides, carbonates, bicarbonates and sulphates of calcium and magnesium. Water having these salts is called **hard water.**

Generally, surface waters are softer than ground waters.

The hardness in water can be temporary or permanent. Temporary hardness is due to the bicarbonates of Ca and Mg while the permanent hardness is caused by the sulfates and chlorides of magnesium or calcium. Hardness is expressed in terms of the concentration of calcium carbonate in ppm units. The term total hardness indicates the concentration of calcium and magnesium ions. According to the value of 'total hardness', water are classified as follows.

Total Hardness (in ppm)	Type of Water
0 - 75	Soft
75 - 150	Medium
150 - 300	Very hard

On boiling the water the soluble bicarbonates are converted to insoluble carbonates, and the temporary hard water gets softened. Boiling, however cannot remove permanent hardness of water. The precipitated carbonates obtained on heating water result in the formation of scales in the pipes of homes and industries using hard water. The 'scales' can act as an insulating layer against efficient heat transfer and may eventually clog valves and pipes in homes and food production facilities. These scales can also be attacked by bacteria, thus making it quite difficult to clean and sanitize equipment.

In the process of cooking in hard water, the calcium ions present in it change the textural properties of the food product. The calcium ions may form insoluble calcium pectates which are beneficial for the firmness of the cooked food. However an excessive amount of calcium may make the food quite tough.

5.7.2 Biological Parameters of Water Quality

The biological species presents in water like algae, fungi, protozoa and bacteria affect the quality of water. You may be aware of a large number of diseases caused by the presence of microorganism like virus, bacteria, protozoa and helminthes. Some such diseases are hepatitis, cholera, amoebic dysentery, hookworm etc. The presence of microbes in water ascertains the **microbiological quality** of water.

The microbiological quality of water used throughout the industrial plant should meet the same standards as are required for drinking water. The fitness of water for drinking purposes with respects to bacterial content is determined by the presence or absence of the *coliform* group of bacteria. In fact the presence or absence of the coliform group of bacteria decides the bacteriological quality of water. The most widely known member of the group is *Escherichea coli.* The total coliform count should not be more than 50 MPN/100ml.

MPN: Most probable number; calculated using statistical methods

Water is used for different purposes in food processing. Some of these are:

- as ingredients in finished products,
- for generating steam,

- for cleaning raw materials,
- for cleaning plant and equipments, and
- as heat exchange medium for heating and cooling etc.

In general, only potable water should be used in the preparation of food intended for human consumption. Potable water is that water which contains no bacteria and is aesthetically satisfactory for drinking purposes, i.e. free from undesirable odours and flavours.

5.7.3 Water Standards

Water standards are prescribed by certain authorised agencies considering the type of use, quality criteria and also other features such as practical attainability, cost, local conditions, public need etc. In India, for instance, drinking water standards set by the following four agencies are commonly used.

i) BIS (Bureau of Indian Standards)

ii) ICMR (Indian Council of Medical Research)

iii) CPHEEO (Central Public Health and Environmental Engineering Organization)

iv) WHO (World Health Organization)

Among the industrial uses of water, the standards prescribed are dependent on the type of industry and its specific needs.

Check your understanding of the water quality by answering the following exercise.

Check Your Progress Exercise 7

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1) Define the following terms in one sentence each.

a) Hard water

b) Soft water

c) Portable water

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

5.8 LET US SUM UP

Water is essential for the sustenance of all forms of life and is called a wonder liquid due to its utilities. It is a major component of all living systems including food products and affects a number of processes like deterioration, dehydration, storage etc., in raw as well as processed foods. Structurally, water molecule is a distorted tetrahedron, with a bond angle of 104.5°, which can be explained in terms of hybridisation. The charge separation in water molecule makes it polar. The strong interaction with the other water molecules through hydrogen bonds makes it liquid at room temperature and also accounts for many of its unique properties like, high heats of fusion, vapourisation, sublimation and high heat capacity and dielectric constant etc. The low density of ice is due to the three dimensional cage like structure of networked water molecules.

The water present in the food products is referred to as their moisture content and is defined as the amount of water lost per gram of the food product at about 100^o C. It affects the texture, taste, appearance and stability as well as the behaviour of foods during processing. The moisture content depends on the partial vapor pressure of water in the surrounding and the temperature for hygroscopic foods whereas for non hygroscopic foods it is not so. Further, depending on its interaction with the surrounding molecules the water in foods can be called free water, available water, imbibed water or adsorbed water. The water content of a safe product varies from product to product and from formulation to formulation.

The microbial and chemical stability of a food product is directly related to the amount of water available for biological or chemical reactions. This is measured in terms of **water activity** which describes the escaping tendency of the water in a sample. Water activity is defined as the ratio of the vapour pressure of water in a food item (p) to the vapour pressure of pure water (p_O) at the same temperature. A number of analytical methods are available for measuring the water activity of a sample based on its vapour pressure.

The water content as well as the water activity are important and must be specified to describe the water status of a food product. However, water activity is the most relevant property for quality and safety issues. The relationship between these two is expressed in terms of a plot between them at a given temperature, called 'sorption isotherm'. A sorption isotherm generally is a sigmoid curve. The monolayer moisture value for a product is an important determinant of its shelf life and can be obtained from the sorption isotherm by using a simple equation called the Brunauer Emmet Teller (BET) equation. The sorption isotherms help in determining the water content at certain critical a_w values related to stability and safety of the food items and can provide useful information for processing and packaging and co-packaging of the food items

The physiological, chemical and biological changes in a food that make it inedible or hazardous to eat is called food spoilage. This is caused by organisms and chemicals present in the food and its environment. These chemical reactions and the microbial growth in a food product depend upon the water or moisture content and water activity or availability of water, besides optimum temperature and other conditions. Though moisture content is important, it is the water activity (a_w) that is critical factor for the shelf life of a food item. It may be used to predict stability with respect to physical properties like texture and caking, rates of deteriorative reactions and microbial growth. Therefore to prevent food spoilage and maintain food quality, the water activity of the food product needs to be lowered. This is normally controlled by drying, addition of sugar or salt, and by freezing.

The physicochemical and biological water quality parameters of the water used in the food processing and preservation are very crucial. The important physical parameters are turbidity, taste, smell and color etc. while the chemical characteristics are expressed in terms of total dissolved solids (TDS), the alkali content etc. The presence of all the inorganic and organic constituents affects the quality of water. The presence of chlorides, carbonates, bicarbonates and sulphates of calcium and magnesium make water hard and it does not give lather with soap. The hard water affects the quality and the texture of the food prepared in it. The presence of biological species like algae, fungi, protozoa and bacteria in water affect its quality and may cause a large number of diseases like hepatitis, cholera, amoebic dysentery, etc. The presence of microbes in water ascertains its microbiological quality and in an industrial plant it should meet the same standards as are required for drinking water. In India, these standards set by BIS, ICMR, CPHEEO and WHO are commonly used.

5.9 KEY WORDS

Bound Water : The water in a food that displays significantly different properties e.g., vapour pressure, binding energy, freezability from those of free water.

Dielectric Constant : Relative dielectric permittivity (RDP), also called the dielectric constant, is a measure of the ability of a material to store a charge from an applied electromagnetic field and then transmit that energy.

Hard Water : Water that contains certain salts, such as those of calcium or magnesium, which form insoluble deposits in boilers and form precipitates with soap. Hardness caused by calcium bicarbonate is known as temporary, because boiling converts the bicarbonate to the insoluble carbonate; hardness from the other salts is called permanent.

Intermediate Moisture Foods : These are semi-moist with about 25% (15-50%) moisture but with some of the water bound (and so unavailable to micro-organisms) by the addition of glycerol, sorbitol, salt, or organic acids, so preventing the growth of micro-organisms.

Most Probable Number : The MPN technique estimates microbial population sizes in a liquid substrate. The methodology for the MPN technique is dilution and incubation of replicated cultures across several serial dilution steps. This technique relies on the pattern of positive and negative test results following inoculation of a suitable test medium (usually with a pH sensitive indicator dye) such as tubes and microwell plates. The results are used to derive a population estimate based on the mathematics of Halvorson and Ziegler.

Sorption Isotherm : A sorption isotherm is the graphic representation of the sorption behaviour of a substance. It represents the relationship between the water content of a product and the relative humidity of the ambient air (equilibrium) at a particular temperature.

Specific Heat : The specific heat is the amount of heat per unit mass required to raise the temperature by one degree Celsius. The specific heat of water is 1 calorie/gram °C = 4.186 joule/gram °C which is higher than any other common substance. As a result, water plays a very important role in temperature regulation. The specific heat per gram for water is much higher than that for a metal

Total Dissolved Solids : TDS tests measure the amount of all dissolved solids in the water. These solids are primarily minerals/salts, but can also include organic matter.

Water Activity : Water activity is defined as the ratio of the vapor pressure of water in a material (p) to the vapour pressure of pure water (p_o) at the same temperature. a_w is activity of water, or the escaping tendency of water in system divided by the escaping tendency of pure water with no radius of curvature.

5.10 TERMINAL QUESTIONS

1) Why does ice float on water?

2) List the unusual properties of water.

3) Why rivers do not freeze from the bottom up?

4) Define heat of fusion, specific heat capacity and latent heat of vapourization of water.

5) The bond angle of a single water molecule is very close to the angle of a perfect tetrahedron. How is this explained?

6) What is the correlation between moisture content and storage shelf-life of food?

7) Define high moisture, intermediate moisture and low moisture foods in terms of moisture content

8) Differentiate between free water and bound water.

9) What is hard water? How can you remove temporary hardness of water?

10) How can a reduced a_w help extend the shelf life of foods?

5.11 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1) c)

Check Your Progress Exercise 2

1) (a) hydrophilic

   (b) heat of sublimation

   (c) specific heat capacity

   (d) polarity

Check Your Progress Exercise 3

1) (i) √ (ii) X

   (iii) X

2) We know that, % Moisture = $(m_w/m_{sample}) \times 100$
   m_w = % Moisture x m_{sample} / 100
   = 90 x 1 / 100 = 0.9 g
   $n_w = m_w \times N_A / M_w$
   = 0.9 x 6.022 x 10^{23} / 18 = 9.76 x 10^{22} molecules

Check Your Progress Exercise 4

1) a) - ii)

   b) - iii)

   c) - i)

Check Your Progress Exercise 5

1) sorption, dry, desorption, wet, gain, loss

Check Your Progress Exercise 6

1) Almonds < Dried peas < Orange juice < Spinach

Check Your Progress Exercise 7

1) Your answer should include following points:

   a) water which do not form lather with soap.
   b) water which forms lather with soap.
   c) water suitable for drinking purposes.

5.12 ANSWERS TO TERMINAL QUESTIONS

The ice floats on water due to its lower density.

1) The unique properties of water are :
   a. high melting and boiling points,
   b. low density in the solid state,
   c. high heats of fusion, vapourisation and sublimation,

d. high dielectric constant,

e. extensive hydrogen bonding,

f. high heat capacity, and

g. Supercooling.

2) The ice formed on the surface of water body floats on it due to its low density and protects the inner bulk of water from cooling.

3) **Heat of fusion:** the energy required to change 1 g of ice at 0°C to liquid.

Specific heat capacity: the energy required in changing the temperature of 1g of the substance by 1°C.

Latent heat of vapourisation: the heat required to change 1g of liquid water to the gaseous state.

4) The formation of water involves the sp^3 hybridisation of the valence orbitals of oxygen atom giving tetrahedrally oriented four hybrid orbitals. Two of these form bonds with hydrogen atoms and two are occupied by lone pairs. As the lone pair-lone pair repulsion is more than the lone pair – bond pair repulsion this causes a slight distortion of the tetrahedral arrangement.

5) The moisture content is an indicator of the storage shelf-life of food; larger moisture content is not desirable if we wish to store the food for long. However, this cannot be generalized because certain food products with high moisture content have a good shelf life.

6) High moisture foods are the ones that have a moisture content of greater than 40% ; the intermediate moisture foods have a moisture content between 20-40% while the moisture content of low moisture foods is in the range of 5-15%

7) The 'bound water' in foods refers to water that is physically or chemically bound to other food components whereas the free water is the bulk water free from any other constituents. The free water is held in narrow channels between food components due to capillary forces. These terms are not absolute and refer to the *relative strength* of the interaction between different food constituents and water.

8) The water that does not form lather with soap is called hard water. It is due to the presence of chlorides, carbonates, bicarbonates and sulphates of calcium and magnesium in water. The temporary hardness can be removed by boiling.

9) A reduced a_w extends the shelf life of foods by reducing the water available for the biological or chemical reactions thus increasing the microbial and chemical stability of a food product.

5.13 SOME USEFUL BOOKS

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Lee Frank (1983). *Basic Food Chemistry,* The AVI Publishing Company Inc.

John deMan (1980). *Principles of Food Chemistry*, The AVI Publishing Company Inc.

Sumati R. Mudambi and Shalini Rao (1985). *Food Science*, Wiley Eastern Ltd.