GATE MATERIAL FOR LIFE SCIENCE

- Chemistry
- Bio Chemistry
- Bio Technology
- Botany
- Micro Biology
- Zoology

CHEMISTRY

Core Unit 1 – Introduction to the tools of Chemistry

In this core unit, you will build the basics to chemistry mastery. With these skills, you will form a solid foundation to understand chemistry and problem solving.

Tutorial 01: SAT Chemistry

SAT Chemistry is a SAT II Subject exam that can be taken to show a college a student's abilities in a specific subject. The test covers content typically covered in a first year, college-prep chemistry course. The test is written to cover every topic…they do not expect any one student to know everything on the exam. You can get the best score (5) without knowing every topic!

- **Move on when you get stuck…you're in a time crunch…move on if there's something that you never learned or studied. Remember, the test is written so that a every student will not know everything!**
- **Only guess if you can eliminate 2 or more choices. You're deducted ¼ point for every wrong answer (to prevent random guessing). It's better to leave it blank (no points awarded but no points deducted) than to guess from 5 choices randomly.**
- **Get used to working without a calculator. The calculations on the MC section are simple, but you need to practice them.**
- **Scan all the choices before choosing your answer.**
  Avoid word traps—try to rephrase things into terms you're more comfortable with.
- **Beware of absolutes—there are very few things in chemistry that are absolute!**

Problem-solving can be a very difficult task. But when a specific "attack" is used, the problems can be solved much more easily.

General Problem-Solving Technique

A technique for solving any type of problem involves:

- **Identify what's being given**
- **Clarify what's being asked**
- **Select a strategy (trial and error, search, recall, deductive reasoning, working backwards, etc)**
- **Solve using the selected strategy**
- **Review your answer**

Problem-Solving Technique for Word Problems

A problem-solving strategy that turns the above "general" strategy into a strategy specifically for solving word problems is the KUDOS method:

- **K = Known (identify the known)**
- **U = Unknown (identify the unknown)**
- **D = Definition (identify definitions, equations, equalities, constants needed)**
- **O = Output (use your definitions to output an answer)**
- **S = Substantiation (check appropriateness, units and significant figures of your answer).**

Tutorial 02: Introduction to Chemistry & the Laboratory

Chemistry is an experimental science, therefore it is necessary to be able to work with units and measurements accurately.

Metric System

The metric system is based on prefixes that indicate a power of 10 with base units.

Metric Prefixes commonly used in chemistry		
Prefix	**Symbol**	**Multiple**
Kilo	**k**	**1000**
Deci	**d**	**0.1**
Centi	**c**	**0.01**
Milli	**m**	**0.001**
Micro	**m**	**0.000001**
Nano	**n**	**0.000000001**

SI System

The International System of units gives a standard unit for each type of measurement.

SI Units commonly used in chemistry		
Measurement	**Unit**	**Symbol**
Mass	**Kilogram**	**kg**
Volume	**Liter**	**L**
Temperature	**Kelvin**	**K**
Length	**Meters**	**m**
Time	**Seconds**	**s**
Amount of substance	**Mole**	**Mol**
Energy	**Joule**	**J**
Charge	**Coulomb**	**C**

There are also some important non-SI units as well.

Non-SI Units commonly used in chemistry		
Measurement	**Unit**	**Symbol**
Length	**Anstrom**	**Å**
Pressure	**Atmosphere**	**Atm**
	Kilopascal	**kPa**
Energy	**Calorie**	**cal**
Temperature	**Celcius**	**°C**

Taking measurements

Measurements must be taken accurately. Always write down one more decimal place than the instrument tells for certain—a "0" if it's "one the line" and a "5" if it's "between the lines."

Lab Safety

There are several important safety rules that should be followed at all times:

- **Wear splash-proof goggles**
- **No eating or drinking**
- **Do not touch, tast or directly smell chemicals**
- **Tie back all loose clothing, hair and jewelry**
- **Always read the procedure ahead of time and follow it closely**
- **Never return unused chemicals to the original container**
- **Dispose of all chemicals as instructured**
- **Always report all incidents (spills, breakage, mistakes in performing a procedure) to our instructor!**

Common Lab Procedures

Some common lab techniques:

- **Always point the end of the test tube away from people when heating**
- **Waft smells towards you to smell**
- **Add acid to water to prevent concentrated acid splashes**
- **Use a fume hood when working with toxic fumes**
- **Never mouth pipette**

Tips for finding mass: Use a balance, don't put hot things on the balance, don't put chemicals directly on the balance, record exact mass. When finding volumes, use a graduated cylinder, read with level at eye level (you go to its level), record exact amount.

Some common techniques for separating mixtures: filtration (solid & liquid), chromatography (liquids based on attractions or size) and distillation (liquids based on boiling points). Some other common lab techniques are calorimetry—indirectly measuring energy changes, density—measure mass and volume of several samples, and titration—Find concentration of unknown solution.

Significant Figures

The significant figure rules are to allow people to read data or calculations and know with what precision the data was taken. The significant rules can be summarized in two rules: (1) If a decimal point is not present, count digits starting with the first the first non-zero number and ending with the last non-zero number; (2) If a decimal point is present anywhere in the number, start counting with the first non-zero number and continue until the end of the number. Rules on how to perform calculations with significant figures will be given in a future tutorial.

Fundamental Constants

Several numbers are used throughout chemistry and are important to be familiar with.

Fundamental constants commonly used in chemistry		
Name	**Symbol**	**Constant**
Avogadro's #	**NA**	**6.02 X 1023 mol-1**
Speed of light	**c**	**3.0 X 108 m/s**
Gas constant	**R**	**8.31** $\frac{L*kPa}{mole*K}$
		0.0821 $\frac{L*atm}{mole*K}$
Planck's constant	**h**	**6.63 ´ 10-34 J·s**
Charge of electron	**e**	**1.6 ´ 10-19 C**
Atomic mass unit	**m**	**1.66 ´ 10-24 g**
Std Temp & Pressure	**STP**	**273.15 K & 1 atm**

Tutorial 03: Math for Chemistry

Math skills are needed throughout a chemistry course.

Algebra

Algebra is used to solve equations by un-doing whatever is being done to an unknown variable. For example, if an equation has "x+2" then you would subtract "2" to solve for "x". Everything that is done to one side must be done to the other side of the equation as well.

Calculations with significant figures

You cannot become more precise after completing calculations than the original data was. Therefore, it is important to write the answer with the correct number of significant figures. When adding and subtracting with significant figures, you write the answer with the least number of decimal places that are in the problem. When multiplying and dividing, write the answer with the least number of significant figures as is in the problems.

Scientific Notation

Scientific notation is a way of writing large or small numbers as a multiple of 10. The decimal place is always placed behind the first non-zero number and the number of times the decimal point was moved to get there is used as the exponent of 10. Positive exponents represent large numbers (>1) and negative exponents represent small numbers (<1).

There are when working with scientific notation numbers:

- **Addition with same powers of 10: Add the numbers and keep the power of 10 the same.**
- **Subtraction with the same powers of 10: Subtract the numbers and keep the power of 10 the same.**
- **Multiplication: Multiply the numbers and add the powers of 10**
- **Division: Divide the numbers and subtract the powers of 10**
- **Power: Take the number to that power and multiply the power of 10 by the power**
- **Roots: Take the root of the number and divide the power of 10 by the root**

Logarithms

Logarithms are a way of counting in multiples of a base number. If $x = \log_b y$ then $y = b^x$. If no base is specified, it's assumed to be 10.

Calculator Tips

People often get incorrect answers simply from a mistake in the way they enter numbers into their calculator. When dividing by more than one number, use the ¸ button each time. When entering scientific notation, always use the EE (or EXP) button rather than entering (^10). Be sure to use parenthesis around addition and subtraction when combining with multiplication and division, and also when taking a value (especially a negative value) to a power.

Tutorial 04: Dimensional Analysis (Factor-Label Method)

Dimensional analysis is used to convert units.

The Principle Behind Dimensional Analysis

The guiding principle of dimensional analysis is that you can multiply anything by "1" without changing the meaning. An equality set into a fraction formation = 1. For example, if x = y, then x/y = 1 and y/x = 1. Therefore, the equalities can be set into fractions and multiplied to convert units.

Another concept necessary to understanding dimensional analysis is that units that are on the top and bottom of an expression cancel out.

Equalities Commonly used in Dimensional Analysis
Several equalities are used often in chemistry.

Equalities commonly used in chemistry	
4.18 J	1.00 cal
1 Å	10-10 m

1 cm3	**1 mL**
1 dm3	**1 L**
1 in	**2.54 cm**
1 kg	**2.2 lb**
1 atm	**101.3 kPa**
1 atm	**760 mm Hg**
1 mole	**6.02 ´ 1023 pieces**

Metric prefixes are also used to form equalities between different metric units.

Dimensional Analysis

To work dimensional analysis problems:

- **Write your known down on the left side**
- **Write down "=_____ [desired unit]" at the right side**
- **Identify equalities that will get you from the known information to the desired unit. If there is no equality that involves both the known and unknown, you'll have to find more than one to more than one step.**
- **Arrange the equalities into a fractional form so that the known unit will cancel out and the desired unit will be left.**
- **Multiply across the top of the expression and divide numbers on the bottom.**

Tutorial 05: Matter & Energy

Chemistry is the study of matter and its changes and interactions. Matter is anything that has mass and takes up space. There are two broad categories of matter—Pure Substances and Mixtures.

Pure Substances

Elements and compounds are both pure substances. A pure substance is when each particle is identical. Elements have each atom the same and compounds have each molecule the same. Compounds are atoms of more than one element chemically bonded together.

Mixtures

Mixtures are more than one type of pure substance physically mixed together. Mixtures can be categorized into homogeneous and heterogeneous. Homogeneous mixtures (also called solutions) look the same throughout; while heterogeneous have visible different types of matter.

Energy

Energy is the ability to produce heat or do work. There are two types of energy: Potential energy (or stored energy) and kinetic energy (energy due to motion).

Changes

Chemical changes produce a new substance while physical changes do not. Changes in state (melting, freezing, boiling, condensing, etc.) are physical changes. Dissolving is also a physical change, although it is often confused for a chemical change. Reacting with another type of matter, burning or rusting are examples of chemical changes. Often confused changes are melting (changing a solid to a liquid by adding heat), burning (chemically reacting with oxygen) and dissolving (combining two types of matter physically to produce a mixture). Mixtures can be separated by physical changes, compounds must be separated by chemical changes and elements cannot be separated by either.

Scientific Processes

There are many paths to follow when undertaking "science"—there is no one scientific method. Science involves observing, posing questions, forming possible explanations (hypothesis), experimenting, processing/analyzing data, looking for trends, more formation of possible explanations or question posing. Scientific processes form theories (which attempt to explain observed behavior) and laws (which describe or predict behavior, and are usually mathematical). A theory cannot become a law—one explains why and one describes what. A hypothesis is a proposed explanation for why something will occur (that may become a theory with enough evidence), while a prediction is simply a guess at what will happen—it does not attempt to say "why" it will happen.

Core Unit 2 – Atoms, Molecules and Reactions

In this core unit, you will learn the language of chemistry and basic calculations.

Tutorial 06: Atoms and Molecules

Matter is made of atoms, which form elements and molecules.

Atoms

Atoms are the building block of matter. They are the smallest particle that retains the chemical properties of the element. Atoms are composed of protons, neutrons and electrons. Protons and neutrons are in the nucleus and contribute to the mass of the atom. Electrons are outside the nucleus, and together with the protons, contribute to the charge of the atom.

Ions

Ions are atoms that have a charge. There is an unequal number of positive protons and negative electrons.

Element Symbols

Element symbols are found on the periodic table. Element symbols can give lots of information: ${}^{A}_{Z}X^{C}_{N}$ where X is the symbol, A is the mass number (protons + neutrons), Z is the atomic number (protons), C is the charge (protons – electrons) and N is the number of atoms present.

Isotopes

Isotopes are elements of the same atom (same number of protons) with a different number of neutrons (and therefore a different mass). The atomic mass found on the periodic table is a weighted average of all the isotope's individual masses. The mass number shown in the element symbol above refers only to 1 specific isotope.

Atoms, Elements and Molecules

Atoms are the smallest particle retaining the chemical properties of the element. Elements are pure substances that contain atoms with the same number of protons. Molecules are pure substances that contain more than one type of atom chemically

Tutorial 07: Writing Chemical Formulas

Chemical formulas are written with rules according to the type of molecule.

Type 1: Binary Ionic

Between a metal and a non-metal and they'll end with "-ide" on the second word. The metal's symbol and charge are written, followed by the non-metals's symbol and charge. The charges are balanced by using coefficients to indicate the number of atoms.

Type 2: Polyatomic Ionic

They either begin with "ammonium" or end with "-ate" or "-ite" in the second word (except "hydroxide" and "cyanide"—those are polyatomic ions). A polyatomic ion is a group of atoms that together have a charge. The metal's symbol and charge are written first (or ammonium, NH4+1, the only polyatomic cation). The polyatomic anion's symbols and charge are written next. The charges are again balanced with subscripts. If a subscript is added to a polyatomic ion, use parenthesis around the ion.

Type 1 or 2 with Multivalent Metals

They will have roman numerals in the name. Multivalent metals are metals that have more than one possibility for the charge. The charge of the metal is indicated with roman numerals following the metal's name. The formula is then written following the rules for either Type 1 or Type 2.

Type 3: Binary Covalent

Between two non-metals. They will have use prefixes indicated the number of atoms. "Mono-" is not used on the first element. The element symbols are written, and the prefixes indicate the subscript for each.

Type 4: Acids

The cation for an acid is H+. The anion is based on the format of the name: "hydro___ic acids" end with a single element; "___ic acids" end with the "___ate" polyatomic ion; "___ous acids" end with the "___ite" polyatomic ion. Write the correct anion's symbol and charge and then balance the charges with subscripts.

Tutorial 08: Naming Chemical Compounds

Chemical formulas are named with rules according to the type of molecule.

Type 1: Binary Ionic

Between a metal and a non-metal—one element of each type. Write the name of the first element (the metal) and then the name of the second element with "-ide" replacing the last syllable. Subscripts are not important when using this type

Type 2: Polyatomic Ionic

It will contain more than 2 elements—with at least one being a metal and one being a non-metal. Write the name of the first element or polyatomic ion. Write the name of the second element or polyatomic ion. If the anion is an element, change the ending to "-ide"; if the anion is a polyatomic ion, do not change the ending. Polyatomic ions must match exactly—including the subscripts. If there are parenthesis, the polyatomic ion is inside the parenthesis.

Type 1 or 2 with Multivalent Metals

They'll start with Co, Cr, Cu, Fe, Hg, Pb, Sn. Multivalent metals are metals that have more than one possibility for the charge. The name of the metal is written, followed by roman numerals in parenthesis indicating the charge of the metal. The charge is determined by knowing the charge of the anion and knowing that the overall charge of the molecule is 0. The name of the anion is written—changing the ending of a single element anion to "-ide."

Type 3: Binary Covalent

Between two non-metals. Write the name of the first element with a prefix indicating the subscript (do not use "mono-" with the first element). Write the name of the second element with a prefix indicating the subscript and "-ide" as the ending syllable.

Type 4: Acids

The cation for an acid is H+. The name is based on the anion. A single element anion is named as "hydro____ic acid"; a "___ate" polyatomic anion is named as "___ic acid"; a "___ite" polyatomic anion is named as "___ous" acid.

Tutorial 09: Counting Molecules: The Mole

Atoms and molecules are so tiny that they need to be counted in very large quantities in order to result in a "workable" number.

The mole

The mole (abbreviation: mol) is used to count particles. 1 mole of anything is 6.02 ´ 1023 of that thing.

Molar mass

We cannot count out a mole of particles in the lab, therefore a connection between moles and mass is needed. The molar mass is the mass (in grams) for 1 mole of the particle. Molar mass (also often called Molecular mass, formula weight, etc.) is found by adding the atomic masses (multiplied by the number of that atom) for each atom in the molecule. Molar mass can then be used in dimensional analysis conversions as the equality between grams and moles. The molar mass value always goes with the "grams" in such conversions.

Percent Composition

"Percent" is part / whole ´ 100. The "part" is the mass of an individual element while the "whole" is the mass of the whole molecule or sample. These calculations can be done with lab data—grams of both the individual element and the whole sample—or with chemical formulas. In the case of chemical formulas, the molar mass is used in the calculations.

Empirical Formula

The empirical formula is the lowest possible ratio of atoms in a molecule. The ratio of atoms is the same as the ratio of moles of atoms. The mass of each element is converted to moles and then all the moles are divided by the smallest to reach the lowest possible whole number ratio. That ratio is used as the subscripts in writing the empirical formula.

Molecular Formula

The molecular formula is the actual ratio of atoms in a molecule. The molar mass of the empirical formula is compared to the given molar mass of the molecular formula. The comparison results in a factor that is used to multiply the subscripts of the empirical formula to reach the subscripts of the molecular formula.

Tutorial 10: Chemical Reactions

Chemical reactions are the “sentence” that shows a chemical change.

Components of a chemical reaction

Chemical reactions are made of reactants are listed first, followed by an arrow that indicates “yields,” “produces,” or “forms.” The arrow is followed by the products of the chemical reaction. Chemical reactions can also show states of matter and energy changes.

Common types of chemical reactions

There are several common types of chemical reactions. Composition reactions are when more than one type of matter combines to form one molecule. Decomposition reactions are the opposite of composition reactions. Single replacement reactions involve and element reacting with a compound and replacing one of the elements in the compound. A double replacement reaction has two compounds that switch ions. A neutralization reaction is a double replacement reaction between an acid and a base. Precipitation reactions are double replacement reactions that produce an insoluble compound. Redox reactions involve the transfer of electrons from one atom to another, resulting in the change of an oxidation number.

Double replacement reactions and precipitations

Solubility rules can be used to determine if a double replacement reaction forms a precipitate, an insoluble ionic compound

Tutorial 11: Balancing Equations

Chemical reactions are balanced with coefficients until the numbers of each atom are equal on the left and the right.

The Law of Conservation of Mass

The Law of Conservation of Mass states that the mass of the reactants equal the mass of the products. Atoms cannot be created nor destroyed in a chemical change—therefore, the number of each type of atom on each side of the reaction must be equal. Coefficients are used to balance chemical reactions.

Choosing which atom to start with

Start with elements that appear only one time on each side and elements that are in the most complex compounds. End

with elements that appear more than once on a side or elements that appear uncombined on one side or the other.

Inspection method of balancing

The Inspection Method is used to balance the simplest reactions. It includes:

1. Make a list of the elements in the reaction
2. Count the number of each type of atom on each side of the reaction
3. Add coefficients to balance the number of atoms
4. Determine the total charge of each side of the reaction and use coefficients to balance charge.
5. When all elements and charge are balanced, place a "1" in any empty coefficient location to indicate that you're done.

Tutorial 12: The Math of Chemical Equations: Stoichiometry

Stoichiometry is the culmination of many concepts in chemistry. It integrates dimensional analysis, moles and molar mass, molar volumes of gases, concentrations and balanced chemical equations to use information about one species in a reaction to determine information about another species in the same reaction.

Review
Chemical equations are used to relate reactants and products in a chemical reaction. Dimensional analysis is a technique that uses ratios of equivalents to convert units. The KUDOS method is a method for solving word problems. Molarity is a concentration unit showing the ratio of moles of solute to volume of solution.

Mole-Mole problems

The balanced equation gives the ratio of moles of each species in the reaction. The balanced equation is used to determine mole ratios for use in dimensional analysis when converting from the moles of one species to the moles of another. Moles is the only unit that may be used to convert from one chemical to another—mass or volume cannot be used to convert between chemicals, just within the same one.

Mole-Mass & Mass-Mass problems

Molar mass is an equivalent between the mass in grams and moles of a substance. The molar mass is used to convert between moles of a substance and mass in a stoichiometry problem.

Mole-Volume problems for solutions

The concentration, in molarity, of a solution gives the equivalent for moles of the solute and liters of solution. The molarity can be used to convert between moles and volume of a solution in stoichiometry problems.

Mole-Volume problems for gases

The volume of 1 mole of any gas at standard temperature and pressure is 22.4 L. The molar volume of a gas can be used to convert between moles and volume of a gas at STP in stoichiometry problems. If a problem asks for the volume at non-standard temperature or pressure, find the STP volume using stoichiometry and then use the appropriate gas law to convert to the desired temperature or pressure.

Core Unit 3 – The Electronic Structures

In this core unit, you will learn the building blocks for chemistry and the most important concept – electrons.

Tutorial 13: Electron Configuration

Electrons are involved in bonding, and therefore, their arrangement in an atom is very important.

Subatomic particle
Atoms are composed of protons, neutrons and electrons. The atomic number is equal to the number of protons. The charge of the atom or ion is equal to the number of protons – the number of electrons. The number of electrons can be determined knowing the atomic number and charge.

Energy levels, subshells and orbitals

Electrons are placed in energy levels. These energy levels are sub-divided into subshells (labeled s, p, d or f). The s subshell is the lowest energy and begins in level 1. The p subshell is higher energy and therefore doesn't begin until level 2. The d is higher energy and begins in level 3 and the f is even higher energy and begins in level 4. The subshells are further sub-divided into orbitals (s has 1 orbital, p has 3 orbitals, d has 5 orbitals and f has 7 orbitals). Each orbital can hold 2 electrons.

Rules for writing electron configurations
The **Aufbau principle** states that energy levels must be filled from the lowest to the highest and you may not move on to the next level unless the previous level is full. Use the periodic table as a guide (read left to right):

1s			
2s			2p
3s			3p
4s		3d	4p
5s		4d	5p
6s	4f	5d	6p
7s	5f	6d	7p

Hund's Rule says that when placing electrons in orbitals of equal energy, place one in each orbital before doubling up in order to arrive at the lowest energy configuration. The **Pauli Exclusion Principle** states that when electrons do share an orbital, they must be of different "spin."

Writing electron configurations

The **Boxes and Arrows method** uses boxes to show orbitals and arrows to signify electrons. An up arrow and a down arrow have different "spins." The **spectroscopic method** uses superscripts to show the number of electrons in a subshell (specific orbitals are not shown). The **noble gas method** uses a noble gas (the far right column) to represent the inner, or core, electrons and just shows the outer level of electrons using the same method as spectroscopic.

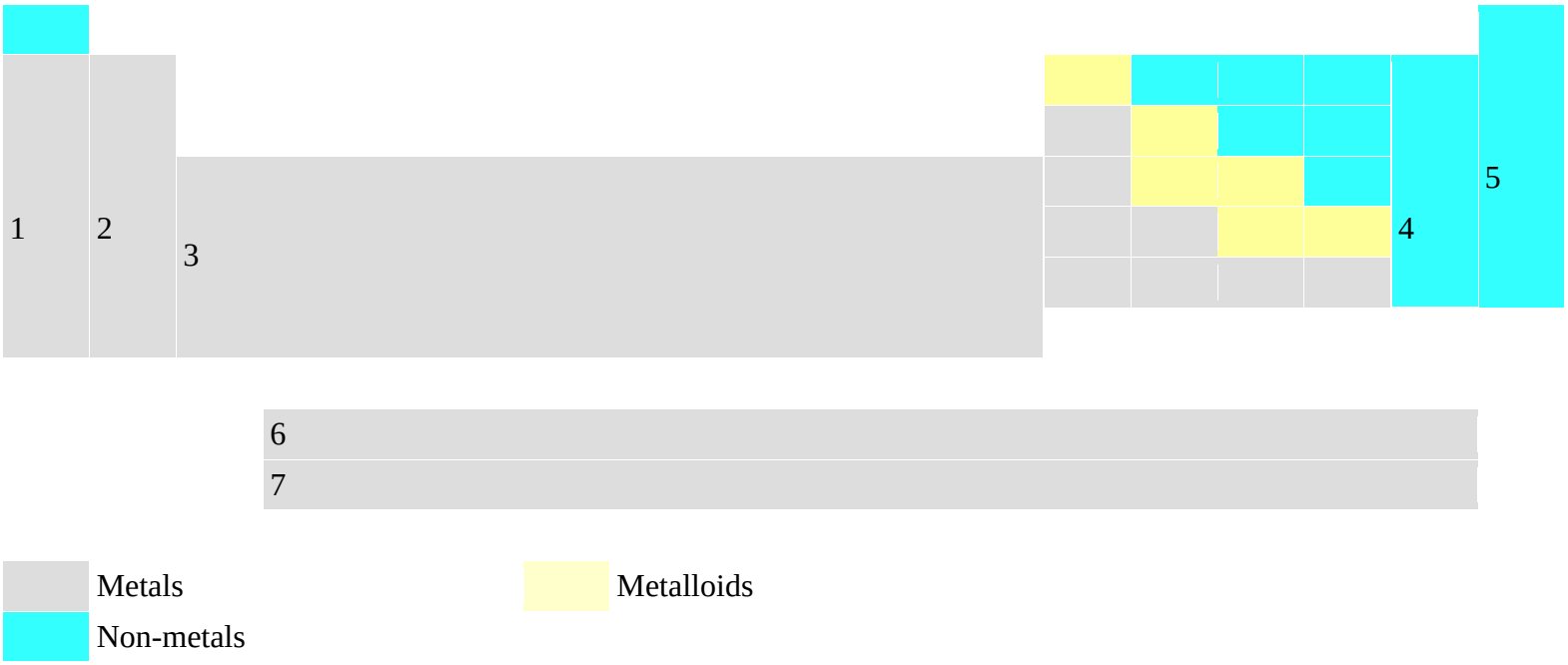
Exceptions to the rules
There are a few exceptions to the rules listed above when filling electron configurations. A half-full "s" orbital and a "d" subshell with 5 or 10 is more stable than following the Aufbau Principle. **Cr, Mo, W:** s1 d5 and **Cu, Ag, Au:** s1 d10

Tutorial 14: The Periodic Table

The periodic table is most likely the key tool for chemists. It organizes the elements, but it also gives a wealth of information.

Key sections of the periodic table
The periodic table is organized in columns, called groups or families, and rows, called periods. There are several groups or periods that have specific names.

Important Regions of the Periodic Table:



1. Alkali Metals
2. Alkaline Earth Metals

3. Transition Metals
4. Halogens
5. Nobel Gases
6. Lanthanides
7. Actidines

8 tall columns = main groups or representative elements

Periodicity

As you move across or down the periodic table, subatomic particles are added. This increases the mass of the elements both across and down the periodic table.

Moving across the periodic table, protons are added to the nucleus while electrons are added to the valence shell. This increase in both the number of positive charges and negative charges increases the attraction between the two. Therefore, when moving across the periodic table, the radius decreases. When moving down the periodic table, protons are again added. But this time, the electrons are added in a completely new valence shell. This new valence shell is shielded from the pull of the protons by all the inner valence shells. Therefore, as you move down the periodic table, atomic radius increases.

Electron affinity (the ease with which an electron is added), electronegativity (pull an electron has on electrons it shares in a bond) and ionization energy (difficulty in removing the outermost electron) are all related to the radius. As radius decreases across the periodic table, all of these properties increase as the electrons are closer to the pull of the protons. As radius increases down a group, these properties decrease as the electrons are farther from the nucleus.

Ionic Radii
The formation of a cation is due to the loss of electrons. A cation has more protons than electrons and therefore the protons have a large pull on each electron. The radius decreases. An anion is formed from the gain of electrons. Anions have a greater number of electrons than protons. Therefore, the pull of the protons on each electron is lower. The radius of an anion is greater than the parent atom.

Tutorial 15: Chemical Bonding

Atoms bond chemically to form molecules.

Types of bonding
The periodic table is organized in columns, called groups or families, and rows, called periods. There are several groups or periods that have specific names.

Bond type	**Happens between**	**Electrons are**
Ionic	Metal & non-metal	Transferred
Covalent	Non-metals	Shared
Polar Covalent	Non-metals	Shared unevenly

Metallic	Metals	pooled

There are general characteristics of each type of bonding:

- **Ionic:** High melting points, most dissolve in water, conduct electricity when dissolved in water, brittle
- **Covalent:** Low melting points, most do not dissolve in water, do not conduct electricity when dissolved in water
- **Polar covalent:** Medium melting points, some dissolve in water, do not conduct electricity when dissolved in water
- **Metallic:** Soft, conduct heat and electricity, do not dissolve in water

Bond Polarity

When nonmetals bond covalently with a large difference in electronegativity, a polar bond is formed. A polar bond has a partial separation of charges. Polar bonds are symbolized with an arrow pointing towards the more electronegative element and a crossed tail by the less electronegative element

Valence Shell Bonding Theory
The **Valence Shell Bonding Theory** assumes that bonds are formed when atomic orbitals overlap. Direct overlap leads to sigma bonds and parallel overlap leads to pi bond.

Tutorial 16: Molecular Structures

Atoms bond chemically to form molecules. Lewis structures are a way to represent this bonding on two dimensional paper and determine the molecular geometry of a structure.

Review of bonding
Covalent molecules share electrons while ionic compounds transfer electrons from one atom to another.

Lewis Structures of atoms
The element symbol is drawn to represent the nucleus and core electrons. The valance electrons are drawn around the symbol—one on each side before doubling up.

Exceptions to the Octet Rule
Most atoms are the most stable with 8 electrons in their valence shell, and will bond until this is reached. However, hydrogen and helium can only hold 2 electrons in their valence shell. Boron and Beryllium can be stable with only 6 valence electrons. Any element in the third row or below can hold more than 8 in the empty d subshells.

Arranging atoms in a Lewis Structure
It is often difficult to know in what order to place the atoms. There are some general rules that can be followed:

- For molecules with only 2 elements, arrange the atoms symmetrically
- “COOH” is a carboxylic acid (both O’s bond to the C and the H goes on one of the O’s)
- Hydrogen and halogens cannot go in the middle

- Write the remaining atoms in the order they appear in the formula
- Write the hydrogen and halogen atoms around the element they are written next to in the formula

Drawing Lewis Structures for covalent compounds
Once the atoms are arranged, a system can be used to complete the Lewis Structure:

- Arrange the atoms as above
- Determine the # of valence electrons for each atom
- Draw the valence electrons—do not double up where a bond is going to form between two atoms
- Count to see if all atoms have full valences
- If two atoms adjacent to each other do not have full valences, move in an electron from each to form a double bond. Repeat for triple bond if necessary.
- If two atoms that are not adjacent to each other need to double bond, try moving a hydrogen to one of them to cause two atoms adjacent to each other to need the double bond.

Another approach to drawing Lewis Structures
There is a second method that is also commonly used to arrive at the same structure:

- Arrange the atoms as above.
- Determine the total # of valence electrons for the whole molecule
- Put one bonding pair between each set of atoms to be bonded.
- Place remaining electrons in lone pairs, starting with the most electronegative element.
- If atoms do not have full valence shells, move a lone pair from an adjacent atom in to double, or triple, bond.

Ionic Structures
Ionic bonds are formed from the transfer of electrons from the metal atom to a non-metal atom or polyatomic ion.
Valence Shell Electron Pair Repulsion Theory
Bonds are made of electrons and electrons are negative and therefore repel each other. Bonds and lone pairs form as far apart from each other as possible. This theory can be used to determine the electron structure (the 3D shape based upon electron regions—bonding regions and lone pair regions—of the central atom) or molecule structure (the 3D shape based on the electron regions, but named after the bonded atoms only).

A = central atom; X = ligands; E = lone pairs

Electron regions	Molecular Formula	Name
2	AX2	Linear
3	AX3	Trigonal Planar
3	AX2E	Bent
4	AX4	Tetrahedron
4	AX3E	Trigonal pyramidal

4	AX2E2	Bent
5	AX5	Trigonal bipyramidal
5	AX4E	See-saw
5	AX3 E2	T-shaped
5	AX2E3	Linear
6	AX6	Octahedron
6	AX5E	Square pyramidal
6	AX4 E2	Square planar

Core Unit 4 – States of Matter

In this core unit, you be introduced to 2 states of matter—gases and solutions

Tutorial 17: The Gas Laws

Gases are the state of matter with the greatest amount of energy.

Pressure
Pressure is created by gas particles running into the wall of the container. Pressure is measured in many units: 1 atm = 101300 Pa = 101.3 kPa = 760 mm Hg = 14.7 psi. Atmospheric pressure is the pressure due to the layers of atmosphere above us.

Kinetic Molecular Theory
The Kinetic Molecular Theory has several assumptions for ideal gases.

- Gases are made of atoms or molecules
- Gas particles are in rapid, random, constant motion
- The temperature is proportional to the average kinetic energy
- Gas particles are not attracted nor repelled from each other
- All gas particle collisions are perfectly elastic (they leave with the same energy they collided with)
- The volume of gas particles is so small compared to the space between them that the volume of the particle is insignificant

Real gases do have a volume (that takes up space which other particles cannot occupy) and they do have attractions/repulsions from one another as well as in-elastic collisions.

The KMT is used to understand gas behavior. Pressure and volume are inversely proportional. Pressure and temperature are directly proportional. Pressure and number of particles are directly proportional.

An expandable container will expand or contract so that the internal and external pressures are the same. Non-expandable containers will explode or implode if the difference in the pressures is too great for the container to withstand.

Gas Laws

Symbols for all gas Laws:

P = Pressure; V = Volume; n = moles; T = Temperature (in Kelvin);

R = Gas constant $8.31\frac{L \times kPa}{mole \times K}$ or $0.0821\frac{L \times atm}{mole \times K}$

"a" and "b" = correction factors for real gases

Combined Gas Law: $\frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2}$ When something is held constant, it cancels out.

Dalton's Law of Partial Pressure: $P_{total} = \sum P_{of\ each\ gas}$

Mole fraction: $\chi_A = \frac{mole_A}{mole_{total}}$ **Partial Pressure and mole fraction:** $P_A = \chi_A P_{total}$

Ideal Gas Law: $PV = nRT$ **Ideal Gas Law with Molar Mass:** $PV = \frac{m}{MM}RT$

Ideal Gas Law with Density: $P = D\frac{RT}{MM}$

Real Gas Law: $\left(P + \frac{n^2a}{V^2}\right)(V - nb) = nRT$

Gas Stoichiometry

Use the molar volume of a gas at STP (1 mole of any gas at STP = 22.4 L) to convert between moles and liters of a gas in stoichiometry. Then use the appropriate gas law to find the volume at non-STP conditions.

Tutorial 18: Liquids and Solids

Liquids and solids are condensed states of matter that have intermolecular forces.

Intermolecular forces

Physical attractions between separate molecules are intermolecular forces. The weakest of these forces is present in all molecules, **London Dispersion Forces**. It's due to the temporary ganging up of electrons on one side of the molecule. This creates a temporary dipole that can be attracted to other dipoles, temporary or permanent. Molecules with a permanent dipole can also display **Dipole-Dipole** attractions, or **Ion-Dipole** attractions with an ion. Since the ability to form these attractions isn't temporary, as with London Dispersion Forces, dipole attractions are stronger. When a hydrogen atom is bonded to a very electronegative atom, N, O or F, it forms a very strong dipole. This extra strong dipole can form strong attractions with an N, O or F on another molecule, called **Hydrogen Bonding**, which is the strongest IMF.

Properties of liquids and solids

Liquids have definite volumes, but not definite shapes, the particles are free to move past each other and they are not very compressible. Solids have definite volumes and shapes, the particles are not able to move past each other and they are not compressible at all.

Vapor Pressure
Vapor pressure is created when molecules on the surface of a solid or liquid have enough energy to escape the intermolecular forces and become a gas. Once it is a gas, it can create pressure. As temperature increases, more molecules have the minimum energy to evaporate, and vapor pressure increases. At first, many molecules escape and the volume of the solid or liquid decreases. But after a while, some begin to collide with the surface of the liquid and rejoin the liquid again. Eventually equilibrium is established.

Solids Structures
Amorphous solids have no repeating structure. Crystalline solids do have a pattern of repeating units. Atomic solids have atoms as the repeating unit and can be metallic (electrons are shared in a large pool throughout the metal) or network (where each atom is covalently bonded to each other atom) solids. Molecular solids have molecules that are all covalently bonded to one another. Ionic solids have a network of ions arranged to maximize electrostatic attractions and minimize repulsions.

Phase Changes
During melting or boiling, intermolecular forces are broken. During freezing or condensing, intermolecular forces are formed. The melting/freezing point is when the vapor pressure of the solid and liquid are equal and the two states of matter are at equilibrium. The boiling/condensing point is when the vapor pressure of the liquid is equal to the atmospheric pressure and is the temperature when the two states of matter are at equilibrium.

Tutorial 19: Solutions

Solutions are formed when a solute is dissolved in a solvent.

Forming solutions
In order for a solution to form, the solute intermolecular forces must be broken as well as the solvent intermolecular forces. Then the solute and solvent form new intermolecular forces with each other. If the energy required to break the intermolecular forces is much greater than the energy released when the new forces are formed, the solution will not form.

Factors affecting solubility
For gases, as the pressure of the gas above the solution increases, the solubility of the gas increases. For gases, as the temperature of the solution increases, the solubility of the gas decreases. For most solids, as temperature increases, the solubility increases.

Concentration calculations

There are many ways to express concentration (which is the ratio of solute to solvent or solution).

% by mass: $$\%\ mass = \frac{mass\ solute}{mass\ solution} \times 100$$

The mass units must match!

% by volume: $\%\,volume = \frac{volume\,solute}{volume\,solution} \times 100$

The volume units must match!

% mass/volume: $\%\,mass/volume = \frac{mass\ solute}{volume\ solution} \times 100$

The volume unit is mL

Molarity (M): $Molarity = \frac{moles\ solute}{L\ solution}$

Molality (m): $Molality = \frac{moles\,solute}{kg\,solvent}$

A sample becomes diluted (less concentrated) when more solvent is added. The dilution equation is

$M_1V_1 = M_2V_2$ M1 = original molarity V1 = original volume M2 = new molarity V2 = new volume.

Volume units must match!

Colloids

Colloids are solutions with solute particles large enough to scatter light. They exhibit the Tyndall Effect, where light is seen traveling through and spreading out as it travels through colloid.

Core Unit 5 – The Control of Chemical Reactions

In this core unit, you will learn all about the reactions.

Tutorial 20: Equilibrium & Rates of Reaction

Kinetics is the study of the rate of reaction and the factors that affect it.

Collision theory

In order for a reaction to occur, the molecules must collide in the correct orientation with the minimum energy needed for the transition from the reactants to the products (the activation energy). Only a very few collisions meet these requirements and result in a reaction.

Reaction Coordinate Diagrams

Reaction coordinate diagrams show the energy of the reactants, the activation energy up to the activated complex, or transition state (the in-between state between the reactants and the products), and the energy of the products. The overall energy change of the reaction is also shown.

Factors affecting rate

Increasing the temperature increases the number of collisions, and also the number of collisions with the needed energy. Therefore, increasing temperature increases the rate of reaction. Increasing the concentration or the surface area also increases the number of collisions, therefore increasing the chance that a successful collision will occur—which increases rate. Adding a catalyst, a species that increases the rate of reaction without being used up in the reaction, also increases the rate.

Equilibrium
Dynamic equilibrium is when the rate of the forward and reverse reactions are equal. The reaction will appear to have stopped, as the concentrations of each species won't change, but the reaction continues to proceed in both directions

Equilibrium constants
Equilibrium constant expressions are the ratio of the concentrations of products to reactants using their coefficients from the balanced equation as exponents. Pure solids and liquids are not included in the equilibrium constant expression. Equilibrium concentrations are plugged into the expression to solve for the equilibrium constant. A large equilibrium constant means that the reaction "lies to the right" with more products than reactants at equilibrium. A small constant means that the reaction "lies to the left" with more reactants the products present at equilibrium.

Reaction Quotients
The reaction quotient is the value when concentrations at any time are plugged into the equilibrium constant expression. If the reaction quotient equals the equilibrium constant, then the system is at equilibrium. If the reaction quotient is too large, the reaction will proceed to the left to produce more reactants (and reduce products). The opposite will happen if the reaction quotient is too small.

Le Chatelier's Principle
Le Chatelier's principle says that if a system at equilibrium is stressed or changed, the system will shift to reach equilibrium again. Whatever you do to the system, it will un-do it. For example, if you add more reactants, the reaction will proceed to the right to get rid of the extra reactants and make more products.

Tutorial 21: Acids and Bases

Acids and bases are used throughout chemistry.

Definitions of acids and bases
There are three common definitions of acids and bases:

- **Arrhenius acid:** Produces hydronium ion in water.
- **Arrhenius base:** Produces hydroxide ion in water.
- **Brønsted-Lowry acid:** Donates a proton (H+1)
- **Brønsted-Lowry base:** Accepts a proton
- **Lewis acid:** Accepts electrons
- **Lewis base:** Donates electrons

Strong acids and bases are ones in which most molecules perform their "duty" while weak acids and bases only have a few acid and base molecules that act as acids and bases. There are only a few strong acids and bases to remember—the rest will most likely be weak. Strong acids: HCl, HBr, HI, HNO_3, $HClO_3$, $HClO_4$. Strong bases: NaOH, KOH, $Ca(OH)_2$, $Ba(OH)_2$, $Sr(OH)_2$

A conjugate acid is what remains after a base does its "job". A conjugate base is what's left after an acid does it's "job." Strong acids or bases form a weak conjugate and vice versa

pH

The pH scale is a logarithmic scale to measure the acidity of a solution. $pH = -\log[H_3O^{+1}]$ Strong acids and bases can be assumed to dissociate completely. Therefore, the concentration of the original strong acid or base is assumed to equal the concentration of the hydrogen or hydroxide ion. For weak acids or bases, the equilibrium constant and ICE charts are used to determine the concentration of the hydronium ion before solving for pH.

Acid/base properties of salts

Some salts can have acid/base properties based on the acid or base they are based off of.
Salts from

- Weak acid + strong base = Basic
- Weak acid + weak base = Neutral
- Strong acid + weak base = Acidic
- Strong acid + Strong base = Neutral

Buffers

A buffer is a solution containing a weak acid and its conjugate base or a weak base and its conjugate acid. Buffers resist changes in pH when acids or bases are added. The pH will still change, but much less than if it was plain water.

Titrations

Titrations are used to find the concentration of an unknown solution using a solution of known concentration. An indicator is used that changes color at the stoichiometric point (the point at which no reactants are left over) based on the pH of the products that are in solution at that point. Stoichiometry is used at that point to determine the unknown concentration.

utorial 22: Thermodynamics

Physical and chemical changes occur with changes in heat.

Energy, heat and temperature

Several definitions are useful in understanding thermodynamics:

- **Energy:** The ability to do work or supply heat.
- **System:** Particles under-going change.
- **Surroundings:** Everything surrounding the system.
- **Temperature:** proportional to the average kinetic energy of the particles.
- **Heat (q):** Flow of energy from a hotter object to a cooler object.
- **Enthalpy (H):** Takes into account internal energy, pressure and volume. In an open-air environment, it's the same as heat.

Physical changes

The specific heat capacity is the amount of energy that can be absorbed before temperature begins to change. $\Delta H = m \times C_p \times \Delta T$ where m = mass; Cp = specific heat capacity and DT = T2 – T1. During changes in state, the heat of fusion and heat of vaporization are used. Melting: $\Delta H = m \times H_{fus}$ Hfus = enthalpy of fusion. Boiling: $\Delta H = m \times H_{vap}$ Hvap = enthalpy of vaporization. Heating curves show the combination of the processes—changing temperatures and changing states.

Chemical changes

The heat of formation is the energy change when a compound is formed from its elements. Hess's law says that since energy is a state function, the path doesn't matter—only where you began and ended, then the heat of a reaction can be found by adding up stepwise reactions that add up to the overall chemical reaction. This allows the heat of reaction to be found from formation values: $\Delta Hrxn = \sum H_f prod - \sum H_f react$

Calorimetry

When the system loses energy, the surroundings gain it and vice versa. Therefore, the energy change in the surrounding can be measured and used to determine information about the system. Calorimetry can be used for physical or chemical processes.

Enthalpy, Entropy and Free energy

Entropy is disorder or randomness. All spontaneous processes result in a net increase in entropy for the universe. The spontaneity of a process (shown with a negative free energy value) is found by relating enthalpy, entropy and temperature to find free energy. $\Delta G = \Delta H - T\Delta S$

Enthalpy	Entropy	Spontaneous at
+	+	High temps
+	-	Never
-	-	Low temps
-	+	All temps

Tutorial 23: Electrochemistry

Electrochemistry studies how chemical and electrical energy are converted

Oxidation numbers & Redox reactions

Oxidation numbers are the charge on an atom if the electrons involved in the bond are assigned to the more electronegative atom in the bond. When oxidation numbers change during a chemical reaction, it is a redox reaction.

Oxidation number method of balancing

The oxidation number method is used for balancing simple redox reactions that cannot be easily balanced by the inspection method. It includes:

- Determine the oxidation numbers of each atom.
- Determine the net change in charge. Use the net change to determine the ratio of atoms that would cancel out the net charge change.
- Use the ratio as coefficients in the simplest compounds containing those elements.
- Finish balancing by the inspection method.

Half-reaction method of balancing
The half-reaction method is for the most difficult redox reactions:

- Use oxidation numbers to determine what's oxidized and what's reduced.
- Write two half-reactions, one for reduction and one for oxidation
- Balance all elements except H and O using inspection method.
- **For an acid redox reaction:** Balance the O's by adding H2O to the side needing more O. **For a base redox reaction:** Balance O by adding twice as many OH- to the side needing more O.
- **For a acid redox reaction:** Balance the H's by adding H+ to the side needing more H's. For a base redox reaction: Balance H's by adding H2O to the side needing more H's.
- Determine the charge of each side of each reaction. Balance the charges by adding electrons to the side with the more positive charge for each reaction.
- Multiply the half-reactions by factors that will allow the electrons to cancel out.
- Add the two half-reactions back together.

Voltaic cells
A voltaic cell separates the reduction and oxidation reaction and forces the electrons to flow over a wire (producing electricity) from the oxidation reaction (at the anode) to the reduction reaction (at the cathode). The cell consists of the two separate half reaction, metal electrodes and a wire for conducting the electrons, and a salt bridge for balancing the charge build-up to extend the time the cell will operate. Line notation is a short-hand way of describing a cell:

- Anode written first
- Reactants written 1st on each side
- Anode & Cathode separated with ‖
- Different states of matter within same side separated with │
- Same states of matter within same side separated with a comma

Cell potentials
The cell potential (or electromotive force) of a voltaic cell is due to the potential energy difference of the electrons before the transfer and after the transfer. A standard reduction potential is the potential that would be produced between a given half-reaction and hydrogen (hydrogen's standard reduction potential has been defined as 0). The standard reduction potentials can be used to calculate the cell potential: EMF = cathode – anode. Positive EMF values indicate a spontaneous process

Electrolytic cells
An electrolytic cell is the opposite of a voltaic cell. An electrolytic cell converts electrical energy into chemical energy

by forcing a reaction to proceed in the non-spontaneous direction by putting electricity in. The voltage need to force the reaction in the opposite direction is at least that produced by the spontaneous process.

Tutorial 24: Descriptive & Organic Chemistry

Descriptive chemistry includes predicting products and periodic trends, which were covered in previous tutorials.

Colored compounds

There are several common colored compounds—both soluble and insoluble

Colored soluble compounds	**Colored insoluble compounds**
Soluble copper salts are blue/green	AgCl is white
Fe salts are red/brown	Chromate precipitates are orange
Cobalt salts are blue	Dichromate precipitates are yellow
Complex ions are often colored	Hydroxide precipitates are white

Transition metals are often colored.

Many oxides produce colored compounds

Oxide	**Color**
Titanium oxide	White
Copper oxide	Green (patina)
Iron oxide	Red (rust)
Silve oxide	Black (tarnish)

Organic chemistry

Organic chemistry is the study of carbon-containing molecules. Simple organic compounds can be found on the AP Exam. Compounds that contain only hydrogen and carbon are hydrocarbons, but many organic molecules contain functional groups. The most common, simple functional groups:

Haloalkane: Halogen replacing a hydrogen on the hydrocarbon; Alcohol: “-OH” replacing a hydrogen on the hydrocarbon; Carboxylic acid: “-COOH” replacing a hydrogen on a hydrocarbon

Properties of organic chemistry

Most are insoluble in water, except: The smallest hydrocarbons and molecules that are polar or have the ability to hydrogen-bond (especially the smaller ones). When they do dissolve in water, they do not dissociate except for carboxylic acids, which are weak acids.

Hydrocarbons: Low melting/boiling points, London Dispersion Forces only, insoluble in water
Haloalkanes: Polar molecules, can exhibit dipole IMF, have higher melting/boiling points than hydrocarbons and are more soluble in water.
Alcohols: polar molecules, can exhibit dipole & hydrogen bonding IMF, have higher melting/boiling points than hydrocarbons and are more soluble
Carboxylic acids: polar molecules, can exhibit dipole & hydrogen bonding IMF's, having higher melting/boiling points and are more soluble. Are weak acids—dissociate weakly.

Naming simple organic compounds

Carbons are counted in the longest chain, starting from the carbon closest to the functional group.

Prefixes are used to denote number of carbons

Number	Prefix
1	Meth-
2	Eth-
3	Prop-
4	But-
5	Pent-
6	Hex-
7	Hept-
8	Oct-
9	Non-
10	Dec-

Suffixes are used for functional groups:

Type	Suffix
Alkane	-ane
Alkene	-ene
Alkyne	-yne
Alcohol	-ol
Carboxylic acid	-ic acid

BIO CHEMISTRY

Core Unit 1 – Review and Introduction

Tutorial 01: The Science of Chemistry

What is chemistry?

Chemistry is the study of matter, its properties and interactions. Some of the technologies which make use of chemistry are computer chips, art supplies, medicines, power plants, plastics, alternative fuels etc.

Branches of chemistry

There are several subdivisions in chemistry. They are organic, inorganic, physical and analytical. In addition to these four main, there are biochemistry, environmental, polymer, computational, organometallic, solid state and many others.

Classification of matter and energy

Matter is anything that has mass and takes up space. Matter can be classified into pure substances and mixtures. Pure substances are further classified into elements and compounds. Mixtures can be homogeneous or heterogeneous. Energy is the ability to do work or cause changes. Energy is of two types: Kinetic and Potential energy.

Determination of physical or chemical changes

Physical change is the one in which the chemical structure of the substances is not changed. In chemical change, chemical structure of the substances is changed. There are several signs that may indicate a chemical change has taken place. Ex: Gas production (bubbling). Physical property is the property of matter that can be observed or measured without changing the matter chemically while chemical property describes how a sample of matter reacts chemically with other matter.

Scientific processes

A hypothesis is an educated guess (prediction) and a theory can become a law if enough evidence is found. There are common aspects of scientific experimentation like observations, questions, hypothesis formation, experimentation, trend recognition, conclusion formation, communication and validation of results and model formation.

How to study chemistry

Memorize basic information to save time later. Learn vocabulary quickly for understanding when it is used later. Take each problem in steps. Connect each thing u learn with previous concepts. Keep up with the work – chemistry builds on prior knowledge.

Tutorial 02: Chemistry Review for Biochemistry

Atomic and Molecular structure

An atom is made up of protons, neutrons and electrons. Protons are positively charged and they denote the atomic number. Neutrons have no electrical charge. Protons and neutrons are present in the nucleus. Electrons are negatively charged and present in the orbits surrounding the nucleus. Valence electrons are the number of electrons in the outer shell. Organic acids are those that are derived from living organisms, usually from metabolism. Esters are condensation products of carboxylic acids with the removal of water. . Isotopes have same number of protons but different number of neutrons. Loss or gain of electrons is seen in ions. Radicals have a single electron; there is no loss or gain of electrons in them. . Lewis structures are drawn using the valence electron. Each pair of electrons makes one bond.

Types of carbon molecules

Carbon molecules are of four types: Stable neutral molecule, carbanion, carbocation and radical. A stable neutral molecule has not gained or lost electrons, carbanion has gained electrons, carbocation has lost electrons and radical is neutral and has a single electron.

Stereospecificity

Stereoisomers have the same atomic formula and connectivity but differ in the 3D position of the atoms. Chiral carbon has four different groups attached.

Intramolecular bond interactions

Electronegativity is an atom's ability to attract electrons. Bond polarity occurs when the bonding electrons are not shared equally in a covalent bond. There are mainly two types of bonding, ionic and covalent. In ionic bonding, transfer of electrons takes place. In covalent bonding, sharing of electrons occurs. It may be either polar covalent bonding or non polar covalent bonding. Bond cleavage is of two types: hemolytic- each fragment gets one electron, radicals are formed. Heterolytic – one fragment gets both electrons and the other fragment gets no electrons, ions are formed.

Intermolecular forces

Intermolecular forces are of three types: London dispersion forces – between non polar molecules, dipole-dipole forces between polar molecules, hydrogen bonding between molecules with OH, -NH or HF.

Tutorial 03: Intoduction to Biochemistry

Introduction

Living organisms should be able to transform matter and energy into different forms, show response to changes in their environment and show growth and reproduction. All living organisms undergo changes due to large organic compounds called macromolecules. Four main types of macromolecules control all activities. They are proteins, carbohydrates, nucleic acids and lipids.

What is Biochemistry?

Molecules belong to different chemical groups based on their affinity for water. Hydrophobic groups – they can not form hydrogen with water. Ex: Hydrocarbons. Hydrophilic groups – they are attracted to the charges within water. They can form hydrogen bonds with water. Amphipathic groups – have both polar and non polar groups. Ex: Hydrocarbon chain is non polar and carboxyl group is polar.

Biochemical compounds

There are four major classes of biochemical compounds - Carbohydrates, lipids, proteins and nucleic acids. In carbohydrates, sugar units are connected together by ‘glycosidic bonds’. Lipids are insoluble in water but soluble in organic solvents. All proteins are composed of amino acids which are connected by a peptide bond. There are 20 amino acids. Nucleic acids are composed of nucleotides.

Major types of biochemical reactions

Oxidation, reduction, hydrolysis, Phosphorolysis, Decarboxylation, deamination and transamination are the major biochemical reactions. Oxidation is the loss of electrons. Reduction is the gain of electrons. Hydrolysis is the chemical process in which a molecule is cleaved into two parts by the addition of a water molecule. Phosphorolysis is the splitting of a bond by the addition of phosphoric acid to a compound. Decarboxylation is the loss of carbon dioxide. Deamination is the removal of amino group. Transamination is the transfer of amino group from one molecule to another.

Common Abbreviations

Abbreviations of amino acids, coenzymes, enzymes, nucleic acids have been listed.

How to study biochemistry

The various methods to study biochemistry are – summarize, forming a study group, question-answer sessions with batch mates, practice drawing the biochemical structures to recollect during exams.

Tutorial 04: Water

Weak interactions in aqueous systems

Water is a good solvent for polar solutes with which it forms hydrogen bonds. Non-polar compounds dissolve poorly in water. They can not form a hydrogen bond with the solvent. Numerous weak non covalent interactions influence the folding of macromolecules. The physical properties of aqueous solutions are strongly influenced by the concentration of solutes. Ex: The tendency for water to move across a semi permeable membrane is the osmotic pressure.

Ionization of water, weak acids and weak bases

Pure water is slightly ionized. pH is defined as the negative logarithm of the molar hydronium ion concentration. An acid that ionizes completely in water is a strong acid. An acid which is partially ionized in water is a weak acid. pk provides the measure of the ease of the dissociation of the proton. The lower the number the stronger is the acid.

Buffering against pH changes in biological systems

Buffers are aqueous systems that tend to resist in changes in pH when small amounts or acids or base are added. It consists of a weak acid and its conjugate base. As an example a mixture of equal concentrations of acetic acid and acetate ion is a buffer system. Every life form is extremely sensitive to slight pH changes. Human blood for example needs to remain within the pH range of 7.38 to 7.42. The relationship between pH and pk is described by Henderson – Hasselbach equation. It is used to calculate the pH of biological fluids. Two especially important biological buffers are the phosphate and bicarbonate systems. The property of a solution that depends on the concentration of a dissolved solute but not on its chemical identity is known as colligative properties. Substances that do not ionize in water are non electrolytes. Vapor pressure, boiling point, freezing point and osmosis are colligative properties.

Water as a reactant

Water is very often a direct participant in the chemical reactions of living cells. Formation of ATP from ADP and inorganic phosphate is an example of a condensation reaction in which the elements of water are eliminated. Two amino acid molecules are covalently joined through a peptide bond with a loss of water molecule.

Fitness of the aqueous environment for living organisms

The high specific heat of water is useful to cells and organisms because it allows water to act as a ‘heat buffer’, keeping the temperature of an organism relatively constant as the temperature of the surroundings fluctuates.

Tutorial 05: Thermodynamics Principles

Thermodynamics

It is the study of heat changes. Increased temperature increases molecular motion. Energy is the ability to do work. Joules (J) and calories (cal) are the most common energy units. Energy can be transferred through work applying a force over a distance.

Energy changes of physical and chemical processes

First law of thermodynamics states that energy can not be created or destroyed in physical or chemical changes. Heat is the flow of energy from higher temperature particles to lower temperature particles.

Enthalpy, entropy and free energy

Enthalpy (H) takes into account the internal energy of the sample along with pressure and volume. Under constant pressure, heat and enthalpy are the same. Enthalpy of reaction is the net energy change during a chemical reaction. In endothermic reaction, the system takes in energy from the surroundings. ΔD is positive. In exothermic reaction, the system gives off energy to the surroundings. Here, ΔH is negative. Heat capacity is the amount of energy that can be absorbed by a particle, before the temperature increases. When changing between solids, liquids and gases, the temperature does not change. Entropy is the randomness. Spontaneity occurs without outside intervention. Second law of thermodynamics states that every spontaneous process has an increase in entropy of the universe.

Determining spontaneity of a process

Spontaneity occurs without outside intervention. Temperature can determine whether a process is spontaneous. Free energy (G) relates temperature, enthalpy and entropy. Free energy is used to determine if the reaction is spontaneous at a specific temperature.

Relating free energy and equilibrium

A chemical reaction that can proceed in both directions is called a reversible reaction. A reaction is said to be at equilibrium when the rate of the forward reaction equals the rate of the reverse reaction. It takes time to establish equilibrium. The reactions continue to proceed in both directions, but at the same rate is said to be in dynamic equilibrium. At thermal equilibrium, two objects at different temperatures, placed together will come to the same temperature.

Core Unit 2 – Biomolecules

Tutorial 06: Amino Acids, Peptides and Proteins

Structure, classification and nomenclature of amino acids

Amino acid refers to any compound containing an amino group and a carboxyl group. Amino acids are the basic structural units of proteins. They contain an amino group and a carboxyl group. Chiral carbon has four different types of atoms or groups attached to it. Most proteins are formed of 20 amino acids. Glycine is the simplest amino acid. Usually, amino acids are coded with three letters. Ex: Alanine is coded as Ala. Amino acids are classified into three categories: Aliphatic, aromatic and heterocyclic. Aliphatic amino acids are further classified into monoamino-monocarboxylic, monoamino-dicarboxylic, diamino-monocarboxylic, sulphur containing carboxylic acids. In neutral solution, amino acids are zwitterionic, with a positive charge on the nitrogen atom and a negative on the carboxyl group. All amino acids have the same general structure except proline.

Formation and classification of peptides

Peptide bond is formed by dehydration. Two amino acid molecules can be covalently joined through a peptide bond to yield a dipeptide. Peptide chain can be formed by the process of peptide bond formation between joining amino acids. When there are a few amino acids in a chain, usually 10-20, its called an oligopeptide. When there are more than 20, it is called a polypeptide.

Structure and function of proteins

Proteins are among the fundamental molecules of biology and are responsible for most of the complex functions that make life possible. The amino acid sequence of a protein determines its 3D structure. There are 4 classes of structure: Primary, secondary, tertiary and quaternary. Primary structure of proteins refers to linear number and order of the amino acids present. The ordered array of amino acids in a protein confers regular conformational forms upon that protein. These conformations constitute the secondary structures of proteins. β- Sheets are either parallel or anti parallel. α- helices and β sheet regions are connected by loop regions. Tertiary structure describes the relationship of different domains to one another within a protein. Quaternary structure describes about proteins containing several distinct polypeptide chains along with the non protein groups.

Tutorial 07: All about Proteins

Amino acids – Building blocks

All amino acids incorporated into proteins by organisms are in the L form. All amino acids have acidic and basic functional groups. All amino acids except glycine have a chiral center. The pka for a functional group is the pH at which acidic or basic groups on 50 % of the molecules in a solution are deprotonated.

3D structures and conformation

Proteins are complex structures. Average protein contains 300 amino acids. Average amino acid contains 8 heavy atoms. Average structure contains 2400 atoms. X ray crystallography and NMR spectroscopy are the techniques which allow getting atomic resolution pictures of proteins.

Protein folding

Protein molecules fold by interacting between atoms within the protein chains and by interacting between the protein and the solvent. The forces involved are van der waals forces, disulphide bonds, hydrogen bonds, electrostatic attraction, and hydrophobic interactions. Defect in primary structure of proteins may arise due to mutations. Sickle cell anemia is a defect in the hemoglobin – a protein found in RBCs. Change in primary sequence decreases protein solubility and protein aggregates. For a protein of n residues, there are 20n possible sequences. It can fold into any pattern which is decided by its function.

Covalent backbone and sequence

Alpha helix is formed by hydrogen bonds. Backbone does not follow any actual bonds. They are used for structural super impositions. Peptide bond has a partial double bond character

Protein functions

Proteins are divided based on their functions. Ex: Collagen, fibrous protein is classified under structural proteins. The globular proteins have a number of biologically important roles. Myoglobulin is present in the muscle and hemoglobin in the RBC. Proteins act as biocatalyst – enzymes. They regulate metabolism too.

Tutorial 08: Carbohydrates

Carbohydrates and Classification

Carbohydrates are the most abundant biomolecules on earth. They have either an aldehyde or a keto group in addition to many hydroxyl groups. Dihydroxyacetone is the simplest carbohydrate with a keto group. Carbohydrates are defined as the polyhydroxy aldehydes or polyhydroxy ketones or substances that yield such compounds on hydrolysis. The empirical formula of carbohydrates is (CH2O) n. Carbohydrates serve as energy stores, structural elements and they are precursors for many organic compounds like fats and amino acids. Carbohydrates are classified into four categories. Monosaccharides (simple sugars) containing a single polyhydroxy aldehyde or ketone unit. Ex: Glucose. Disaccharides consist of two monosaccharides linked by glycosidic linkage. Ex: Maltose. Oligosaccharides consist of three to twelve monosaccharides. Ex: Maltotriose which is a trisaccharide, made up of three glucose units. Polysaccharides consist of more than twelve monosaccharides. Ex: Cellulose.

Monosaccharides

Monosaccharides with an aldehyde group are called an aldose sugar. Ex: Glucose and with keto group called ketose sugar. Ex: Fructose. On the basis of number of carbon atoms, monosaccharides are classified as trioses, tetroses, pentoses, hexoses and heptoses. Glyceraldehyde is an aldrotriose with a single asymmetric carbon atom. Fischer projection of a molecule with asymmetric carbon is discussed. D and L glyceraldehdye are the mirror images of each other, also called enantiomers. Monosaccharides exhibit isomerism. Glucose and fructose are aldose-ketose isomers of one another. Glucose and mannose are epimers. They differ in configuration at the 2nd carbon of these aldohexoses. Mostly monosaccharides occur in aqueous solution as aqueous ring. In the process, carbonyl group (-CHO/-C=O) forms a covalent bond with oxygen of a hydroxyl group along the chain. The ring structure hemiacetal is formed by the combination of an aldehyde and an alcohol group. The ring has six members and is called pyranose ring. Ex: α-D-Glucopyranose. With the ketose group, hemiketal is formed. The ring contains five members and is called furanose ring. Ex: α-D-Fructofuranose. Anomerism is the process in which there is a creation of asymmetric carbon, called anomeric carbon. Ex: α-D-Glucopyranose and β-D-Glucopyranose. Mutarotation is the process in which cyclic α and β anomers produce equilibrium in a solution.

A constant source of blood glucose is compulsory for human life. Glucose is the preferred energy source of the brain. Glycogen stored in muscle releases hexose units for glycolysis within the muscle itself. Glycogen in the liver is concerned with export of hexose units for maintenance of the blood glucose, particularly between meals. Monosaccharides are degraded by a process called glycolysis which takes place in cytosol and a series of reactions in citric acid cycle in mitochondria. When one molecule of glucose is oxidized to carbon dioxide and water, 38 ATP molecules are generated. Reducing action of monosaccharides depends on the free anomeric carbon in their molecules, which are capable of reducing cupric to cuprous ions and themselves get oxidized to sugar acids. Oxidation of glucose gives rise to glucuronic acid. Two monosaccharides join covalently (glycosidic bond) when hydroxyl group of one reacts with anomeric carbon of the other forming a glycoside. Deoxy sugars, amino sugars, sugar acids and sugar alcohols are derivatives of monosaccharides.

Disaccharides

Maltose is a reducing disaccharide. It is made up of 2 glucose units linked by α (1-4) glycosidic linkage. Anomeric carbon of second glucose residue is free. It is produced during starch digestion and it exhibits mutarotation. Lactose is also a reducing disaccharide made up of one glucose and one galactose, linked by β (1-4) glycosidic linkage. It is present in milk and exhibits mutarotation. Sucrose is a non-reducing sugar. It is composed of one glucose and one fructose linked by α1- β2 glycosidic linkage. Anomeric carbon units are involved in linkage; hence no free anomeric carbons are available.

Polysaccharides

Consist of repeating units of monosaccharides or their derivatives held together by glycosidic bonds. Ex: Starch, Hyaluronic acid, homopolysaccharides contain only a single type of monosaccharide. Ex: Starch, glycogen, cellulose, chitin. Starch is found in cereals, legumes, potatoes. Here, glucose is the monosaccharide unit. They are made up of amylase and amylopectin with α (1-4) linage in linear structure of amylase and α (1-4) and α (1-6) linkage in branched structure amylopectin. In cellulose, polymer of glucose is linked by β (1-4) glycosidic linkage. Cellulose is present in plant cell wall and functions as a dietary fiber. Glycogen is the main storage polysaccharide in animals and is abundant in the liver. Glycogen is more extensively branched. Heteropolysaccharides are composed of different types of monosaccharides or their derivatives. Mucopolysaccharides are known as glycosaminoglycans. They are negatively charged large complexes. Ex: Hyaluronic acid, heparin, chondroitin sulfate, dermatan sulfate, keratin sulfate etc. Glycoproteins mostly contain oligosaccharides which are tightly bound to proteins. Ex: Immunoglobulins, mucin of stomach. They function as enzymes, hormones, receptors, structural proteins, transport proteins. In proteoglycans, proteins are covalently bound with mucopolysaccharides. Found in the bone, elastin and collagen.

Tutorial 09: Lipids and Membranes

Introduction

Lipids are heterogeneous compounds insoluble in water but soluble in organic solvents like chloroform. Biological membranes are the organized assemblies of lipids and proteins with some amount of carbohydrates. Lipids are mainly classified into storage lipids and membrane lipids.

Storage Lipids

Fatty acids are the components of storage lipids. Fatty acids are mainly classified into saturated (no double bond) and unsaturated fatty acids (double bond present). Some of the polyunsaturated fatty acids are called essential fatty acids. They are linoleic acid, linolenic acid and arachidonic acid. Fats are the esters of fatty acids with glycerol as the alcohol. Simple fats contain same kinds of fatty acids in all three positions while mixed fats contain two or more different fatty

acids. Oils are fats but liquid at room temperature. Waxes are the esters of fatty acids with long chain mono hydroxyl alcohol.

Membrane Lipids

Glycerophospholipids, sphingolipids and cholesterol are the membrane lipids. Glycerophospholipids contain glycerol as the alcohol, fatty acids, a phosphate group and a nitrogenous or non-nitrogenous group. Lecithin, cardiolipin, plasmalogens are some of the important glycerophospholipids. Sphingolipids are the derivatives of sphingosine, which is an unsaturated amino alcohol. Sphingosine bonded with a fatty acid by amide linkage is known as ceramide. Sphingomyelins are the common sphingolipids. Since they have a phosphate group, they are known as sphingophospholipids. Cerebrosides are the simplest sphingoglycolipids, which have monosaccharides as carbohydrate moiety. Gangliosides are the ceramide-oligosaccharide complexes. Cholesterol is a major component of animal plasma membranes. It has a steroid nucleus. Cholesterol is the metabolic precursor of steroid hormones.

Lipid Aggregates

The sphere aggregates of amphipathic lipids are called micelles. In them, polar head groups are on the exterior and nonpolar tails are in the interior. Lipid bilayer is the basic structure of cell membrane. Liposomes are the spherical vesicles of lipid bilayer. They act as carriers for substances like drugs, proteins, enzymes, genes, etc to target organs.

Biomembranes

Plasma membrane envelops a cell. Moreover, the Subcellular organelles are membrane bound. Plasma membrane has got several important functions since it has high selective permeability properties. In the fluid- mosaic model of membrane, peripheral and integral membrane proteins are found.

Lipoproteins

They are lipid-protein complexes. The protein part is called apoprotein. They are classified based on density: Chylomicrons, very low density lipoproteins, low density lipoproteins and high density lipoproteins.

Eicosanoids

They are derived from twenty carbon unsaturated fatty acids. They are mainly of two types: Prostanoids and leukotrienes. Prostaglandins, prostacyclins and thromboxanes are called prostanoids. Prostaglandins are known as local hormones due to their diverse physiological role.

Tutorial 10: Nucleic Acids

Introduction

Nucleic acids are polymers of ribonucleotides or deoxyribonucleotides and are associated with the nucleus of a cell. DNA and RNA are the important nucleic acids found in the cells.

Structure

A nucleotide contains a nitrogenous base, phosphate group and sugar. An organic molecule containing a nitrogenous base called purine or pyrimidine is present in nucleotide. Purines are adenine or guanine and pyrimidines are cytosine, thymine or Uracil. Depending on the number of phosphate groups present in nucleotides, they are known as nucleotide monophosphates, diphosphates or triphosphates.

Types of nucleic acids

There are two types of nucleic acids, deoxyribonucleic acid and ribonucleic acid.

DNA

DNA is a very long thread like molecule made up of a very large number of deoxyribonucleotides joined together. DNA is a linear double stranded polymer made up of deoxyribonucleotides. Deoxyribonucleotide is made up of a sugar called deoxyribose, a nitrogenous base and a phosphate group. DNA is located in the nucleus. Nucleotides are joined together by a phosphodiester bond in a condensation reaction. Double helix is formed when two strands are joined together by hydrogen bonds. Double helix is anti parallel. Both the stands run in opposite direction and are parallel to each other.

RNA

RNA is a linear polymer in which nucleotides are linked together by means of phosphodiester bridges. It does not form a double helix like DNA. There are three different types of RNA: mRNA, tRNA and rRNA. Most RNA molecules usually have secondary structure, consisting of stem and loop domains. mRNA is linear in structure, variable in size, has a poly A tail and acts as a template for protein synthesis. tRNA has a clover leaf structure. rRNA is large in size and is associated with protein. All the three types of RNA are associated in the production of a protein.

Core Unit 3 – Enzymology

Tutorial 11: Enzyme: The Basic Concept

Enzyme structure

An enzyme is a protein that catalyzes a chemical reaction and a substrate is a molecule which is acted upon by an enzyme. The substrate binds with the enzyme's active site and the enzyme

catalyzes the chemical reaction involving the substrate. The active site is the location on the surface of the enzyme where the catalysis of chemical reaction takes place. A Peptide bond is formed by amino acid condensation. Substrate is held by weak interactions at the binding site of the enzyme. Reaction catalysis and product formation occurs at catalytic site of the enzyme.

Mechanism of enzyme action

Several steps of enzyme action results in the formation of products and eventually the enzyme is regenerated. In lock and key hypothesis, enzyme holds the substrate as a lock holding the key. As per induced fit hypothesis, active site expands and contracts on substrate interaction.

How enzymes Act as Biocatalysts

Activation energy is the amount of energy required to convert all the reacting substances from ground state to transition state. It determines the rate of reaction. Enzymes work by lowering the activation energy. Lower the activation energy, faster is the rate.

Enzyme cofactors

Cofactor of an enzyme is the non-protein component and is essential for its catalytic activity. Coenzyme is a loosely bound organic cofactor that is required for enzyme activity. Prosthetic group is a metal ion or an organic compound that is covalently bound to an enzyme required for its activity. Activators are inorganic ions working as cofactors. They are either loosely or firmly bound.

Enzyme properties

Enzyme specificity is the ability of an enzyme to discriminate among competing substrates for it. There are four different types of specificity: Absolute, group, linkage, stereo chemical specificity.

Tutorial 12: Enzyme: The Kinetics and Catalysis

Enzyme catalysis

Enzymes act by lowering the activation energy. They do not change the equilibrium of the reactions. Enzyme binds with the substrate to form an unstable complex which breaks up into products liberating enzymes. Lock and key theory and induced fit theory explain the enzyme-substrate complex formation. Small region on the enzyme where the substrate binds and catalysis takes place is called an active site. Enzymes are highly specific in their action. Three types of enzyme specificity are well recognized: They are stereo specificity, reaction specificity and substrate specificity. There are different mechanisms to explain enzyme catalysis. Different mechanisms are: acid base catalysis, covalent catalysis and metal ion catalysis and transition state stabilization.

Enzyme kinetics

Various factors like concentration of substrate, pH and product concentration of products affect enzyme activity. Michaelis-Menten kinetics is based on substrate concentration. When a graph is plotted for substrate concentration [S] on x-axis and velocity [V] on the y axis, a rectangular hyperbola is obtained. A linear plot that is obtained by rearranging the M-M equation is called Lineweaver-Burk plot or double reciprocal plot. Km value is the substrate concentration at half maximal velocity of an enzyme catalyzed reaction. Enzymes having many subunits may not strictly follow the M-M kinetics. Chemical substances which inhibit enzyme activity and reduce velocity of an enzyme catalyzed reaction are known as inhibitors. Enzyme inhibition is broadly classified into reversible and irreversible inhibition. Reversible inhibition is further divided into competitive, non competitive and uncompetitive inhibition. Suicide inhibition is a reversible inhibition.

Regulatory Properties of Enzymes

In each enzyme system, there is at least one enzyme that catalyzes the rate limiting reaction. It is known as a regulatory enzyme. There are two major classes: Allosteric enzymes acting through reversible, non covalent modulator. Enzymes regulated by reversible covalent modification. The allosteric sites are different from its active site. Feedback inhibition is the best example for allosteric modulation. Localization of enzymes related to one pathway partly in mitochondria and partly in cytosol is called compartmentation. Ribozymes are the enzymes made of RNA.

Core Unit 4 – Metabolism

Tutorial 13: Introduction to Metabolism and Bioenergetics

Introduction

Living organisms are not at equilibrium. They require a continuous influx of free energy to maintain order in a universe where there is maximum disorder. Metabolism is the overall process through which free energy is acquired and utilized by living systems to carry out their various functions. By coupling the exergonic (energy releasing) reactions of nutrient oxidation and endergonic (energy consuming) reactions, they maintain the living state. Metabolism is the overall process through which free energy is acquired and utilized by living systems to carry out their various functions. Free energy is the most useful thermodynamic concept in biochemistry. A reaction can occur spontaneously only if ΔG, the change in free energy is negative. The reactions are coupled by the shared chemical intermediate. Energy is extracted from foodstuffs by three different stages.

In the first stage, large molecules of food are broken down into smaller units. No useful energy is liberated.

In the second stage, small molecules are degraded to a few simple units of metabolic importance like acetyl CoA. Some amount of ATP is generated here.

In the third stage, final common pathways in the oxidation of fuel molecules are citric acid cycle

and oxidative phosphorylation. More than 90% ATP generation from degradation of food stuffs takes place in the third stage.

Universal carrier molecules

Processes involving the transfer of electrons are of immense biochemical significance. Oxidation-reduction reactions resemble other types of chemical reactions in that they involve group transfer. In Redox reactions, the groups transferred are electrons which are passed from an electron donor to an electron acceptor. NADPH is the major electron donor in reductive biosynthesis. NADH and FADH2 is the major electron carrier in the oxidation of fuel molecules. Coenzyme A is the acyl group carrier which is an important molecule in metabolism.

Bioenergetics of phosphate compounds

ATP is the universal currency of free energy in biological systems. It is an energy rich molecule because its triphosphate unit contains two phospho anhydride bonds. ATP on hydrolysis liberates a large amount of energy. Creatine phosphate is a reservoir of high potential phosphoryl groups in the muscle which can readily transfer its phosphoryl group to ATP.

Regulation of metabolic processes

Metabolism is regulated by controlling the amount of particular enzymes, catalytic activities and the accessibility of substrates. Many reactions in metabolism are controlled by the energy status of the cell. Index of energy status is the energy charge. An alternative index of the energy status is the phosphorylation potential. It depends on the concentration of inorganic phosphate and is directly related to the free energy available from ATP.

Tutorial 14: Glycolysis

Release of energy from glucose

Glycolysis is the sequence of reactions that converts glucose into pyruvate with the concomitant production of a relatively small amount of ATP. Glucose is the starting material and two molecules of pyruvate are the end products of the pathway. Subcellular site of the pathway is the cytosol. Glycolysis is a linear pathway of ten enzyme mediated steps.

Phases of glycolysis

Pathway has two phases: Energy investment phase and energy generation phase. Energy investment phase is also called preparatory phase and consists of first five steps. Here the end product is glyceraldehyde - 3 – phosphate. Energy generation phase is also known as payoff phase and consists of last five steps and end products are two pyruvate molecules.

Energy yield from the pathway

It can occur in presence or absence of oxygen. Altogether there are ten steps involved and in aerobic glycolysis net ATP gain is 8 and the pyruvate enters the citric acid cycle, oxidized to CO_2 and H_2O.

Anaerobic glycolysis
Under anaerobic conditions, net ATP gain is 2 from substrate level phosphorylation. NADH gets accumulated which is reoxidized via lactic acid and alcohol fermentation.

Sources of glucose for glycolysis
Glycogen, dietary disaccharides and monosaccharides also enter the glycolytic pathway, since they are the sources of glucose.

Tutorial 15: The Citric Acid Cycle

TCA cycle

Cellular respiration
Cellular respiration is a process in which cellular energy is generated through the oxidation of nutrient molecules, with oxygen as the ultimate electron acceptor.

Stages of cellular respiration
There are two stages of cellular respiration. In stage I, pyruvate is converted to acetyl CoA with the help of pyruvate dehydrogenase complex by oxidative Decarboxylation. Coenzyme A activates acetyl group derived from pyruvate. In stage II, acetyl CoA enters the TCA cycle and gets oxidized through 8 steps, generating ATPs.

The Citric acid cycle
TCA cycle is a cyclic pathway and the subcellular site of the reaction is mitochondria in eukaryotes. Formation of citrate, then, isocitrate, oxidation of isocitrate, oxidation of α ketoglutarate, conversion of succinyl CoA to succinate, oxidation of succinate, hydration of fumarate, oxidation of malate to oxaloacetate. They are the 8 steps of TCA cycle. Net ATP gain from one glucose molecule is 38.

Phases of reactions of citric acid cycle
Amphibolic pathway is the metabolic pathway used in both catabolism and anabolism. TCA cycle acts as an amphibolic pathway since it is involved in both breakdown as well as synthesis of biomolecules. There are Anaplerotic reactions which replenish the supply of intermediates in the citric acid cycle. Ex: Malate is formed from pyruvate by the malic enzyme.

Tutorial 16: Additional Pathways in Carbohydrate Metabolism

arbohydrate Metabolism II

Pentose phosphate pathway
Pentose phosphate pathway (PPP) is a secondary pathway of glucose metabolism, primary being

glycolysis. Glucose enters PPP as glucose 6-phosphate. It occurs in the cytosol of tissues active in fatty acid biosynthesis. Those tissues are liver, mammary and adrenal glands and adipose tissue. There are two phases in the pathway: oxidative and non-oxidative. There are four steps involved in oxidative phase, during which glucose-6 phosphate gets converted to ribose 5-phosphate. In the non-oxidative phase, transaldolase and transketolase enzymes catalyze the reversible reactions for the regeneration of glucose 6-phosphate.

Glyoxylate cycle
Glyoxylate cycle is a variant of TCA cycle and occurs in bacteria and glyoxysomes of plants. It bypasses decarboxylations of citric acid cycle and allows net synthesis of glucose from acetyl CoA.

Gluconeogenesis
Gluconeogenesis is a process of biosynthesis of glucose from simpler non carbohydrate precursors such as oxaloacetate or pyruvate. It is a universal pathway in animals, plants, microbes and fungi. It converts pyruvate to glucose (reverse of glycolysis). The irreversible steps of glycolysis are circumvented by four key enzymes of gluconeogenesis. They are pyruvate carboxylase, phosphoenol pyruvate carboxy kinase, fructose-1, 6-bisphosphatase and glucose-6-phosphatase.

Glycogen synthesis
Glycogen synthesis takes place in the liver and muscle. All the enzymes of glycogen synthesis are located in the cytosol. Activation of glucose takes place followed by the sequential addition of activated glucose units by glycogen synthase. A brancher enzyme creates alpha 1-6 linkage.

Starch synthesis
Starch is synthesized in the chloroplasts of plants with the help of enzymes ADP-glucose phosphorylase and starch synthase.

Disaccharide synthesis
Lactose is synthesized in lactating mammary glands of animals with the help of enzyme lactose synthase. Lactose is made up of galactose and glucose. Sucrose is synthesized in plants.

Tutorial 17: Electron Transport and Oxidative Phosphorylation

Electron Transport and Oxidative phosphorylation

Introduction
The electron transport system is the place in the cell where electrons generated by oxidation are transferred. Passage of the electrons through the system generates potential energy that is used to make ATP in oxidative phosphorylation.

Components of electron transport chain
Components of ETC are arranged in the inner mitochondrial membrane involved in the process of electron transport. In biological system, fuel molecules are oxidized by losing electrons, which are transferred through the carrier molecules like NAD and FAD. Finally electrons are donated

to oxygen to reduce it to a water molecule. Coenzyme Q is a respiratory electron carrier. Cytochromes are a group of heme containing proteins. The major respiratory cytochromes are b, c and c1 and a or a3.

Electron Transport – Carriers and arrangement of carriers into complexes
Integral membrane proteins embedded in the inner mitochondrial membrane are arranged into complex I, II, III and IV. They accept or donate electrons from preceding carrier to the following in sequence.

Pathway of Electron Transfer through the Carriers
I NADH dehydrogenase, II Succinate dehydrogenase, III CoQ – Cytochrome c oxidoreductase, and IV Cytochrome oxidase are the four complexes. Electrons are transferred through these complexes. Through complex I, III and IV, protons are pumped out of mitochondrial matrix creating proton gradient.

Proton Motive Force
Coupling of ATP synthesis to electron transfer via an electrochemical H+ gradient across a membrane is called chemiosmosis. Energy from electron transport drives an active transport system which pumps protons out of the mitochondrial matrix into inter- membrane space. An electrochemical gradient of protons is created, with a lower pH value outside the inner mitochondrial membrane than inside. The protons on the outside have a thermodynamic tendency to flow back in, so as to equalize pH on both sides of the membrane.

ATP Synthesis
When protons from inter-membrane space do flow back into the matrix, the free energy arising from the gradient is used to drive the synthesis of ATP. ATP synthase also called complex V is the site where ADP is phosphorylated to ATP.

Tutorial 18: Photosynthesis

Photosynthesis

Basic process of photosynthesis
Photosynthesis is a process where by energy from light is harvested and used to drive synthesis of carbohydrates from carbon dioxide and water.

Physics of light
Quantum is the elemental unit of energy. Photon is a quantum of electromagnetic energy and it is particle of light.

Chloroplast structure
Chloroplast is a plant subcellular organelle where photosynthesis takes place. Outer membrane of chloroplast is permeable. Inner membrane encloses stroma. Thylakoid is flattened membrane surrounded vesicle. This is the place where light reaction occurs. In stroma, fluid surrounding the thylakoids is the place where the dark reaction occurs. Chlorophylls are the green pigments; they are present in the thylakoid membrane of chloroplast. They absorb deep blue and red light.

Secondary light absorbing pigments are called accessory pigments. They are carotenoids and phycobilins. Photosystems are the light absorbing pigments of thylakoid membrane arranged in functional sets.

Light reaction and photophosphorylation
Photosystems are of two types: PS I P700, PS II P680. Components of photosystem I and II transfer the electrons from water to NADP. Light is absorbed by these photosystems and electrons are transferred from water to NADP. Photophosphorylation is a process where the light energy captured by the photosynthetic organisms is transformed into the phosphate bond energy of ATP. During the transfer of electrons, ATP is synthesized. Electron flow is cyclic. As a result oxygen is not released and ATP is formed as a result of proton gradient created by Cytochrome bf pump.

Dark reaction – Calvin cycle
Second step of photosynthesis is called Calvin's cycle and it is a dark reaction. There are two stages here, I and II. In Stage I carbon dioxide is incorporated into 5 carbon ribulose bisphosphate. In stage II ribulose bisphosphate is the regenerated.

Photorespiration
Photorespiration is the process wherein oxygen consumption occurs in illuminated temperature zone of plants under high oxygen and low carbon dioxide. Oxygen is consumed and carbon dioxide is released. Moreover, ATP is expended without benefit.

C4 pathway
C4 cycle is the pathway adopted by C4 plants to conserve the carbon dioxide released via photorespiration. It occurs in mesophyll cells. Carbon dioxide is incorporated to form 4 carbon oxaloacetate.

Tutorial 19: Lipid Metabolism

Lipid Metabolism

Lipid digestion and absorption
Lipids play an important role in cell structure and metabolism. TAGs are the major storage form of energy. Cholesterol is a component of cell membranes and precursor of steroid hormones. Lipid digestion occurs at lipid water interfaces since TAG is insoluble in water and digestive enzymes are water soluble. Lipids are digested and absorbed with the help of bile salts. Products of lipid digestion aggregate to form mixed micelles and are absorbed into the small intestine. Lipids are transported in the form of lipoproteins.

Fatty acid oxidation
Fatty acids have to be activated prior to their entry into mitochondrial matrix where the enzymes of β-oxidation of fatty acids are located. Activated fatty acids are then transported from cytosol to the mitochondrial matrix with the help of carnitine transporter. Total net yield of ATP per molecule of palmitic acid is 129. Similarly oxidation of unsaturated and odd chain fatty acids also take place with additional reactions. B-oxidation in peroxisomes involves three enzymatic

reactions. Minor pathways of oxidation such as α-oxidation of branched chain fatty acids and ω-oxidation of medium and long chain fatty acids in microsomes do take place in our body.

Ketone body metabolism
Ketone bodies are acetoacetate, β-hydroxy butyrate and acetone. Ketone bodies are synthesized in the liver but they are utilized by extra hepatic tissues as fuels. Ketone bodies are accumulated in the blood if the rate of synthesis exceeds the ability of extra hepatic tissues to utilize them. This leads to excess ketone bodies in blood, excretion of ketone bodies in urine and smell of acetone in breath. All these three together are known as ketosis. In uncontrolled diabetes mellitus and starvation, ketone bodies are formed.

Fatty acid biosynthesis
The enzymes of synthesis are located in the cytoplasm. Acetyl CoA is the source of carbon units and NADPH provides reducing equivalents. ATP is the supplier of energy. Synthesis is not the reversal of oxidation. Dimer of fatty acid synthase takes part in fatty acid synthesis. TAGs are synthesized from fatty acyl CoA and glycerol 3-phosphate or dihydroxy acetone phosphate. TAG gets deposited in adipose tissue.

Cholesterol biosynthesis

80% of endogenous cholesterol is formed in the liver. Enzymes involved in the synthesis are partly located in the endoplasmic reticulum and partly in the cytoplasm. Acetyl CoA is the precursor. HMG CoA, mevalonate, isopentenyl pyrophosphate, squalene are some of the important intermediate compounds formed during cholesterol synthesis. Cholesterol is transported in lipoprotein complexes. Elevation of lipids in blood leads to the deposition of cholesterol on the arterial walls leading to atherosclerosis.

Eicosanoids
Prostaglandins are synthesized from arachidonic acid. Cycloxygenase enzyme catalyzes the reaction in which C20 fatty acid is converted to prostaglandins. Leukotrienes are also derived from arachidonic acid.

Synthesis of phospholipids and sphingolipids
Glycerol is the starting material in the synthesis of glycerophospholipids. CDP-diacylglycerol is the activated intermediate of this pathway. Sphingolipids are synthesized from palmitoyl CoA and serine, initially to form ceramide. Sphingomyelins and glycolipids are synthesized from ceramide. Various sphingolipids storage diseases are resulted due to hereditary absence of hydrolytic enzymes.

Tutorial 20: Amino Acid Metabolism

Amino Acid Metabolism

Digestion of dietary proteins
Digestion of dietary proteins starts in the stomach. Secretion of HCl activates formation of

pepsin from pepsinogen which hydrolyses peptide bonds of dietary proteins to release aromatic amino acids. Similarly, in the small intestine digestion continues. Zymogens are activated for the breakdown of peptide bonds to release amino acids which are absorbed into the small intestine.

Amino acid deamination
Transamination is a process by which amino group is transferred to the keto acid to yield the keto acid of the original amino acid and a new amino acid, catalyzed by amino transferases. Glutamate is oxidatively deaminated in the mitochondrion and release ammonia.

The Urea Cycle
This cyclic pathway takes place in the liver, partly in the mitochondria and partly in cytosol. There is interrelation between urea cycle and citric acid cycle. Fumarate of the urea cycle is taken up by citric acid cycle. Carbamoyl phosphate synthetase I is the regulatory enzyme.

Metabolic breakdown of individual amino acids
Catabolism of amino acids gives rise to the intermediate compounds of citric acid cycle. Alanine, serine, cysteine and asparagine are converted to oxaloacetate. Glutamine, proline, arginine and histidine are converted to α-ketoglutarate through glutamate. Succinyl CoA is a point of entry for non polar amino acids like methionine, valine and isoleucine. Leucine is degraded to acetyl CoA and acetoacetate. Tryptophan, lysine, leucine, phenylalanine, tyrosine and isoleucine donate their carbons to acetyl CoA. Various disorders of amino acid catabolism are observed due to the defective enzymes. Tryptophan, tyrosine, glycine and glutamate are the precursors of some of the biologically important compounds. Biotin, Tetrahydrofolate or S-Adenosyl methionine is the enzyme cofactors in catabolism which transfer carbon compounds.

Amino acid biosynthesis

Nonessential amino acids are formed from intermediates of carbohydrate metabolism. Alanine is formed from pyruvate and aspartate from oxaloacetate. Asparagine is formed from aspartate. Glutamate is formed from α ketoglutarate and glutamine from glutamate. Glutamate is the precursor of proline and arginine. Cysteine is synthesized from 3 – phosphoglycerate. During the process, serine is the intermediate compound which gives rise to glycine.
Threonine is an essential amino acid. It is formed from β-aspartate. Methionine and lysine also have a common precursor. Valine, Leucine and isoleucine are formed from pyruvate. Phenyl alanine, tyrosine and Tryptophan are formed from phosphoenol pyruvate and erythrose – 4 – phosphate through the intermediate compound called chorismate. Histidine originates from PRPP and ATP.

Tutorial 21: Nucleotide Metabolism

Introduction

Nucleotides play a variety of important roles in all cells. They are the activated precursors of DNA and RNA. ATP, an adenine nucleotide, is a universal currency of energy in biological systems. GTP is an essential carrier of chemical energy. Adenine nucleotides are components of

the coenzymes NAD+, NADP+, FMN, FAD and Coenzyme A. UDP-Glucose in Glycogen synthesis and CDP-diacylglycerol in Phosphoglyceride synthesis are the nucleotide derivatives that act as activated intermediates. Cyclic AMP is a ubiquitous mediator for the action of many hormones. All cells can synthesize nucleotides from simple building blocks (de novo synthesis) or by the recycling of pre-formed bases (Salvage pathway). Nucleotides are phosphate esters of pentoses in which a nitrogenous base is linked to C1' of the sugar residue. A nucleotide without the phosphate group is known as a nucleoside. The major purine components of nucleic acids are adenine and guanine residues. The major pyrimidine residues are those of Cytosine, Uracil and Thymine. Pyrimidines are bound to ribose through N 1 atoms.

Synthesis of purine ribonucleotides

IMP is synthesized from ribose 5-phosphate. There are 11 reactions in the formation of IMP. IMP is converted to GMP and AMP with the help of ATP and GTP respectively. Nucleoside monophosphates are converted to nucleoside diphosphates by base specific monophosphate kinases. Purine nucleotide synthesis is regulated by feedback inhibitor – AMP, GMP and IMP. An important regulatory factor is the availability of PRPP. Salvage pathway for purines is observed in RBC and the brain. Free purines are salvaged by APRTase and HGPRTase enzymes

Synthesis of pyrimidine ribonucleotides

Pyrimidine ring is synthesized as free pyrimidine and then it is incorporated into the nucleotide. 6 reactions are involved in the synthesis of UMP. UDP and UTP are synthesized from UMP with the help of ATP. CTP is formed by adding an amino group from glutamine. Pyrimidine can also be salvaged using PRPP. In orotic aciduria, excretion of large amount of orotic acid is observed. It results from the deficiency of either orotate phospho ribosyl transferase or OMP decarboxylase.

Formation of deoxyribonucleotides

Ribonucleotide reductase catalyzes the synthesis of deoxyribonucleotide. The reductant is NADPH. Thioredoxin transfers electrons from NADPH for reduction of 2'-OH of ribose. dTMP is formed by thymidylate synthase by methylation of deoxy uridine monophosphate.

Degradation of nucleotides

Nucleotides of a cell undergo continuous turnover. Purines are catabolized and the end product is uric acid. Gout is a disease characterized by elevated levels of uric acid in body fluids. Sodium urate crystals are precipitated in the joints and soft tissues to cause painful arthritis. In Lesch-Nyhan syndrome, HGPRT deficiency occurs, leading to excessive uric acid production through PRPP accumulation. Gout is treated by allopurinol administration. Animal cells degrade pyrimidine nucleotides to their component bases by dephosphorylation, deamination and glycosidic bond cleavages to give rise to carbon dioxide, ammonia, β-alanine and β-amino isobutyrate.

Nucleotide Coenzymes

Nucleotides are the components of many enzyme cofactors. Adenosine is a part of their structure in a variety of enzyme cofactors serving a wide range of chemical functions. Coenzyme A is synthesized from pantothenic acid and ATP.

Core Unit 5 – Information Pathway

Tutorial 22: DNA Structure and Replication

DNA structure and replication

Structure of DNA
Purine and pyrimidine nucleotides are the building blocks of DNA. Adenine specifically binds to thymine with 2 hydrogen bonds and cytosine specifically binds to guanine with three hydrogen bonds. Hydrogen bond is a type of attractive intermolecular force that exists between two partial electric charges of opposite polarity. Two strands of DNA are anti parallel with major and minor grooves.

DNA replication
The process of making an identical copy of a section of duplex DNA, using existing DNA as template for the synthesis of new DNA strands. DNA undergoes semi conservative nature of replication. There are three steps in the replication process: Initiation, elongation and termination. Initiation always begins at the origins of replication, it is bidirectional with most genomes and priming is with RNA. Elongation has three steps: unwinding of DNA, relieving of torsional stress and polymerization of poly nucleotide chain. One strand of DNA is made continuously while the other strand is synthesized in fragments.

Functions and structures of DNA replication enzymes
Many enzymes are involved in DNA replication such as topoisomerase, helicase, primase, DNA polymerase and ligase. Topoisomerases relax the super coiling of DNA, helicases unwind double strand of DNA, primases synthesize a primer, DNA polymerases add and read proof new bases and ligases link the added bases.

Tutorial 23: RNA Structure and Synthesis

RNA structure and synthesis

Structure of RNA
Ribonucleic acids are made up of nitrogenous bases such as adenine, Uracil, guanine and cytosine, ribose sugar and phosphate group. RNA is normally single stranded which can have a diverse form of secondary structures. tRNA shows secondary and tertiary structure.

Types of RNA
mRNA represents about 5-10% of cellular RNA. It contains the sequence of bases coding for a particular amino acid sequence in a polypeptide chain. tRNA represents about 15-20% of cellular RNA. Each tRNA molecule is specific for one amino acid. There is an enzyme for each amino acid which recognizes the amino acid and its specific tRNA and joins the two together. The specific joining of tRNA to amino acid is the only place where the genetic code is realized. rRNA represents about 70-80% of cellular RNA. It is associated with specific set of ribosomal proteins. It functions as non-specific ‘workbench’ for the assembly of polypeptides. Many copies

of genes coding for rRNA are located in nucleolar organizer regions of certain chromosomes. =

RNA synthesis
RNA synthesis occurs in both prokaryotes and eukaryotes. There are three steps to RNA synthesis: Initiation, elongation and termination. In the initiation step, RNA polymerase binds to gene regulatory elements. In the elongation step, RNA polymerase unwinds DNA duplex next to a gene. RNA is transcribed 5' to 3' from the template of 3' to 5'. Termination in eukaryotes is by cleavage and polyadenylation.

RNA polymerase
RNA polymerase searches DNA for initial site. It unwinds a short stretch double helical DNA to produce a single stranded DNA template from which it takes instructions. Also selects the correct ribonucleotide and catalyzes the formation of phosphodiester bond and detects the termination signals which specify where a transcript ends. RNA polymerase interacts with activated and repressor proteins that modulate the rate of transcription initiation over a wide dynamic range. In prokaryotes, only one type of RNA polymerase is present. It transcribes mRNA, tRNA and rRNA. Eukaryotes possess three RNA polymerases: RNA polymerase I, II and III.

Post transcriptional controls/ RNA splicing
mRNA undergoes significant processing within the nucleus prior to transport to cytoplasm: by removal of non coding into internal sequences called introns. It undergoes modification of the 5' base and an addition of adenine to 3' end (poly A tail) takes place. RNA splicing is a process that removes introns and joins exons in a primary transcript.

Tutorial 24: Protein Biosynthesis

RNAs involved in protein biosynthesis
Information flow in the cell: DNA is transcribed to mRNA which is translated (decoded as) into Protein. Protein biosynthesis takes place in the ribosomes. A series of ribosomes (poly ribosome) can simultaneously translate the same eukaryotic mRNA molecule. RNA brings specific amino acid to ribosome and mRNA carries the genetic information to protein. Codons that encode the same amino acid often differ only by their third base. The binding of the third base is less stringent than the other two. Because of this wobble, one RNA can pair with multiple mRNA codons.

Process of protein biosynthesis
There are signal sequences before the real coding sequence at the translation initiation sites. Amino acid activation is catalyzed by amino acyl-RNA synthetase and couples it to its corresponding RNA. Anti codon in RNA molecule forms base pairs with the appropriate codon on the mRNA. In the initiation step, initiation factors are involved. Initiation factor is the protein that promotes the proper association of ribosomes with messenger RNA. In the elongation step, incorporation of an amino acid into a protein takes place. As a result, polypeptide chain is grown. Termination is the last stage in protein biosynthesis.

Quality control and chaperones
If at all, a wrong amino acid is added, RNA synthetase removes the incorrectly attached amino acid through hydrolytic editing. There are protein molecules called chaperones that catalyze the correct folding of other proteins within the cell. They also help in preventing aggregation. The hsp70 family of molecular chaperones helps in correct folding after synthesis.

BIO TECHNOLOGY

Introduction:

Early knowledge of agriculture was an accumulation of experiences that were passed on from father to son. Some of these have been preserved as religious commandments and some in the ancient inscriptions. There is evidence to show that as early as 2000 BC the Egyptian civilization followed particular dates for sowing and reaping. Some Greek and Roman classics give instructions on how to get a higher yield.

The development of agriculture made it apparent that more food could be extracted from a given area of land by encouraging useful and hardy plant and animal species, and discouraging others.

At the turn of the 19th century, a movement began in central Europe to train farmers in specific farming skills. A truly scientific approach was begun by Justine von Liebig of Darmstadt who in his classic work introduced the systematic development of agriculture science. From the 19th century onwards plant production became a scientific discipline.

In the early 20th century, the legendary work of Gregor Mendel laid the foundation of modern day genetics. His work explained the basics of inheritance in terms of the factor we today call genes.

Apart from selection and hybridization, new and innovative techniques such as genetic engineering that aid plant breeders have been developed in the recent past. One example of this is BtCotton. With advances in human and plant biology, more intricate details about the cell – the basic unit of life – were illuminated. The possibility of raising whole plants from various plant tissues, commonly know as tissue culture, has thrown open the doors for expedited evolution both in terms of generation of genetic variability and multiplication of elite plant types. The knowledge of the wonder molecule DNA has also opened a new area of plant breeding research. These new technologies have been collectively referred to as biotechnology. It is a collective effort for plant breeding in the future and will compliment man's crusade for more and better food. In India, the reen Revolution saw the rapid progress of agriculture and the application of different methods to enhance production. Biofertilizers have been proven to be more environmentally friendly fertilizers that do not cause harm to life. Bioremediation methods have been used to clear oil spills using bacteria.

Biotechnology

Biotechnology is short for biological technology. Technology is the ability to better utilize our surroundings. Biotechnology applies the same principles to living organisms as do other technologies. Biotechnology can be defined as the application of our knowledge and understanding of biology to meet practical needs. It is as old as the growing of crops. Today’s biotechnology is largely identified with applications in medicine and agriculture based on our knowledge of the genetic code of life. Fermentation, used in making bread, beer, and cheese, is an example of biotechnology. Modern biotechnology simply allows scientists to be more specific in their work.

Different types of crops have been produced using the molecular tools of biotechnology and are beginning to be utilized in agricultural systems all over the world. At the same time, an increasing number of farmers are adopting sustainable cultural practices.

Biotechnology has the potential to assist farmers in reducing on-farm chemical inputs and produce value-added commodities. Conversely, there are concerns about the use of biotechnology in agricultural systems including the possibility that it may lead to greater farmer dependence on the providers of the new technology.

Plant Breeding

As a part of agriculture, man started rearing plants and animals to meet his requirements. This is when humans started to learn how to influence the process of natural evolution so as to breed plant or animals.

Slowly and gradually, this process of expedited evolution, through selection and cultivation of plants, acquired the form of a routine endeavor—what we today call 'plant breeding'. In this, heredity, which refers to the passage of various characteristic features from the main plant (the parent) to the plantlets (the progeny), plays an important role. The effects of heredity had been apparent to early man and he had taken advantage of them ever since the advent of agriculture.

Various methods have evolved in plant breeding. One of the most important methods is that of selection.

The ability to choose gave birth to the idea of selection. This is the most primitive and by and large the most successful method of plant breeding. Selection as a part of plant breeding started with the domestication of plants by early man. Domestication refers to the process of bringing wild species under human management. Not all selection over the years have been human influenced—many of the important crop species have resulted from the natural selection process, which is an integral part of evolution. As human knowledge of agriculture grew, man started shuffling crop species from one geographical terrain to another, thus making new introductions.

The first prerequisite of selection is the availability of variability, i.e. different types of forms. After a variable population is recognized, individuals that are the best performers for the desired feature, say fruit size in the case of tomatoes, are chosen and the rest of the population is discarded or rejected. The progeny of the selected individuals is grown further and again screened for the desired feature. This process is repeated until a uniform plant population is attained which has the best-desired characters. Eventually, a desired uniform crop variety is produced by this successive selection followed by multiplication of the selected individuals.

Selecting higher yielding plant varieties is no easy task. Various tools have been devised to deal with plant selection. In fact, the birth of genetics as an independent discipline in plant science started with some clever mathematical computations. This brainchild of yesteryears is now an important branch of genetics known as biometrics. Biometrics is defined as the application of statistics in biology. This has contributed greatly to the development of various systems based on which selection of plants is done. There are various methods by which plant selection is carried out, namely selection for uniform plants, known as pure line selection; selection from field-grown plants, known as bulk selection or mass selection; and selection from a well-documented list of parentage, commonly known as the pedigree system. Overall, the hallmark of selection lies in human ability to chose the best plants from a cluster of many.

Hybridization

In traditional terms, hybridization refers to the union of the male and the female gamete to produce a zygote. In plant science, hybridization also refers to the crossing or mating of two plants. The story of scientific hybridization of crop plants started with J G Kolreuter, who in 1761 published his work on the scientific bases of hybridization. Since then, hybridization followed by selection, has been the major tool of plant breeding.

In his quest to find more variability, man started experimenting with hybridization of plants so as to achieve the perfect plant type. This process was actually the beginning of expedited evolution since it led to the formation of new plant types artificially or due to human intervention at a much faster pace than it would have happened in nature. For example, the bread wheat that we eat today has taken about 500 years to evolve to its present form through human intervention. This form of wheat would have taken thousands of years to evolve had it been left to the natural evolution process.

Ways in which hybridization is used

Some of the ways in which hybridization has been exploited in breeding crop plants are given below

Combination breeding:

The main aim of combination breeding is to transfer one or more characters into a single variety or plant type from many others. For this, an existing plant variety may be used as the recipient parent while many other crop varieties or wild relatives may contribute as donor parents. The most commonly used method to achieve this goal is known as the backcross method. The plant type in which the character or the trait is being transferred is known as the recipient parent and the other as the donor parent. For this, the two plants are mated or crossed and the progeny is screened for the desired trait. The progeny plants possessing the desired trait are then selected and crossed back to the recipient parent. This process is repeated until the desired plant type having all the characteristics of the recipient in addition to the trait being transferred is finally obtained. This exercise is known as backcrossing. Backcrossing involves both hybridization and selection.

Hybrid varieties:

Plant scientists exploit the characteristic feature of better yielding ‘hybrids’ in plants. Hybrid vigour, or hetrosis as it is scientifically known, exploits the fact that some offspring from the progeny of a cross between two known parents would be better than the parents themselves. Many hybrid varieties of several crop species are being grown all over the world today. An example of this is the hybrid tomatoes that we eat commonly. The philosophy of hybridization has been extended from ‘within the same species or genera (the same type of plants)’ to ‘different species or genera (totally different plants)’. This is known as wide or distant hybridization. Wide hybridization has helped breeders to break what is known as the species or genera barrier for gene transfer, i.e. it has helped breeders to transfer beneficial characteristics from wild and weedy plants to the cultivated crop species.

The Green Revolution

The world's worst recorded food disaster occurred in 1943 in British-ruled India. Known as the Bengal Famine, an estimated 4 million people died of hunger that year in eastern India (which included today's Bangladesh). Initially, this catastrophe was attributed to an acute shortfall in

food production in the area. However, Indian economist Amartya Sen (recipient of the Nobel Prize for Economics, 1998) has established that while food shortage was a contributor to the problem, a more potent factor was the result of hysteria related to World War II, which made food supply a low priority for the British rulers.



When the British left India in 1947, India continued to be haunted by memories of the Bengal Famine. It was therefore natural that food security was one of the main items on free India's agenda. This awareness led, on one hand, to the Green Revolution in India and, on the other, legislative measures to ensure that businessmen would never again be able to hoard food for reasons of profit.

The Green Revolution, spreading over the period from1967/68 to 1977/78, changed India’s status from a food-deficient country to one of the world's leading agricultural nations. Until 1967 the government largely concentrated on expanding the farming areas. But the population was growing at a much faster rate than food production. This called for an immediate and drastic action to increase yield. The action came in the form of the Green Revolution. The term ‘Green Revolution’ is a general one that is applied to successful agricultural experiments in many developing countries. India is one of the countries where it was most successful.

There were three basic elements in the method of the Green Revolution



- Continuing expansion of farming areas
- Double-cropping in the existing farmland
- Using seeds with improved genetics.

The area of land under cultivation was being increased from 1947 itself. But this was not enough to meet the rising demand. Though other methods were required, the expansion of cultivable land also had to continue. So, the Green Revolution continued with this quantitative expansion of farmlands.

Double cropping was a primary feature of the Green Revolution. Instead of one crop season per year, the decision was made to have two crop seasons per year. The one-season-per-year practice was based on the fact that there is only one rainy season annually. Water for the second phase now came from huge irrigation projects. Dams were built and other simple irrigation techniques were also adopted.

Using seeds with superior genetics was the scientific aspect of the Green Revolution. The Indian Council for Agricultural Research (which was established by the British in 1929) was reorganized in 1965 and then again in 1973. It developed new strains of high yield variety seeds, mainly wheat and rice and also millet and corn.

The Green Revolution was a technology package comprising material components of improved high yielding varieties of two staple cereals (rice and wheat), irrigation or controlled water supply and improved moisture utilization, fertilizers, and pesticides, and associated management skills.

Benefits

Thanks to the new seeds, tens of millions of extra tonnes of grain a year are being harvested.

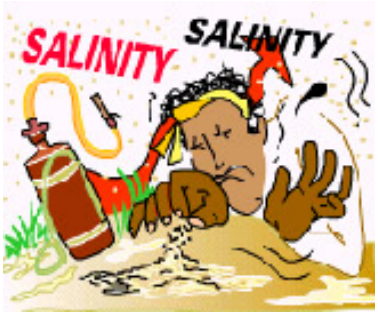


The Green Revolution resulted in a record grain output of 131 million tonnes in 1978/79. This established India as one of the world's biggest agricultural producers. Yield per unit of farmland improved by more than 30% between1947 (when India gained political independence) and 1979. The crop area under high yielding varieties of wheat and rice grew considerably during the Green Revolution.

The Green Revolution also created plenty of jobs not only for agricultural workers but also industrial workers by the creation of related facilities such as factories and hydroelectric power stations.

Shortcomings

In spite of this, India's agricultural output sometimes falls short of demand even today. India has failed to extend the concept of high yield value seeds to all crops or all regions. In terms of crops, it remains largely confined to foodgrains only, not to all kinds of agricultural produce.



In regional terms, only the states of Punjab and Haryana showed the best results of the Green Revolution. The eastern plains of the River Ganges in West Bengal also showed reasonably good results. But results were less impressive in other parts of India.

The Green Revolution has created some problems mainly to adverse impacts on the environment. The increasing use of agrochemical-based pest and weed control in some crops has affected the surrounding environment as well as human health. Increase in the area under irrigation has led to rise in the salinity of the land. Although high yielding varieties had their plus points, it has led to significant genetic erosion.

Plant Tissue Culture

In 1965, French botanist George Morel was attempting to obtain a virus-free orchid plant when he discovered that a millimetre-long shoot could be developed into complete plantlets by micropropagation. This was the beginning of tissue culture. Thereafter, in the 1970s developed countries began commercial exploitation of this technology. It entered the developing world in the 1980s. It was earlier used to develop ornamental plants and flowering plants for export. With tree species, the technique of tissue culture remained confined for many years to the laboratory stage and had generally invited only academic interest. But in most developing countries, the shortage of biomass and the ever-increasing energy requirements created the need to explore possibilities of mass propagation of trees by tissue culture.

Tissue culture or mass cloning methods of elite tree species is done for increasing land productivity. They are being modified or adapted for large-scale modification.

Species are selected for tissue culture on the following basis.

- Species that have regeneration problems, specially because of poor seed set or germination (as in Anogeissus and bamboo). In these cases, seeds collected from superior trees are used for initiating cultures.
- Species that vary markedly in their desirable traits, i.e. Eucalyptus. The selected trees are marked from the variant population for the desirable trait such as disease resistance, straight bole, higher productivity, etc. in consultation with officials from state forest department or growers.
- Species where plants of any one particular sex is of commercial importance, for example female plants of papaya and male plants of asparagus

In tissue culture cells, tissues, and organs of a plant are separated. These separated cells are grown especially in containers with a nutrient media under controlled conditions of temperature and light. The cultured plant requires a source of energy from sugar, salts, a few vitamins, amino acids, etc. that are provided in the nutrient media. From these cultured parts, an embryo or a shoot bud may develop, which then grows into a whole new plantlet. Similarly, portions of organs or tissues can be cultured in a culture media. Generally, these give rise to an unorganized mass of cells called callus (soft tissue that forms over a cut surface).

Tissue culture plantlets have poor photosynthesis efficiency and lack the proper mechanism to control water loss. They need to be hardened gradually by moving them along a humidity gradient in the greenhouse. Once these plants are in the research fields, they are evaluated under field conditions and the data is collected every 6 months. A large number of tissue culture plants that have grown into trees are remarkably uniform and show an increase in biomass production over the conventionally raised plants.

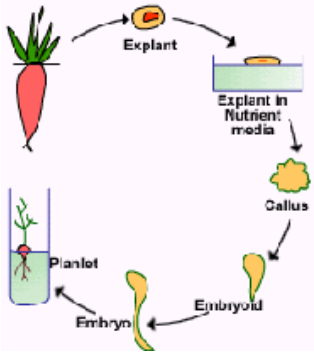


Figure Tissue culture and totipotency

Application of tissue culture

- **Micropropagation**

Rapid vegetative multiplication of valuable plant material for agriculture, horticulture, and forestry.

- **Production of disease-free plants**

When the apex of shoot is used for multiplication by tissue culture, we get disease free plants because the shoot apical meristem, a group of dividing cells at the tip of a stem or root, is free from pathogens.

- **Plant breeding**

Tissue culture has also been successfully used in plant breeding programmes.

- **Production of disease- and pest-resistant plants**

Plants grown from tissue culture usually pass trough callus phase and show many variations. These show some agronomic characteristics like tolerance to pests, diseases, etc.

Cloning

Genetically identical plants derived from an individual are called clones. Processes that produce clones can be put under the term ‘cloning’. This includes all the methods of vegetative propagation such as cutting, layering, and grafting. Propagation by tissue culture also helps in producing clones. Using the shoot tip, it is possible to obtain a large number of plantlets. This technique is used extensively in the commercial field for micropropagation of ornamental plants like chrysanthemum, gladiolus, etc. and also crops such as sugar cane, tapioca, and potato. Thus an unlimited number of plants that are genetically similar or are clones can be produced in a short span of time by tissue culture.

Large-scale propagation

To bridge the gap between research and application, the Department of Biotechnology, Government of India sponsored the setting-up of two pilot-scale facilities for large-scale propagation of elite planting material of forest trees through tissue culture. One of these facilities

has been established at TERI's 36-hectare-campus in Gual Pahari, Haryana with an annual capacity of a million plantlets. Research at these facilities focuses exclusively on developing new protocols for mass cloning of elite planting material, mainly of trees.

Till date, over 4 million plants have been dispatched for field plantation from these facilities. The tissue culture raised plants are presently being evaluated under field conditions. This is being done in tandem with the forest departments of Haryana, Uttar Pradesh, Madhya Pradesh, Bihar, Jammu and Kashmir, and Orissa. For initial screening for phenotypically superior trees only a few hundred plantlets of the same are raised and tested under various agroclimatic zones. The best clones are then mass multiplied and monitored regularly for their performance. Field data suggest a survival percentage of more than 90% even in the harsh conditions of Aravalis without the life-saving irrigation. At half the rotation age some of the selected clones of Eucalyptus are showing a significant increase in productivity as compared to the conventional seed raised progenies.

More information on Biotechnology DNA

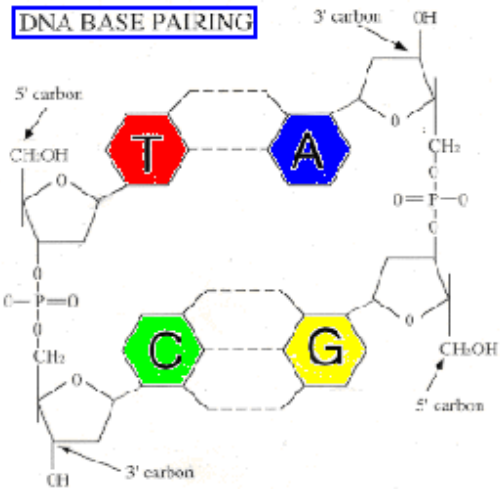
DNA

Since the time Gregor Mendel began studying about inheritance in garden plants some 150 years back, researchers have worked to learn more about the language of life – how characteristics pass from one generation to another. Researchers began to understand DNA from the 1800s when they stated that all living beings, whether plants, humans, animals, or bacteria, comprised cells that have the same basic components.



Living organism are made up of cells, i.e. cells are the basic units of life. For example, each of us is made up of billions of this basic unit. If one closely inspects the structure of the cell, one is likely to find various smaller bodies or organelles like mitochondria that generates the energy required to perform all life processes ('the powerhouse'), chloroplast (only in green plants and responsible for their coloration), the central core – 'the nucleus, to name a few. The nucleus harbours the blueprint of life and the genetic material – DNA or deoxyribonucleic acid – and is the control centre of any cell. The genetic material or the blueprint is contained in all the cells that make up an organism and is transmitted from one generation to another. A child inherits half of the genetic material from each of his/her parents.

The chemical structure of everyone's DNA is the same. Structurally, DNA is a double helix: two strands of genetic material spiraled around each other. Each strand contains a sequence of bases, also called nucleotides. A base is one of four chemicals: adenine, guanine, cytosine, and thymine. The two strands of DNA are connected at each base. Each base will only bond with one other base, as follows: Adenine (A) will only bond with thymine (T), and guanine (G) will only bond with cytosine (C). If one strand of DNA looks like A-A-C-T-G-A-T-A-G-G-T-C-T-A-,the DNA strand bound to it will look like T-T-G-A-C-T-A-T-C-C-A-G-A-T-C.



Together, the section of DNA would be represented as given in Figure

T-T-G-A-C-T-A-T-C-C-A-G-A-T-C

A-A-C-T-G-A-T-A-G-G-T-C-T-A-G

The length of the DNA strand varies from organism to organism but within individuals of a particular species it is nearly constant. For example, a certain virus may have only 50 000 (5×10^4) bases constituting the genetic material whereas a human cell contains nearly 3.2 billion (3.2×10^9) bases in each of the cells (except the germ line cells). The amount and sequence in all the cells of an organism is identical. The DNA is for most part of the time present as condensed body called chromosomes (coloured body) except when it is replicating or dividing. A piece of a chromosome that dictates a particular trait, for example, eye and skin colour in humans, is called a gene. In any cell, the DNA can be classified into two categories – the sequence that codes for traits or genes and the sequence that has no apparent function or the non-coding DNA. The coding sequence (genes) in humans constitutes only five per cent of the total DNA and is identical in all humans. The non-coding sequence, which is nearly 95% in humans, varies from one individual to another, and forms the basis of DNA fingerprinting.

DNA fingerprinting

The only difference between two individuals is the order of the base pairs. Each individual has a different sequence of DNA, specially in the non-coding region. Using these sequences, every person could be identified solely by the sequence of their base pairs. However, because the entire DNA is so huge, the task would be time-consuming and nearly impossible. Instead, scientists are able to use a shorter method.

The steps involved in DNA fingerprinting can be summarized as follows.

- Isolating the DNA in question from the rest of the cellular material in the nucleus.
- Cutting the DNA into several pieces of different sizes.
- Sorting the DNA pieces by size. The process by which the size separation, or ‘size fractionation’, is done is called gel electrophoresis.

This is the basic concept behind fingerprinting technique.

DNA fingerprinting in plants

The concept of DNA fingerprinting can also be extended to plants and many institutions in the country are doing it today. TERI has successfully generated fingerprints of various medicinal plants such as neem, ashwagandha, and amla with the objective of determining their identity.

With the help of fingerprints one can find out the genetic diversity in India. This knowledge has profound implications. Based on the extent of genetic diversity, one can establish the centre of origin of a particular plant species. And having done that we are better equipped to prevent bio-piracy or the theft of our genetic resources.

Genetic Engineering

Genetically modified plants are created by the process of genetic engineering, which allows scientists to move genetic material between organisms with the aim of changing their characteristics. All organisms are composed of cells that contain the DNA molecule. Molecules of DNA form units of genetic information, known as genes. Each organism has a genetic blueprint made up of DNA that determines the regulatory functions of its cells and thus the characteristics that make it unique.



Prior to genetic engineering, the exchange of DNA material was possible only between individual organisms of the same species. With the advent of genetic engineering in 1972, scientists have been able to identify specific genes associated with desirable traits in one organism and transfer those genes across species boundaries into another organism. For example, a gene from bacteria, virus, or animal may be transferred into plants to produce genetically modified plants having changed characteristics. Thus, this method allows mixing of the genetic material among species that cannot otherwise breed naturally. The success of a genetically improved plant depends on the ability to grow single modified cells into whole plants. Some plants like potato and tomato grow easily from single cell or plant tissue. Others such as corn, soy bean, and wheat are more difficult to grow.

After years of research, plant specialists have been able to apply their knowledge of genetics to improve various crops such as corn, potato, and cotton. They have to be careful to ensure that the basic characteristics of these new plants are the same as the traditional ones, except for the addition of the improved traits.

The world of biotechnology has always moved fast, and now it is moving even faster. More traits are emerging; more land than ever before is being planted with genetically modified varieties of an ever-expanding number of crops. Research efforts are being made to genetically modify most plants with a high economic value such as cereals, fruits, vegetables, and floriculture and horticulture species.

Public concern

The potential of biotechnology as a method to enhance agricultural productivity in the future has been accepted globally.



However, because of its revolutionary nature, there is a great degree of risk and uncertainty attached to the process of genetic engineering and the resultant genetically modified products.

Risks are also associated with genetically modified plants that are released into the environment. The nature of interactions with other organisms of the natural ecosystems cannot be anticipated without proper scientific testing. For example, modified plants with enhanced resistance to pests or disease threaten to transfer resistance to the wild relatives. This may have implications for biodiversity and ecosystem integrity. These and other numerous doubts plague the minds of common people and the decision-makers.

BBt cotton

Cotton and other monocultured crops require an intensive use of pesticides as various types of pests attack these crops causing extensive damage. Over the past 40 years, many pests have developed resistance to pesticides.

So far, the only successful approach to engineering crops for insect tolerance has been the addition of Bt toxin, a family of toxins originally derived from soil bacteria. The Bt toxin contained by the Bt crops is no different from other chemical pesticides, but causes much less damage to the environment. These toxins are effective against a variety of economically important crop pests but pose no hazard to non-target organisms like mammals and fish. Three Bt crops are now commercially available: corn, cotton, and potato.

As of now, cotton is the most popular of the Bt crops: it was planted on about 1.8 million acres (728437 ha) in 1996 and 1997. The Bt gene was isolated and transferred from a bacterium bacillus thurigiensis to American cotton. The American cotton was subsequently crossed with Indian cotton to introduce the gene into native varieties.



The Bt cotton variety contains a foreign gene obtained from bacillus thuringiensis. This bacterial gene, introduced genetically into the cotton

seeds, protects the plants from bollworm (A. lepidoptora), a major pest of cotton. The worm feeding on the leaves of a BT cotton plant becomes lethargic and sleepy, thereby causing less damage to the plant.

Field trials have shown that farmers who grew the Bt variety obtained 25%–75% more cotton than those who grew the normal variety. Also, Bt cotton requires only two sprays of chemical pesticide against eight sprays for normal variety. According to the director general of the Indian Council of Agricultural Research, India uses about half of its pesticides on cotton to fight the bollworm menace.

Use of Bt cotton has led to a 3%–27 increase in cotton yield in countries where it is grown.

Biofertilizers

One of the major concerns in today's world is the pollution and contamination of soil. The use of chemical fertilizers and pesticides has caused tremendous harm to the environment. An answer to this is the biofertilizer, an environmentally friendly fertilizer now used in most countries. Biofertilizers are organisms that enrich the nutrient quality of soil. The main sources of biofertilizers are bacteria, fungi, and cynobacteria (blue-green algae). The most striking relationship that these have with plants is symbiosis, in which the partners derive benefits from each other.



Plants have a number of relationships with fungi, bacteria, and algae, the most common of which are with mycorrhiza, rhizobium, and cyanophyceae. These are known to deliver a number of benefits including plant nutrition, disease resistance, and tolerance to adverse soil and climatic conditions. These techniques have proved to be successful biofertilizers that form a health relationship with the roots.

Biofertilizers will help solve such problems as increased salinity of the soil and chemical run-offs from the agricultural fields. Thus, biofertilizers are important if we are to ensure a healthy future for the generations to come.

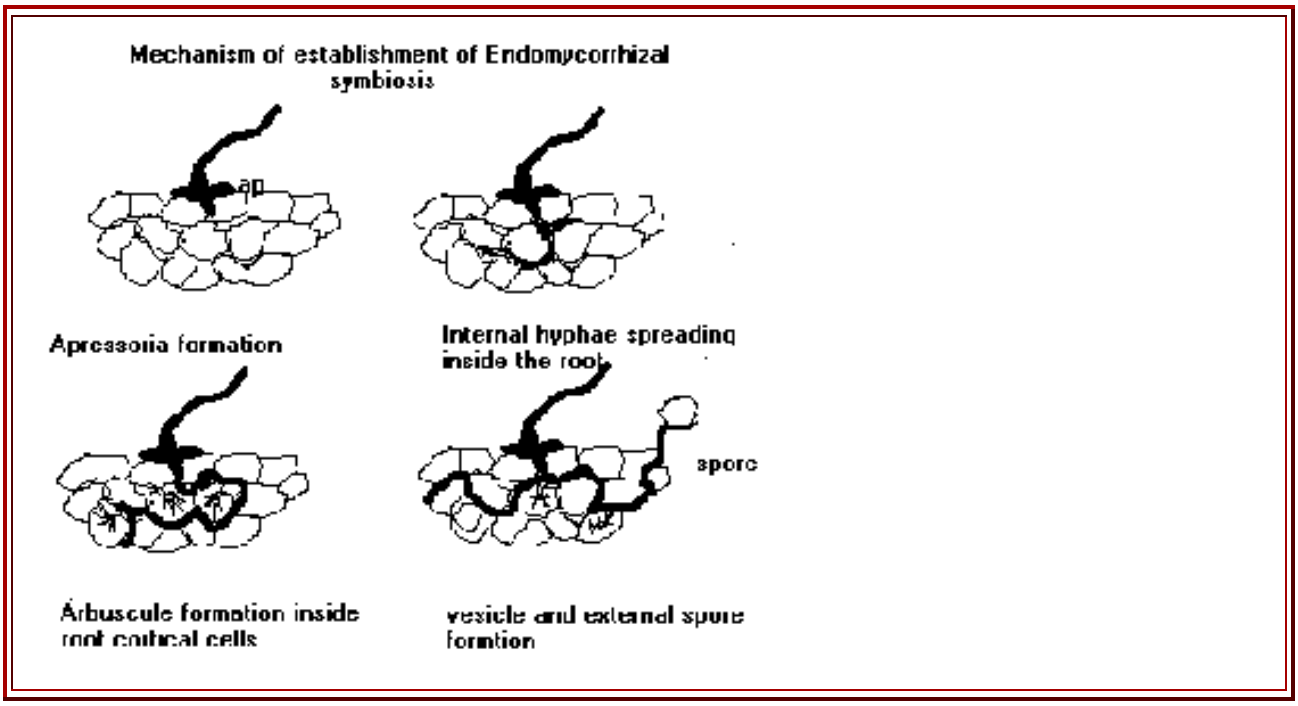
Mycorrhiza

Mycorrhizae are a group of fungi that include a number of types based on the different structures formed inside or outside the root. These are specific fungi that match with a number of favourable parameters of the the host plant on which it grows. This includes soil type, the presence of particular chemicals in the soil types, and other conditions.

These fungi grow on the roots of these plants. In fact, seedlings that have mycorrhizal fungi growing on their roots survive better after transplantation and grow faster. The fungal symbiont gets shelter and food from the plant which, in turn, acquires an array of benefits such as better uptake of phosphorus, salinity and drought tolerance, maintenance of water balance, and overall increase in plant growth and development.

While selecting fungi, the right fungi have to be matched with the plant. There are specific fungi for vegetables, fodder crops, flowers, trees, etc.

Mycorrhizal fungi can increase the yield of a plot of land by 30%-40%. It can absorb phosphorus from the soil and pass it on to the plant. Mycorrhizal plants show higher tolerance to high soil temperatures, various soil- and root-borne pathogens, and heavy metal toxicity.



Legume-rhizobium relationship

Leguminous plants require high quantities of nitrogen compared to other plants. Nitrogen is an inert gas and its uptake is possible only in fixed form, which is facilitated by the rhizobium bacteria present in the nodules of the root system. The bacterium lives in the soil to form root nodules (i.e. outgrowth on roots) in plants such as beans, gram, groundnut, and soybean.

Blue-green algae

Blue-green algae are considered the simplest, living autotrophic plants, i.e. organisms capable of building up food materials from inorganic matter. They are microscopic. Blue-green algae are widely distributed in the aquatic environment. Some of them are responsible for water blooms in stagnant water. They adapt to extreme weather conditions and are found in snow and in hot springs, where the water is 85 °C.

Certain blue-green algae live intimately with other organisms in a symbiotic relationship. Some are associated with the fungi in form of lichens. The ability of blue-green algae tophotosynthesize food and fix atmospheric nitrogen accounts for their symbiotic associations and also for their presence in paddy fields.

Blue-green algae are of immense economic value as they add organic matter to the soil and increase soil fertility. Barren alkaline lands in India have been reclaimed and made productive by inducing the proper growth of certain blue-green algae.

Bioremediation



Enormous quantities of organic and inorganic compounds are released into the environment each year as a result of human activities. In some cases these releases are deliberate and well regulated (e.g. industrial emissions) while in other cases they are accidental (e.g. chemical or oil spills). Petroleum and its products are one of the most common environmental pollutants. They are a fire hazard, threat to marine life, and a source of air and groundwater pollution. They contaminate land and water bodies by accidental spills like the Alaska Oil spill in 1989 and oil spills during the Gulf War, leakage from pipelines, and other human activities. Detoxification of the contaminated sites is expensive and time consuming by conventional chemical or physical methods.

Tag Cloud

- Study Materials
- Contaminated Sites
- Study Material

Bioremediation consists of using naturally occurring or laboratory cultivated micro-organisms to reduce or eliminate toxic pollutants. Petroleum products are a rich source of energy and some organisms are able to take advantage of this and use hydrocarbons as a source of food and energy. This results in the breakdown of these complex compounds into simpler forms such as carbon dioxide and water. Bioremediation thus involves detoxifying hazardous substances instead of merely transferring them from one medium to another. This process is less disruptive and can be carried out at the site which reduces the need of transporting these toxic materials to separate treatment sites.

Using bioremediation techniques, TERI has developed a mixture of bacteria called 'oilzapper' which degrades the pollutants of oil-contaminated sites, leaving behind no harmful residues. This technique is not only environment friendly, but also highly cost-effective.

BOTANY

Introduction to Plants and Botany

Gene Mutation
As the text mentions, genes mutate, change accidentally, and in mutating may cause a plant to have new characteristics. These mutations are important for the evolution of plants in natural environments, for breeding improved crops, and for studying how genes control plant metabolism and development. Some of the easiest mutations to study are the ones that cause

visible changes in the plants. At the web site "Mutants of Maize" there are sets of descriptions and photographs corn, also called 'maize,' mutants.

Study several of these and notice some of the many ways that plant development can be altered. Some of the mutants cause leaves to have white spots, so the mutation is probably preventing the plant from synthesizing the green pigment chlorophyll. As you look at photos of other mutants, can you guess what the mutated gene might be doing (or not doing)? Causing mutations is easy for plant scientists, understanding what the mutated genes do is the big problem.

Characteristics of Life: Exploring the Solar System
We are actively searching for life in the solar system, looking for 1) living bacterium-like creatures, 2) traces that life existed in the past on Mars and 3) evidence that life could still originate in the future on one of the moons of Jupiter or Saturn. The "National Aeronautics and Space Administration (NASA)" web site contains a great deal of information on this topic.

The site is updated frequently, so you may have to use your own ingenuity to find a site related to searching for life, but once you arrive at the page entitled "Solar System Exploration", scroll down until you find a list of topics. There should be headings related to Pathfinder, Mars Global Surveyor, Galileo (which is in orbit around Jupiter) or Cassini (on its way to Saturn and its moon Titan, but it will not arrive there until about 2004). As you examine these web sites, notice that we are searching for life in very different types of places. Read the text in Box 1.1 in your text book, and think about how the various characteristics of life must be used as the basis for this exploration of the solar system.

Introduction to the Principles of Chemistry

Plant Metabolism: Poisonous Plants
Plant metabolism involves many types of chemicals and reactions occurring simultaneously or in sequence. Some of the reactions help others while some compete or interfere with others. The result of all the normal reactions is life itself.

A toxic chemical causes a reaction that disrupts other reactions so significantly that the normal reactions of metabolism cannot continue properly, and the organism dies. For a list of some of the more common toxic chemicals, visit the Cornell University "Poisonous Plants" page, then select "The types of poisons present".

You might be surprised at the number of toxic chemicals present. This web site is maintained by the Animal Sciences Department at Cornell, so these are compounds that are present in plants and poisonous to animals: they interfere with animal metabolism but not the plant's own metabolism.

Cell Structure

Structure and Organization of Plants as Related to the Invention of the Microscope
People have observed the form and structure of plants, animals and fungi for thousands of years. But the study of structure and organization really increased after the invention of the microscope.

Visit the "History of the Light Microscope" web page for very interesting details and illustrations.

Microscopy
There are several types of microscopy. Several types, light microscopy, transmission electron microscopy (which uses electrons instead of light, and magnetic lenses instead of glass lenses) and scanning electron microscopy are described and illustrated in the "SEM" web site.

Growth and Division of the Cell

Mitosis

This QuickTime movie of mitosis is from the "McGill University Mitosis Page."

Meiosis
Visit the "The Biology Project" web site and take the tutorial on meiosis. Can you answer the quiz questions? Be sure to watch the movies of cell events during meiosis (be certain to watch both meiosis I and meiosis II). You wil need Quicktime to see these movies.

Tissues and the Primary Growth of Stems

Plant Stems
Your textbook describes various types of stems, but there are many varieties, and those in parasitic plants can be very highly modified. Visit "The Parasitic Plant Connection" and once there, scroll down to " Lists: Orders, Families and Genera." Under that click on either the heading "Santalales" or "Parasites of Dubious Affinity". Under these two headings, examine some of the plants in the photos (you might want to select photos whose descriptions mention stems). Some of these have more or less ordinary stems, others are very unusual.

Stems and Their Parts
The "Texas A & M University" site presents interesting, concise descriptions of stems and their parts, along with good photos. Enter the site at "Lab 2: Vegetative Characters".

Leaves

Leaves and Their Parts
The "Texas A & M University" site presents interesting, concise descriptions of leaves and their parts, along with good photos.

Insect Traps
Plants that trap and digest insects have evolved into several species. Use this site to learn more about carnivous plants, include care, research, and preservation activities.

Roots

Sugar Beets
One of the most important roots is the sugar beet; these roots are used as the raw material for producing a large percentage of the sugar we eat. The "Monitor Sugar Company" and "The Sugar Association" have web sites that offer information about sugar processing and other aspects of agribusiness.

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Living Reference Cultures
West Virginia University maintains a web site called "The International Culture Collection of Arbuscular and VA Mycorrhizal Fungi (INVAM)" that has a tremendous amount of interesting information that you might enjoy examining. This link will take you to the home page. Once there, scroll down to a button that says "New: Detailed descriptions of 37 species from living reference cultures" and click on it to investigate.

Structure of Woody Plants

Arboreta
Woody plants are trees and shrubs, and botanical gardens that emphasize woody plants are often called arboreta (sing. arboretum). To tour several visit "The Huntington Library, Art Collections, and Botanical Gardens" homepage. Once there, scroll down and click on "Botanical Gardens" and wander around. Near the bottom is a heading "Other garden resources on the internet" that has links to the pages of other gardens and arboreta.

Dendochronology
The thickness of annual rings depends on growing conditions during the years they are formed. In good years trees produce thick rings, and in poor years they produce thin ones. The study of tree rings is called dendrochronology. Visit the "Laboratory for Wood Anatomy and Dendrochronoly " to see how the study of tree rings are carried out, and the types of information that can be obtained.

Flowers and Reproduction

Flowers and Pollination
There are many ways that flowers attract pollinators, or catch wind-carried pollen.
The textbook has given you the basics, and now you can explore the web for examples of various types of flowers. Visit the "Flower Structure" web site. To seethe answers to teh fill-ins, scroll over the blank sports and anywhere you see a carrot ">" symbol.

Fruits
There are many different types of fruit, as you might have noticed from your grocery store- and

those are only the edible fruits! Table 9.5 on page 256 gives the definitions and classifications of fruit types, but visit the "ARS Image Gallery" web site for further descriptions and illustrations.

Energy Metabolism: Photosynthesis

Photosynthesis by Undergraduates!
Are you looking for an explanation of photosynthesis in your own terms? The "Photosynthesis" site was designed and built by undergraduates at the University of Texas, and you mayfind it to be one of the most fun.

Energy Metabolism: Respiration

Glycolysis
The "Glycolysis" contains additional information, and of special interest, it has numerous models and diagrams of themolecules and processes involved in respiration.

Yeasts
The anaerobic respiration that produces wine, beer, and cheese must use the correct yeasts to develop the properflavor. For a description of the many types of brewer's yeasts, visit the "Lallemand Yeasts" web site. While there you may also want to visit the "In Ferment" page as a source of interesting information source. You might also find the "Budweiser" site to be interesting.

Budweiser
The anaerobic respiration that produces wine, beer, and cheese must use the correct yeasts to develop the properflavor. For a description of the many types of brewer's yeasts, visit the "Lallemand Yeasts" web site. While there you may also want to visit the "Basics of Mead Fermentation" page as a good information source. You might also find the "Budweiser" site to be interesting.

Fermentation
The anaerobic respiration that produces wine, beer, and cheese must use the correct yeasts to develop the properflavor. For a description of the many types of brewer's yeasts, visit the "Lallemand Yeasts" web site. While there you may also want to visit the "In Ferment" page as a source of interesting information that is changed periodically. To find the "In Ferment" newsletter click on "Consumer Products" and then "Lalvin." The newsletter link is in the menu on the left. You might also find the "Budweiser" site to be interesting.

Soils and Mineral Nutrition

Toxic Agents
Mineral elements are essential for animals as well as plants, but plants sometimes accumulate such high concentrations of minerals that they actually kill the animals that eat them.More information is available at the "List of Toxic Agents Found in Plants" web site.
For mineral toxins, scroll down to the heading " Cheating poisons".

Carnivorous Plants
Plants growing in bogs usually cannot obtain enough nitrogen from the soil, and in habitats like this, carnivorous plants that catch insects have a selective advantage over plants that cannot obtain nitrogen from digested insects. To see what types of plants these are, check out the "Carnivorous Plant Database".

Development and Morphogenesis

The Genetic Modification of Crops
The use of genetic engineering for developing new medicinesand treating disease is often in the news, but the geneticmodification of crops is also important (people spend vastlymore money on food than they do on medicine). Thetechniques involved are explained on "The Soybean Tissue Culture and Genetic Engineering Center" web site. Click on the "Protocols" button. Soybeans don't interest you because you don't eat them? Explore the site a bit (especially the "WWW" and "Members" pages) and you may be surprised.

Plants and Space Travel
NASA's Space Research website provides great information on studies of the effects of weight and endogenous rhythms are carried out by NASA. It is important to know how microgravity and artificial rhythms affect not only humans in space flight, but also how microgravity affects plants that might be the subjects of experiments, or that might be used as food crops or to purify the air on long-duration space travel. Check out the articles on plants and general biology under the General Information tab. Then under the Research and Projects tab, use the navigation bar on the left to explore the current Programs. Interesting topics include: microgravity, fundamental space biology and space product development.

Genes and the Genetic Basis of Metabolism and Development

Codon Information
There is a web site called "DNA Learning Center", with avariety of links to many sites as well as information that Dolan DNA Learning Center and Cold Springs Harbor Labs present. Explore this site to see many of the ways that DNA research is being carried out and how it affects our lives. Be sure to follow some of the links (see "LINKS" on thehomepage).

KDRI Database
There is a web site called "Codon Table", with a table of codons and the nucleotide bases that they code for, similar to Table 15.2 in your textbook. This page is operated by the "Kazusa DNA Research Institute" in Japan. Once on theirhomepage, you might want to click on the "KDRI Database" button, then on the "The Kazusa Arabidopsis thaliana Genome Project" button, this will give you some maps of a Arabidopsis chromosomes that might be somewhat advanced, but which you might enjoy seeing and which will initiate you into this kind of data presentation.

Genetics

Mendel's Research
Visit the site "MendelWeb", which provides information about Mendel, and comments and notes about his research.

The Human Karytype
Visit the "Genetic Science Learning Center" web site, and view the human karyotype, seeing the consequences of having too many or too few chromosomes.

Kingdom Monera: Prokaryotes

Bacteria
Visit the web site "Major Groups of Prokaryotes" to gather a great deal of information about bacteria, including photographs and explanations of the poisons some bacteria secrete.

Archaebacteria
Information is accumulating about Archaebacteria rapidly you will find many interesting sites if you search for them. This site posted by the University of California Museum of Paleontology at Berkeley provides a wealth of information on archaebacterial fossil records, habitats, and morphology.

Seed Plants I: Gymnosperms

Living Fossils
The Wollemi pine is a living fossil -- a plant whose closestrelatives all seem to be extinct. A few living plants of Wollemi pine were discovered in an isolated groove in Australia in 1996, and their location is being kept secret to protect them. Information about these remarkable trees can be found at the "Wollemi Pine" web site, which is maintained by "The Royal Botanic Gardens Sydney".

Conifers of the U.S.A.
Visit the web site "Trees of the Pacific Northwest" to view photographs and read text information about the conifers of this region of the United States. The site also has a helpful dichotomous key if you have specimens that you would like to try to identify.
Cyanobacteria
Cyanobacteria have their own web site, "Cyanosite" , check it out for great information and photographs.

Seed Plants II: Angiosperms

Flowering Plants
Visit "The Flowering Plant Gateway" for a web site that offers a tremendous amount of information, and images that willsupplement your textbook. On the home page of this site, click on the heading "Browse Cronquist",and the information will be presented in the same order as in your textbook, making the site very easy to use.

Angiosperms
The Internet Directory for Botany web site has a page called "Vascular Plant Families". Visit this page and scroll down until you see the large black heading "ANGIOSPERMS". Below this heading, subheadings list the names of families, and below each are links in blue. As you read Chapter 25, if any particular family is of interest to you, search for information about it here- the sites will be variable in quality, but many have good photographs and information.

Populations and Ecosystems

Invasive Exotic Plants

When plants are taken from their native habitat and introduced into a new area, they sometimes become serious weeds. Visit the "Hawaii's Most Invasive Horticultural Plants" for details.

The Galapagos Islands
Visit the "Galapagos National Park" for information about a unique ecosystem with sharply limited geographical range**.**

Micro Biology

Introduction to Microbiology

- Microbiology is the study of microorganisms which must be viewed with the aid of a microscope orelectron microscope.
- The importance of microbiology includes: used in biomedical research, creation of medicines,environmental applications and new research tools.
- Disease causing organisms include: protists, bacteria, viruses and other microorganisms.
- Bacteria are important for fixing N2 in a usable form for plants.
- Bacteria and some fungi are important in decomposition and recycling of raw materials.
- Industry applications of microbiology: waste management, food industry, mining, medicine, research and biotechnology.
- 1660’s Robert Hooke observed microorganisms for the first time with a microscope and coined the term “cell”.
- 1632-1723 Anton van Leeuwenhoek credited with having observed the first bacteria.
- 1828-1898 Ferdinand Cohn developed the first classification scheme based on bacteria shape. Cohn detailed and described the life cycle of Bacillus. Cohn’s Classification System:
    - Sphaerobacteria are spherically shaped.
    - Microbacteria are rod shaped
    - Desmobacteria are filamentous
    - Spirobacteria are spiral shaped

- 1822-1895 Louis Pasteur Defined pasteurization to prevent spoilage of food by bacteria,

develop vaccines and disproved the scientific dogma of “Spontaneous Generation”. He defined “Germ Theory” and demonstrated that germs were responsible for disease.

- 1843-1910 Robert Koch identified anthrax and developed agar growth medium. Koch’s postulates was a systematic method to establish the microbial cause of disease.
- Ignaz Semmelweis was the first to recognize the need for good hygiene during medical procedures. The first to identify nosocomial infections.
- 1827-1912 Joseph Lister developed antiseptic methods for use in surgery and medicine.
- 1854-1915 Paul Ehrlich developed chemotherapy to cure infectious diseases and discovers antibiotics to treat sleeping sickness and syphilis.
- 1881-1951 Alexander Fleming discovered penicillin and lysozyme.
- 1864-1920 Dmitri Ivansvski discovered the first virus which is known as the tobacco mosaic virus (TMV).
- 1952 Hershey & Chase Experiments identified that DNA was the genetic material of bacteriophages.
- Hershey Case Experiment: using phage radioactively labeled with P32 (DNA) or S35 (protein) they infectedbacteria cells. They found the P32 inside the bacterianot S35.

Recommendations for Success in Microbiology

- Successful completions of general biology 2 semesters
- Knowledge of basic chemistry and biochemistry
- Basic understanding of classification
- Review layout of text book used in the course.
- Read and master learning objectives laid out in the text book.
- Master definitions presented in the course.

Techniques in Microbiology

Microscopy:

- Electron Microscopy: uses electrons to create animage of the specimen.
- Brightfield Microscopy: specimen is visualized afterthe light has passed through it.
- Dark Field Microscopy: used when staining a sample is difficult or impossible.
- Inverted Microscope: lenses are under the stage point upward used for thick samples.
- Upright Light Microscope: lenses are above the specimen point down.

Slide Preparation and Cell Stains:

- Wet Mount slide preparation: can be done with specificdyes or water.
- Common Laboratory Stains: Gram-Negative stain with safranin and appear red.
- Gram-Positive: crystal violet sometimes methylene blue.

Aseptic Techniques: Method to collect, grow and preserve a sample such that no other microbes are introduced or lost from the original culture.

Agar Plates:

- Streak Plate Procedure: plate is streaked in a zig zag patter to dilute a sample spread out sample for the purpose of isolating individual colonies.
- Selective Agar: growth medium with chemicals mixed in to select bacteria based on specific physiological characteristics e.g. antibiotic resistance.
- Quantification: Colony forming units (CFU) method to determine the number of bacteria in ample.
- Dilution Plating: successive dilution of a sample to quantify and isolate single colonies.
- Isolation of pure bacteria colonies: method to create a pure culture.
- Colony Characteristics: Shape, size, morphology and growth patterns.
- Phage Quantification: PFU, plaque forming units, clear areas of growth on a bacterial lawn plated on agar which indicate the presence and numbers of phage present.

DNA Methods

- PCR: Polymerase Chain Reaction, method used to amplify specific DNA sequences for ease of identification and sequencing.

- Electrophoresis: DNA sample place in a gel substrate between two electrodes. The charge and size of the DNA determines how fast the DNA migrates in the electrical field.
- DNA sequencing: Method to determine the order of which nucleotides are arranged on a strand of DNA.

Chemistry of Life

Structure of Atoms:

- Consist of protons, neutrons and electrons.
- Atomic nuclei have protons and neutrons (each 1 amu).
- Each element has a different number of protons, e.g. hydrogen has 1 proton, carbon 14.
- The number of protons equals the atomic number of an element.
- Atoms with the same number of protons but differentnumbers of neutrons are isotopes.
- Cells of living organisms consist of organic andinorganic molecules which are made up of atoms.

Electrons

- The number of electrons (e-) equals the number of protons in the nucleus.
- Electrons move at near light speed, have both wave and matter properties, when their energy level is raised they are said to be in an "excited state", emission spectra is when this excited electron drops back to its ground state.
- Electrons orbit the nucleus at specific levels called shells. The shell closes to the nucleus is the innermost shell and has up to 2 electrons. Second and third shells (L and M) have a maximum of 8electrons. If an element has another shell that is filled it is chemically inert.

Chemical Bonds

- Bonds are formed by gaining, loosing or sharingelectrons.
- The formation of ionic or covalent bonds depends on the differences between electronegativity in the atoms involved.
- Covalent bonds: formed when atoms share electronsand are very strong. They are

polar if they are between different types of atoms e.g. oxygen and hydrogen as in H2O.

- Ionic Bonds: atoms become ions when they gain or lose electrons and are weaker than covalent and dissociate in water.
- Hydrogen Bond: are weak intra or inter molecularattractions between molecules with a net dipole. Dipoles are created when there is unequal sharing ofelectrons between H and an electronegative atom like oxygen or nitrogen.

Organic Molecules

- Molecular formulas describe the composition of a substance**.**
- Structural formulas describe how atoms are arranged in a molecule**.**
- Nomenclature is the naming procedure for organicmolecules.
- Stereochemistry are isomers that have the same molecular formula but different structural formulas.

Nomenclature

- Single bond share one pair of electrons and name ends in (–ane).
- Double bonds share two pairs of electrons, name ends in (-ene).
- Triple bonds share three pairs of electrons, name ends in (-yne).

Biological Macromolecules

- Carbohydrates: made up of monosaccharides (e.g. glucose), stores energy, and modifies other macromolecules (glycolipids, glycoproteins).
- Lipids fat triglycerides (glycerol), phospholipids, stores energy, makes up cell membranes and steroid hormones.
- Proteins: single amino acids join forming peptides, functions as structural proteins and enzymes.
- Nucleic Acids: individual nucleotides link to form genetic material, RNA, DNA.

Acids, Bases and Buffers

- Electrolytes are substances that release ions in water.
- Acids release H+ in water.
- Bases release OH- in water.

- Strong acids and bases completely dissociate in H2O.
- pH is the concentration of hydrogen ions [H+] in solution. At pH 7 hydrogen ion concentration equals hydroxyl concentration, [H+] = [OH-].
- Buffers provide pH stability by resisting changes to pH when small amounts of acid or base are added.
- Buffers are weak acids or weak bases and their salts.

Biochemical Reactions
Thermodynamics:

- First Law: Energy is always concerned and cannot be created or destroyed.
- Second Law: Systems tend to become disordered.
- Entropy (S): describes the degree of disorder in a system.
- ΔG Gibbs Free Energy is the amount of energy available to do work.
- $\Delta G = \Delta H - T\,\Delta S$ (ΔH is enthalpy change), ΔS entropy change, T=temperature (K)
- If $\Delta G<0$ spontaneous reaction, If $\Delta G>0$ non-spontaneous reaction, If $\Delta G=0$ reaction is at equilibrium.
- Enzymes in biochemical reactions lower the activationenergy. Activation energy is the energy required to begin a reaction.
- Types of enzyme reactions: oxidoreductase, transferase, hydrolase, ligase, isomerase and ligase.

Prokaryotic and Eukaryotic Cells:
Structure and Function Review

Prokaryote:

- Do not have membrane bound organelles. The DNA of prokaryotes is simple in structure and floats freely in the cell. The cell walls typically consist of peptidoglycan molecules.
- The cell wall of prokaryotes is a fluid phospholipid bilayer having no carbohydrates on the membraneand typically no sterols. Although the membranedoes have hopanoids (which are sterol like)molecules.

Eukaryote:

- Eukaryotes have membrane bound organelles. Their DNA is complex and typically associated with structural and regulatory proteins and it is contained within a membrane bound nucleus. The cells are about ten times larger then those of

prokaryotes. Some eukaryotes (e.g. plants) have cell walls but are not made up of peptidoglycan molecules.

- Replication in prokaryotes involves mitosis and meiosis. Meiosis occurs in sex cells like sperm and egg. The eukaryote cell member is a fluid phospholipid bilayer containing sterols andcarbohydrates. The membranes can endocytose, phagocytose, pinocytose and exocytose.
- In animal cells the plasma membrane is the onlyseparation between the cell's interior and the environment.
- In fungi, bacteria and plants there is an additional cell wall as the outer most boundary.
- The plasma membrane is about 10 nm thick and is a selective barrier.

Cell wall*:* A cell membrane is a lipid bilayer that usually has proteins associated with its surface, interior or even transmembrane.
The membrane is selectively permeable.
Microbe Evolution: The concept of common evolutionary ancestor is introduced.
Cell Mobility and Locomotion:
The motion of eukaryotes and prokaryotes when done using flagella is fundamentally different. Structurally the flagella are different and eukaryotes typically used ATP (myosin) as an energy source to drive the motion of the flagella.

Classification of Microorganisms

- Traditional classification schemes were based on overt morphology of an organism, its habitat, method of getting energy, nutrition and method of replication. With the advent of DNA and protein sequencing many of the old categories were modified and new ones created. In the 18th century when classification was first formalized all living things were placed into two kingdoms, Plants or Animals likewise there were two Domains: Prokaryota and Eukaryota.
- The three-domain system was introduced by Carl Woese in 1970's. Based on 16S rRNA gene sequences he split the Prokaryota domain into Eubacteria and Archaebacteria. Their genetic sequences indicated that each of these Domains arose separately from an ancestor. The Domains were renamed: Bacteria, Archaea and Eukarya.
- The biochemistry of Archaea and Bacteria is a significant parameter in their classification. The microbes that are currently in the kingdom archaea was originally grouped with Bacteria. The gross morphology of these two Kingdoms are similar. However the creation of a new kingdom (Archaea) was necessary when information from gene and protein sequencing was combined with the unique demands of the niche these organisms occupy.

- One of the fundamental functions of classification and taxonomy is to determine how organisms are related both physically and in time. One way to do this is to monitor the rate of change in a shared trait, like ribosome sequences.

- A major goal of classification and taxonomy is describe how organisms are related physically and evolutionarily. One method to do this is to monitor the rate of change in a shared trait, like ribosome sequences.

Viruses and Other Non-living Infectious Agents

- A virus is an acellular agent that is infectious, it is small and has one or many pieces of nucleic acid. It can infect humans, animals, plants and bacteria and cause disease. Viruses have a much simpler structure then a bacteria. They do not have cell membranes and are made up of only a few organic molecules. Viruses and viroids do not carry out metabolism, such as transport of nutrients across a cell membrane.

- The major viral characteristics: type of genetic material (DNA or RNA, single or double stranded), viral size, capsid structure and target host are used todetermine how best to classify a virus.

- Viral genomes can be linear, one piece or severalmolecules of nucleic acid (similar to eukaryotic chromosomes).

- Not all viruses are as specific to a host (although most are). Some can infect many different hosts and different tissues within a host. An example of a "generalist" virus is rabies. Rabies can infect many different mammals from humans to dogs to bats.

- Viruses have three basic capsid shapes: helical, polyhedral and complex.

- An envelope surrounds certain viruses. Envelopedviruses acquire their envelope from the host cell during viral replication or when the viral is released from the cell.

- A virion without an envelope is called a nonenveloped or naked virion.

Principles of Disease and Epidemiology

Epidemiology is the study of the frequency, distribution andcauses of diseases in a given population.

Definitions:

- Infection: the growth of a pathogen in a host organism. Infection depends on exposure to the pathogen and host susceptibility.

- Disease: the response by a host to an infection, which when bad evokes a recognizable pattern of clinicalsymptoms.

- Incidence is the number of new cases divided by time.
- Incidence rate is the number of new cases divided by the total population at risk.
- Prevalence is the number of cases existing at any moment in time.
- Prevalence rat is the number of cases divided by the total population at risk.
- Etiology: study of disease causing pathogen.

- Symbiosis: interactive relationship between two species.
- Residents: colonizing microbes.
- Transients: temporary microbes.
- Opportunists: normal flora which become pathogenic under certain circumstances.
- Pathogens: disease causing microbes.
- Immuno compromised: a organism with a weakened immunity.
- Commensalism: the interaction of two organisms in which one benefits and the other is neither harmed nor helped by the interaction.
- Mutualism: relationship where both the host and microbe are metabolically dependent on each other e.g. lichen have a symbiotic association with a fungus.
- Parasitism: the interaction of two (or more) organisms where one is benefited and the other harmed by the relationship.
- Disease Severity: Acute: short duration, Chronic: lasts for a longer time period, Sub-acute: duration between acute and chronic, Latent: causative agent lies dormant within the body and suddenly become active resulting in disease.
- Reservoir: Also known as an asymptomatic infection carrier it is an organisms that carries and spreads the pathogen but is unharmed itself.

Types of Epidemiology

- Descriptive Epidemiology
- Analytical Epidemiology
- Retrospective Epidemiology
- Prospective epidemiology

- Experimental Epidemiology
- Serological Epidemiology

Application of Epidemiology

- Tracking of health problems occurring in a community.
- Establish the clinical picture of the disease or health problem in a community.
- Estimating risk of specific diseases or syndromes.
- Identify syndromes, precursors and treatments fordiseases.
- Investigate epidemiology of unknown etiology.
- Establish the history of a disease in a definedpopulation.

Koch's Postulates & Exceptions

- Pathogen must be present in every instance of disease.
- Pathogen must be grown in pure culture.
- Pathogen must be capable of being re-isolated from an inoculated animal expressing the disease.
- Exception: Some bacteria and viruses cannot be grown in the laboratory.
- Exception: Some diseases are caused by several microbes.
- Exception: Some pathogens are responsible for causing different diseases.
- Exception: Some pathogens can not be grown in animals and exist only in humans.

Distribution Formats

- Sporadic: Few cases
- Endemic: Cases in a local region or area.

- Epidemic: Wide spread outbreak of a disease in excess of what is normally expected. disease like syndrome.
- Pandemic: Spreading throughout the globe.

Disease

- Disease is an interaction between a Host, Pathogen (agent of infection) and Environment.
- Classification of Disease: Communicable Diseases, Contagious Diseases and non-CommunicableDiseases.
- Stages of Disease Development:
    - Incubation period: pathogen is multiplying.
    - Prodromal period: symptoms being to appear
    - Illness: visible signs of disease.
    - Period of decline: pathogen is under control
    - Period of convalescence: patient begins to recover.

Iceberg Concept of Infection

- Cell Response: Exposure no cell entry®Incomplete viral maturation®Cell transformation®Cytophatic effect®Fatal
- Host Response: Exposure but no infections®Infections with no clinical illness®Mild illness®Severe disease®Fatal
- **Mechanisms of Transmission**: Aerosolizing, touch, insect bite, animal bite fomites.
- **Ecological factors of infections**: altered environment, changes in food production, deforestation, global warming, increased use of antibiotics and bacteria in the air.

Factors Influencing Outbreaks and Disease Spread

- Factors effecting outbreak: presence of an infected host, adequate number of potential hosts and an effective methods of transmission by contact.
- Factors affecting spread: stability of virus within it's the environment, number of virion particles releases, virulence and invasiveness of pathogen, availability of proper vector or medium for spread.

Normal Flora

- Can be residents or transients. Resident populationremains constant and prevents invagination by pathogens and raises overall immunity. Residents can in rare situations become opportunists and cause infections.
  Transient population number varies.
- In the body normal biota can inhabit: skin, respiratory tract, intestine, mouth, nose,

throat and vagina.

- Benefits of Normal Flora include: resistance to some pathogens, release of bacteriocins and colicins, production of vitamin K, continued antigenicstimulation from commensals.
- Disadvantages of Normal Flora: commensal bacteria may cause localized infections, can become pathogenic if they acquire virulence factors or are introduced to sterile sties, contribute to body odor.

Innate Immunity:

- Is the basic resistance to disease that an organismsor individual has as a function of birth. It is the initial immune defense system.
- Is non-specific.
- At the species level it refers to the immune response that all members show to a pathogen.
- Within a species there exists subgroups such as race, gender etc. that may exhibit differences in immunity to pathogens.
- Individual immunity refers to differences in an individual's response to a pathogen within a given race.
- Four Types of barriers to infections: anatomic, physiologic, phagocytic and inflammatory.
    - Examples of these barriers: temperature, pH, enzymes and chemical, skin, mucous membranes, phagocytic or endocytic barriers, inflammatory barriers.

Organs Involved in Innate Immunity

- Eyes: tears wash away pathogens and have bacteriocidal enzymes.
- Skin: Difficult for a pathogen to penetrate, sweat creates high salt conditions, oil layer makes an inhospitable environment.
- Stomach: acid kills pathogens and sterilizes food.
- Nose: Mucus traps pathogens which are swallowed or blown out.

- Mouth: Natural microbiota prevents growth ofopportunistic pathogens.
- Lungs: mucus lining of lungs traps pathogens and cilia move particles out to throat and it is swallowed.
- Large intestine: Natural microbiota prevents growth ofopportunistic pathogens.
- Reproductive system: acid conditions and natural microbiota.

Innate Immunity Influences

- Age
- Nutrition
- Endocrine functions: disorders including diabetes, hyperthyroidism, adrenal dysfunction and stress.

Mechanisms of Innate Immunity

- Non-specific broad spectrum response.
- No lasting immunological memory.
- Has limited flexibility and repertoire.
- Responses are evolutionarily ancient.

Immunological Disorders

Components of the Immune System:

- Lymph, bone marrow, thymus, spleen, leukocytes, antibodies, complement, tonsils and adenoids are among the major components of the immune system.

Antibodies-1:

- IgG is the most abundant antibody in blood. Only antibody to cross the placenta.
- IgA is the second most abundant antibody in blood. Is the main antibody found in bodily secretions: tears, saliva, mucous, respiratory, intestinal and others.
- IgM third most abundant antibody in the blood and the largest.

Cytokines:

- Interleukins are modifiers of a body's immune response and modulate inflammation. They are produced by cells such as lymphocytes, macrophages and monocytes.
- Growth factors are proteins that are able to stimulatecellular proliferation and differentiation. They typically act as signaling molecules between cells promoting cell differentiation and maturation.
- Interferons are a group of proteins which inhibit viral replication in the host's body.

Hypersensitivity – Type 1: (Also known asImmediate Hypersensitivity)

- An allergic response due to re-exposure to a specific antigen.
- Is an inflammatory response e.g. asthma, rhinitis.
- Exposure can be a result: ingestion, inhalation, injections or direct contact.
- Mediated by IgE antibodies.
- Results in an immediate release of histamine, tryptase, arachidonate and derivatives by basophils and mast cells.

Hypersensitivity – Type 2: (Also known as Cytotoxic Hypersensitivity)

- Antibody mediated generally by IgG and to a lesser extent IgM.
- Process typically involves K-cells rather than mast cells.
- May involve complement that binds to cell-bound antibodies.
- Antibodies react with "self" antigens.
- Tissue damage may result.
- Antibodies bind to antigens forming complexes that activate the complement for eliminating cells presenting foreign antigens.
- Acute inflammation created at the site were Ag-Ab complexes causing cell lysis and death.
- Example is Erythroblastosis Fetalis the mother produces antibodies that attack the red blood cells of the fetus. This can occur when the mother and baby have different blood types.

Hypersensitivity – Type 3: (Also known as Immune complex Hypersensitivity)

- Circulating antibodies react with free antigen.
- The complexes can be deposited on tissue which may trigger complement reaction resulting in tissue damage.
- Aggregations of antigens and IgG and IgM form in the blood.
- The reaction can take hours to days to develop.
- Systemic Lupus Erythematosus is an example of this. Antinuclear antibodies generate circulating immune complexes that activate complement. Results in systemic inflammation of body tissues.

Hypersensitivity – Type 4: (Also known as Delayed Hypersensitivity)

- Cell mediated immune response.
- CD8 cytotoxic T cells and CD4 helper T cells are keymolecules involved.
- Antigen presenting cell are macrophages and they release Interleukin 1 stimulating CD4 cell proliferation.
- Activated CD8 cells and macrophages destroy target cells.
- Memory TH1 cells release cytokines that recruit and activate macrophages.
- Examples of this is contact dermatitis i.e. Poison Ivy.

Immunodeficiency Disorders - 1

- Immunodeficiency disorders are a malfunction of theimmune system that result in the development and frequent reoccurrence of disease that are also more severe and longer lasting then typical.
- One or more components is defective or missing from the immune system.
- Immunodeficiency disorders can be inherited.
- Temporary immune deficiencies can develop as a function of disease.

Immunodeficiency Disorders - 2

- Depressed immune response due to smoking, stress, surgery transfusions etc.
- Inherited poorly functioning immune system.
- B-cell system not functioning correctly so unable to make antibodies.

Immunodeficiency Disorders - 3

- Thymus missing, small or defective, lacking T-cells.
- Severe Combined Immunodeficiency Disease: birth defect of several immune system organs or defenses.

Autoimmune Diseases:

- The immune system looses the ability to discriminate between self and other.
- T-cells and antibodies (called auto-antibodies) are made and directed against "self" cells. Rheumatoid factor is an auto-antibody.
- Causes of auto immune diseases include: heredity, infections, certain drugs, sunlight and hormones.
- Type 1 diabetes is caused by the immune systemattacking the pancreas cell.
- **AIDS**: The HIV virus attacks and destroys T-cells. Can also be a latent infection.
- **Rheumatoid arthritis**: The body does not distinguish correctly between self and non-self. The body produces an antibody known as Rheumatoid Factor which is directed against the body's ownimmune system.

Definitions:

- Hypersensitivity: an exaggerated immune response to a foreign agent.
- Inflammation: the first response of the immune system it involves leukocytes entering a site of injury or infection.
- Anaphylaxis: is a rapid and severe allergic response.
- Auto-immune disease: the failure of the immune system to recognize "self" from other cells. This results in an immune response against its own cells and tissues.
- Asthma: is a disease of the respiratory system often resulting from an immune response resulting in inflammation.
- Rheumatoid arthritis is a chronic inflammatory autoimmune disease in which the joints are attacked.
- Mast cells: contain histamine and heparin and are involve in allergy and anaphylaxis. They are similar to basophils and granulocytes.
- Cytokines: peptides and proteins that are used as cell to cell signal
- Macrophages

Medical Microbiology

Skin and Eye Infections

- There are three major regions of the skin, epidermis, dermis and hypodermis. Each of the three regionshave a distinctive structure and function.
- Infective agents favor specific regions of the skin and exploit those regions.
- Learn to regard the great diversity of visual symptoms associated with different pathogens.
- Epidermis has 5 layers of cells, each layer forming a “stratum”. The layers of the epidermis include: Stratum Corneum, Stratum Lucidum, Stratum Granulosum and Stratum Spinosum.
- Dermis has two distinct layers:
- Papillary layer with bumps called papillae
- Reticular layer under the papillae layer
- Blood vessels in the dermis do not enter the epidermis. Nutrients and wastes of the epidermis move by diffusion between the layers. The papillae increase the contact surface area between the epidermis and dermis this enhances adhesion between the layers as well as diffusion of nutrientsand wastes.
- Hypodermis Structure: Lies under the dermis, is not part of the skin, connects the skin to underlying tissues and stores energy.
- Sweat and sebaceous glands are the two primary glands of the skin. Both glands create their secretions within the dermis then dump them onto the surface ofthe skin. The skins surface is typically covered with salt that is left aft sweat evaporates and sebum. Sebum is an oily lipid secreted by sebaceous glands in the dermis. Chemicals in sweat and sebum are antimicrobial
- Although the sweat is formed in the deepest coiled portion of the sweat gland, the tube that lead to the surface of the skin actively refines the concentrations of ions and that will ultimately reach the surface. In the case of cystic fibrosis, the function of ion channels has been altered and therefore also the concentration of ions that appear in the sweat.
- There are four nerve sensors in the skin. Of which only one is located in the epidermis and is called the merkel cell.
- Bacterial Infections Described: Acne, Rocky Mountain Spotted Fever, Impetigo, Necrotizing Fasciitis (Flesh Eating Bacteria), Cat Scratch Fever, Cutaneous Anthrax, and Pseudomonas.

- Viral Infections of the Skin: Poxviruses, Herpes, Warts, Rubella, Rubeola, Chicken Pox, Shingles and Varicella-zoster.
- Fungal infections of the skin are categorized by theregions of the body they infect. The categories of Mycoses: Superficial, Cutaneous, Subcutaneious and Systemic (affecting internal organ systems).
- The Protozoa infection, Leishmaniasis is profiled as an example of this type of infection.
- Basic Eye Structure:
- The cornea is the first structure crossed as light enters the eye; it offers the greatest degree of bending of the light. Next the light passes through the iris which through the motions of two muscles, a sphincter and a dilator, controls the amount of light that enters the eye. Next the light passes through the lens of the eye which controls the fine focusing of the eye. Interesting, when the focusing muscles of the lens relax, the eye focuses on close objects. The lightexits the lens, transits the clear jelly-like vitreous humor to strike the optically active retina where the energy of the photons will be converted into neural signals. The neural signals are conducted to the brain via the optic nerve (CN II). The sclera is very tough fibrous exterior structure which is the site ofattachment for all of the muscles that move the eye. One can imagine that the sclera is pretty special, because it must not change shape when the muscle attached to it move the eye.
- Aqueous humor is produced in the posterior compartment and drained away by the canal of Schlemm in the anterior compartment. Blockage of this canal cause blindness. Excessive pressure from the aqueous humor damages the tissues. This is called glaucoma. It is a very serious condition !!!

Adaptive Immunity:

- Functions: (1) Destroy invading pathogen or toxin, (2) Specific to pathogen, (3) Innate and Adaptive immune collaborate to eliminate the pathogen, (4) Immune memory protects for a long period of time and (5) Distinguishes self from non-self.
- Two types of adaptive immunity: active and passive.
- Active Immunity: resistance by an organism to a pathogen or antigen as a result of antigenic stimulation. The antigen would have evoked an immune response.
- Passive Immunity: is immune protection by exogenously supplied antibodies. Examples of this include transplacental transmission of antibodies from bother to fetus and immune globulin injections.
- Cells involved: Lymphocytes which make B lymphocytes (B cells) and T lymphocytes (T cells). Antigen presenting cells (APC's) which include

macrophages, B cells and Dendritic cells.

Lymphocytes:

- Circulate through blood and lymphatic system. They produce and display receptors for antigen binding. They are further classes into B-cells, T-cells, or T-lymphocytes.

- B-Cells, B-lymphocytes come from the bone marrow and mature there. B-cells have receptors that are membrane bound antibody molecules. They are inactive (naïve) before exposure to an antigen. Once activated they proliferate into memory cells and antibody secreting effector cells or plasma cells.

- T-Cells, T-lymphocytes migrate to a lymphoid organ such as the thymus where they mature. The mature T cell express a novel antigen binding receptor called the T cell receptor (TCR). TCRs only recognize antigens that are associated with cell membrane proteins known as MHC (Major Histocompatibility Complex) molecules. Cytotoxic T-cells defend against infections by viruses and bacteria, diseases, tumors cells and transplanted tissues.

- Antigen Presenting Cells (APC) is a cell that holds a foreign antigen complexed with MHC on it surface. T-cells may recognize the complex with the TCR. Many cells can present antigens to T cells via MHC I molecules but the term is usually limited to cells that prime T cells.

- Dendritic cell is APC and can be found in the skin, mucosa and lymphoid tissues. They are involved in initiation of immune responses by activating lymphocytes and secreting cytokines. They have long membrane processes.

- An effective immune response involves lymphocytes and antigen presenting cells.

- Two types of lymphocytes are B-cells and T-cells.

- Three main antigen presenting cells are: macrophages, B cells, and dendritic cells.

Humoral Responses

- Two classes of adaptive immune responses: Humoral (antibody) and Cell Mediated immune responses.

- Humoral immune responses are carried out by B-lymphocytes. Primary focus on exogenous antigens.

- B-cells are activated to secrete antibodies.

Cell Mediated Immune Response (CMI)

- Cell mediated immune responses are carried out by T-lymphocytes. Primary function endogenous antigens.
- Activated T cells react directly with a presented antigen.
- CMI responses are carried out by TH cells and TC cells.
- A function of T cell would be to kill a host cell that is infected by a virus and is displaying viral antigens.
- T cells produce signal molecules that activate macrophages to destroy the microbes that they have phagocytoses.

Clonal Selection B-Cells

- B-cells that have been antigenically committed mature in the bone marrow.
- Different antibodies are produced against the same antigen via gene rearrangement in the step cell.
- Antigen dependent proliferation and differentiation into plasma and memory cells.
- Clonal selection by antigen antibody binding occurs.
- Clonal selection of an antigen activated B cell leads to a clone of effector B-cells and memory B-cells.
- Plasma cells secrete antibodies to neutralize and eliminate the antigens.

Clonal Selection T-Cells

- Clonal selection is similar to that of B cells.
- T-cell population results in the clone of effector T-cells and memory T-cells.
- Effector T-cells include T helper cells and cytotoxic T lymphocytes.

Processing and Presentation of Antigen

- An antigen must be degraded into small units (peptides) and complexed with MHC I or II molecules in order for a T-cell to recognize it.
- Antigen processing and presentation is the conversion of antigens into MHC

associated fragments.

- The route that an antigen enters a cell determines if it will be processes and presented with class I or class II MHC molecules (extracellular or intracellular entry).
- Exogenous antigens are degraded by APCs (macrophages, B-cells, dendritic cells) and complexed with class II MHC and displayed on the cell surfaced.
- Endogenous antigens like tumor or viral proteins which alters “self cells” are degraded in the cytoplasm and displayed with class I MHC molecules on the cell surface.

Cardiovascular, Lymphatic and Systemic Infections

Blood Structure

- Blood consists of several different types of cells.
- Red blood cells are also called erythrocytes.
- The cells are suspended in plasma.
- Red blood cells carry oxygen.
- White blood cells are also called leukocytes and are used to fight disease
- Platelets are involved in blood clotting.

Cardiovascular System

- The heart is a muscle that acts like a pump.
- Consists of a closed system where blood is pumped by the heart.
- The heart pumps blood into arteries, veins carry blood back to the heart.
- The major arteries are the pulmonary arteries which carry blood to the lungs and the aorta that take theblood to the remaining parts of the body.
- The major veins are: pulmonary veins which carry blood from the lungs to the heart, superior vena cava head neck and arms to heart and inferior vena cava from the rest of the body to the heart.
- The heart itself is supplied by coronary arteries which come from the aorta and cardiac veins which drain into the left atrium.

Human Heart

- The human heart is a muscle with four chambers.
- The heart is enclosed in a pericardial sac that is lined with a serous membrane. The pericardial sac is an important target for infection or inflammation by microbes.
- The wall of the heart is made up of an outer, fibrous pericardium, muscular myocardium and inner endocardium.
- Chambers of the Heart: The internal cavity of the heart is divided into four chambers: right & left atrium, right & left ventricle.
- The right atrium receives deoxygenated blood from systemic veins; the left atrium receives oxygenated blood from the pulmonary veins.
- The valves of the heart are another target for microbial infection. The valves keep the fluid flowing in one direction.
- The heart acts like two pumps, one on the right and one on the left.
- Blood goes from the right atrium to the right ventricle, and then is pumped to the lungs

where it is oxygenated.

- From the lungs the blood goes to the left atrium and then to the left ventricle. From there it is pumped to the body for systemic circulation.

Lymphatic System

- The lymphatic system is a network of lymphoid organs, lymph nodes, ducts, tissues, vessels and fluid.
- The lymphatic system is an important component of the immune system.
- There are three functions of the lymphatic system: removes excess fluid from body tissues, absorbs fatty acids and takes them to the circulatory system and finally make immune cells such as lymphocytes, monocytes and antibody producing cells called plasma cells.
- The lymphatic system is made up of thin vessels that branch throughout the body similar to the blood system. The vessels carry a clear liquid called "lymph". Blood plasma leaks from the capillaries of the blood circulatory system and fill the spaces between the cells of tissue, this is called interstitial fluid. The fluid accumulates slowly and is similar to the blood plasma. Most is returned to the circulatory system via the capillaries. Lymph has a large number of white blood cells. The remaining fluid, about 10% is collected as lymph (or lymphatic fluid which is colorless) by the lymphatic system. It is processed by the lymph nodes before it returns to the circulatory system.
- Lymph nodes are bean shaped and function as filters. They are filled with lymphocytes (white blood cells) which increase rapidly when fighting an infection.
- Pathogens and toxins that target vulnerabilities of the cardiovascular and lymphatic systems can spread throughout the body to cause what is referred to as systemic diseases. Several different pathogens are profiled that demonstrate these concepts.

Microbiology outside the Human Body

Microbiology and the Environment

Microorganisms in Ecosystems:

- An ecosystem is an area of nature that includes biotic and abiotic components. These components haveprocesses that make up and define a certain section of the environment. The biotic and abiotic components are linked by nutrient cycling and the flow of energy.
- Microorganisms in the ecosystem decompose organic substrates called mineralization and are a source of food for some chemoheterotrophic microbes.
- Some organisms produce antimicrobial substancessuch as antibiotics.
- Adaptations of a microbe to its environment can include modifying its metabolism to optimize its survival in a given place.

- Fungi play an important role in decomposition of organic matter.
- Algae are very important in converting atmospheric CO2 into organic matter.
- Protozoan have adapted the ability to move and acquire digestible organic food.
- Bacteria and Archaea are involved in virtually all the cycles of essential elements.
- Ecosystem and its components: Abiotic Substances, Producers, Consumers, Decomposers.
- Ecosystems consist of: living organisms which interact with inanimate substances, other organisms and each other resulting in changes in the abiotic environment. The interactions of organisms is called ecology.
- Microenvironment is a subset of the largerecosystem. It is characterized by the presence of overlapping gradients of resources, toxic material and limiting factors.
- The most important aspect of microbes on their environment is the ability to recycle essentialelements that make up cells.

Essential Cycles

- Biogeochemical cycle – is chemical interactions between the atmosphere, lithosphere, hydrosphere and biosphere.
- Recycling of elements (CHONSP)
    - Essential elements must be converted from one form to another.
    - Microbial cells are crucial to the transformation of these elements.
    - The elements include, carbon, hydrogen, oxygen, nitrogen, sulfur and phosphorus.
- Carbon Cycle Geological
    - CO2 in the atmosphere is recycles via the oceans and land.
- Carbon Cycle – Biological
    - The combined processes of photosynthesis, decomposition, and respiration in which carbon is recycled.
- Sulfur Cycle
    - The process were by sulfur that is a part of organic molecules, as in proteins, are reduced by fungi or bacteria.

    - The reduced H2S is then oxidized the H2S and lithotrophic bacteria further oxidizes it to SO4.
    - Plants and bacteria then incorporate it into organic molecules.

- Phosphorus Cycle
    - Phosphorus cycle is a biogeochemical cycle in which the atmosphere does not play a significant role in its movements.
    - Plants absorb phosphates from the soil and can then be eaten herbivores that may then be eaten by carnivores. Upon death the animal or plant will decay and the phosphate is returned to the soli.
    - Phosphates are important components of nucleotides, energy storage molecules such as ATP, bones and phospholipids.

- Iron Cycle
    - Is a biogeochemical cycle through landforms, atmosphere and oceans.
    - Bacteria such as Pseudomonas and Thiobacillus ferroxidan can reduce and oxidize (respectively) iron to make it bioavailable.
- Nitrogen Cycle
    - Nitrogen exists in the atmosphere as a gas (mostly N2).
    - Nitrogen is often a limiting nutrient for plant growth.
    - Atmospheric nitrogen become a part of biological matter primarily by the actions ofbacteria and algae in a process called nitrogen fixation.
    - Nitrogen fixing bacteria form nodules on the roots of legumes and take nitrogen from the air and convert it into ammonia NH3. The NH3 is further converted by other bacteria into NO2- and then into NO3-. Plants use the nitrate ion as a nutrient or fertilizer to grow.
    - Nitrogen is incorporated into amino acids.

Definitions

- Microenvironment: small spaces deep in the earth with varying environmental factors.
- Food Chain is a series of organisms each feeding on a preceding one.

- Food Web a complex interlocking series of food chains.
- Liebig's Law of the Minimum: this principle says that the growth of organisms is not controlled by the total amount of resources available but rather by the least or scarcest resource.
- Biogeochemical cycling is the cycling of essentialelements by microbes.
- Nitrification is the process were by ammonia NH4+ is oxidize to (NO3-) by autotrophic bacteria.
- Habitat is the physical place that an organism lives.
- Niche the habitat and biological adaptations an organism posses to live.
- Population – the number of like organisms in a place at any given time.
- Community – a collection of organisms of different species that interact with each other.
- **Biological Oxygen Demand**: BOD is an indirect measure of organic matter in an aquatic environment. The amount of dissolved oxygen needed for microbial oxidation of biodegradable organic matter. BOD levels in sewage and waste water have been set.
- **Bioremediation** is the use of microorganisms to clean up an environment. By chemotaxis and other mechanisms microbes move around environments that have the contaminate that is broken down or recycled.

Microbiology and Industry

Industrial Microbiology and the Food Industry:

- Yeast is used make breads, baked goods, alcohol, yogurt and other foods and drink items.
- Today's yeast are specially engineered to work in large scale industrial applications.
- Specialized bacteria and molds are used to make cheeses of different types.
- Biofertilizers include bacteria such as Rhizobia that fixnitrogen.
- Food additives increase nutritional value, retard spoilage, change consistency and enhance flavor. These may be natural compounds such as guar gum and xanthan gum or flavor enhancers and vitamins.

Industrial Microbiology and Medicine:

- Biosensors are monitors used in the detection ofspecific targets in the

environment, human body or other organisms.

- Antibiotic production is a capacity that many microbes have naturally.
- Microbes have been developed as a drug delivery system.
- Lactic acid bacteria (LAB) has been exploited to make and deliver vaccines and other bioactive materials.
- Microbes have been developed that degrade oil so that they it may be more easily extracted.
- Microbes are involved in the production of paper.

Industrial Microbiology and Economics:

- In the cosmetic industry the botulism toxin derived from Clostridium botulinum is utilized.
- Biopesticides have been developed for the control of insect, nematodes and other pathogens that effect plants.
- Synthetic energy fuels such as ethanol, methane, hydrogen and hydrocarbons are produced by microbes.
- Gasohol which is a 9:1 blend of gasoline and ethanol is a popular fuel alternative. The ethanol is produced as a by product of yeast fermentation.
- Microbes have been used in mining. An example of this is the recovery of metals is facilitated by bacteriaby helping to solubilize it making it more easily extracted.
- Microorganisms have been used to clean up the environment in a process called bioremediation. In bioremediation a microbe is introduced into an environment where its natural metabolism results in the detoxification or break down of hazardous chemicals or pollutants.

Specialized Microbes:

- Rhizobia are bacteria that fix nitrogen and make it available for plant nutrition and growth. They form nodules on the roots of legumes.
- Azolla is a fee floating water plant that fixes nitrogenin association with cyanobacteria. It acts as a renewable biofertilizer.
- Azotobacter are nitrogen fixing bacteria that do not form nodules on plant roots or associate with legumes. They are free living and in addition to fixingnitrogen they can produce antibiotics and beneficial growth substances.
- Azospirillum fix nitrogen inside plant roots. They produce

beneficial compounds for plant growth and can survive in wetland conditions as well as soils.

- Mycorrhiza are fungi that form symbiotic relationships with plant roots. Vesicular arbuscular mycorrhiza (VAM) is the most important member of this group. VAM colonies take up nutrients and water which is available for the plant and they act as root extensions.

Definitions:

- Probiotics are live microbes that may have a beneficial affect on a host eating them.
- Biofertilizers are living microbes that enrich the nutrient quality of soil.
- Biopesticides are microbes which are used to manage pests including insects, nematode or other organisms.
- Food additives are substances used to enhance the nutritional value, stabilize or increase the palatability of a food.

Zoology

The Cell

The cell is the basic building block of living organisms. Bacteria and the parasite that causes malaria consist of single cells, while plants and animals are made up of trillions of cells. Most cells are spherical or cube shaped but some are a range of different shapes (see diagram 3.1).

Most cells are so small that a microscope is needed to see them,although a few cells, eg the ostrich's egg, are so large that they could make a meal for several people.

A normal cell is about 0.02 of a millimetre (0.02mm) in diameter. (Small distances like this are normally expressed in micrometres or microns (µm). Note there are 1000 µms in every mm).

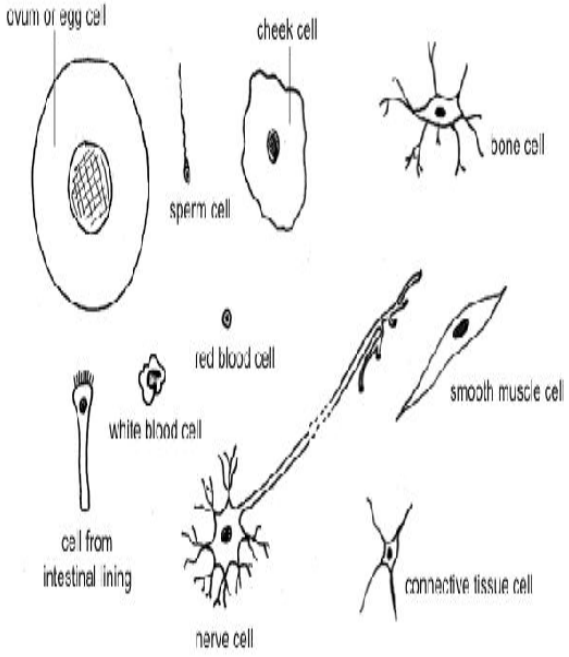


Diagram 3.1. A variety of animal cells

When you look at a typical animal cell with a light microscope it seems quite simple with only a few structures visible (see diagram 3.2).

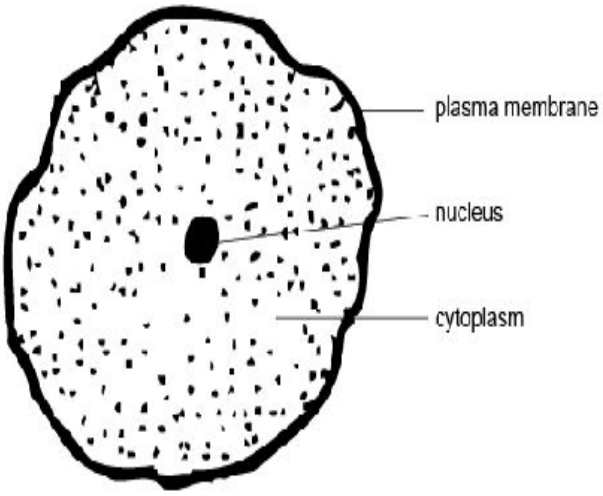


Diagram 3.2 An animal cell

Three main parts can be seen:

- an outer cell wall or plasma membrane,
- an inner region called the cytoplasm and

- the nucleus

However, when you use an electron microscope to increase the magnification many thousands of times you see that these seemingly simple structures are incredibly complex, each with its own specialized function. For example the plasma membrane is seen to be a double layer and the cytoplasm contains many special structures called**organelles** (meaning little organs) which are described below. A drawing of the cell as seen with an electronmicroscope is shown in diagram 3.3.

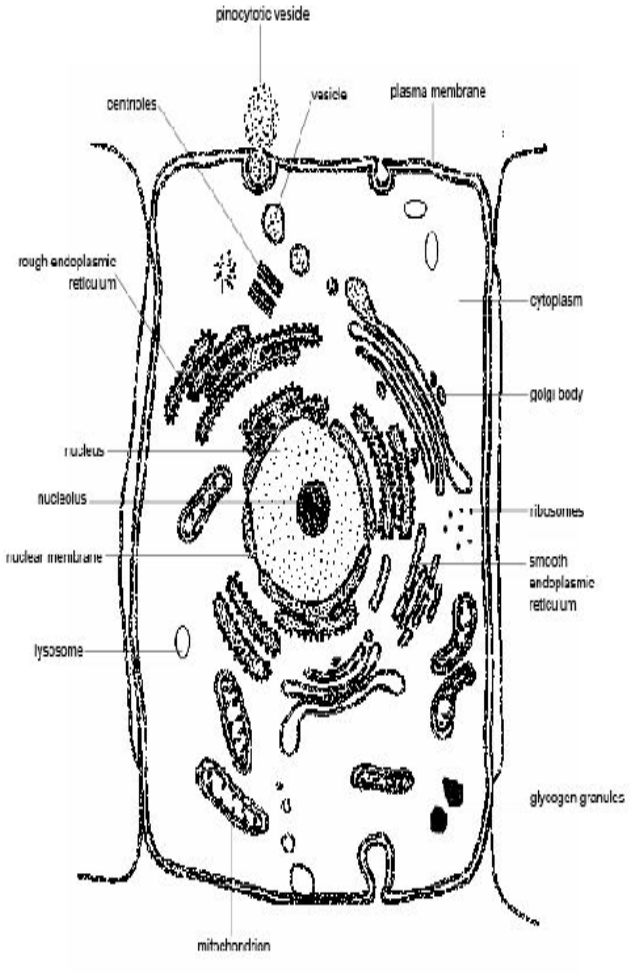


Diagram 3.3 An animal cell as seen with an electronmicroscope

The Plasma Membrane

The thin plasma membrane surrounds the cell, separating its contents from the surroundings and controlling what enters and leaves the cell. The plasma membrane is composed of two main molecules, fats (in fact phospholipids) and proteins. The fats are arranged in a double layer with the large protein molecules dotted about in the membrane (seediagram 3.4). Some of the protein molecules form tiny channels in the membrane while others help transport substances from one side of the membrane to the other.

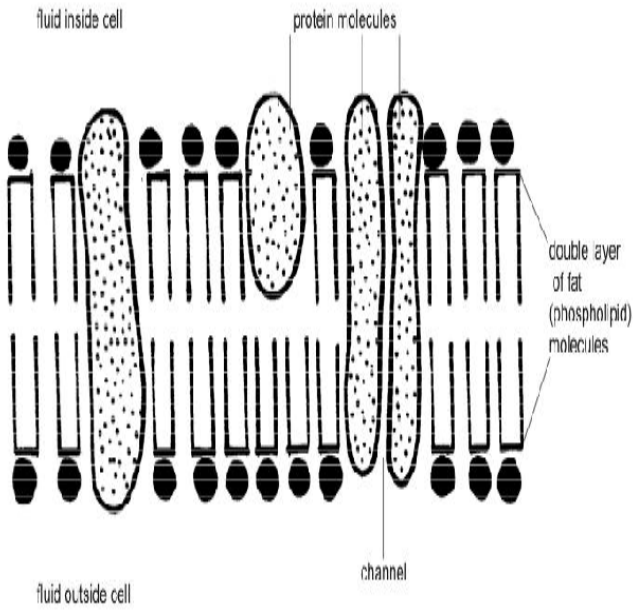


Diagram 3.4 The structure of the plasma membrane

How substances move across the Plasma Membrane

Substances need to pass through the membrane to enter or leave the cell and they do so in a number of ways. Some of these processes require no energy i.e. they are passive, while others require energy - they are active, while others require energy i.e. they are **active**.

Passive processes include: a) diffusion and b) osmosis, while active processes include: c) active transport, d) phagocytosis, e) pinocytosis and f) exocytosis. These will be described below.

a) Diffusion

Although you may not know it, you are already familiar with the process of diffusion. It is diffusion that causes a smell (expensive perfume or smelly socks) in one part of the room to gradually move through the room so it can be smelt onthe other side. Diffusion occurs in the air and in liquids.

Diagram 3.5 shows what happens when a few crystals of a dark purple dye called potassium permanganate are dropped into a beaker of water. The dye molecules diffuse into the water moving from high to low concentrations so they become evenly distributed throughout the beaker.

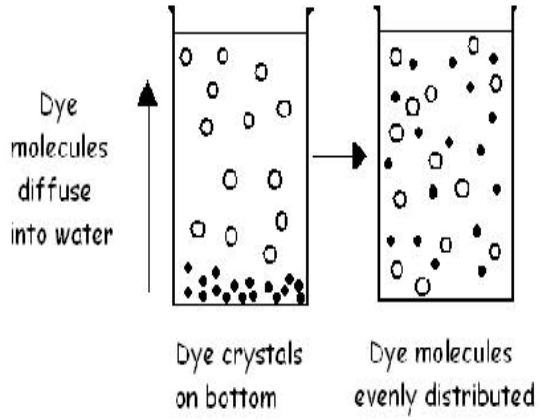


Diagram 3.5 - Diffusion in a liquid

In the body, diffusion causes molecules that are in a high concentration on one side of the cell membrane to move across the membrane until they are present in equal concentrations on both sides. It takes place because all molecules have an in-built vibration that causes them to move and collide until they are evenly distributed. It is an absolutely natural process that requires no added energy.

Small molecules like oxygen, carbon dioxide, water and ammonia as well as fats, diffuse directly through the double fat layer of the membrane. The small molecules named above as well as a variety of charged particles (ions) also diffuse through the protein-lined channels. Larger molecules like glucose attach to a carrier molecule that aids their diffusion through the membrane. This is called **facilitated diffusion**.

In the animal's body diffusion is important for moving oxygen and carbon dioxide between the lungs and the blood, for moving digested food molecules from the gut into the blood and for the removal of waste products from the cell.

b) Osmosis

Although the word may be unfamiliar, you are almost certainly acquainted with the effects of osmosis. It is osmosis that plumps out dried fruit when you soak it before making a fruit cake or makes that wizened old carrot look almost like new when you soak it in water. Osmosis is in fact the diffusion of water across a membrane that allows water across but not larger molecules. This kind of membrane is called a **semi-permeable membrane**.

Take a look at side **A** of diagram 3.6. It shows a container divided into two parts by an artificial semi-permeable membrane. Water is poured into one part while a solution containing salt is poured into the other part. Water can cross the membrane but the salt cannot. The water crosses the semi-permeable membrane by diffusion until there is an equal amount of water on both sides of the membrane. The effect of this would be to make the salt solution more diluted and cause the level of the liquid in the right-hand side of the container

to rise so it looked like side **B** of diagram 3.6. This movement of water across the semi-permeable membrane is called osmosis. It is a completely natural process that requires no outside energy.

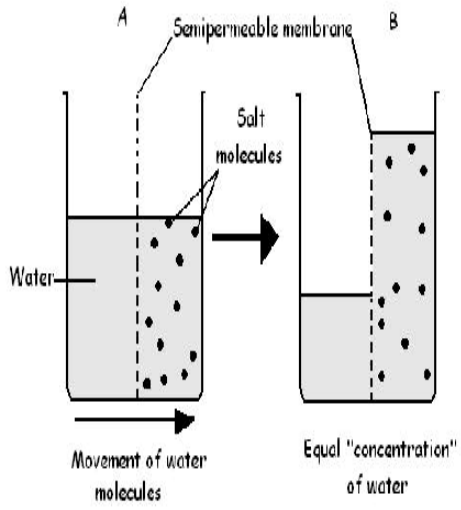


Diagram 3.6 - Osmosis

Although it would be difficult to do in practice, imagine that you could now take a plunger and push down on the fluid in the right-hand side of container **B** so that it flowed back across the semi-permeable membrane until the level of fluid on both sides was equal again. If you could measure the pressure required to do this, this would be equal to the**osmotic pressure** of the salt solution. (This is a rather advanced concept at this stage but you will meet this term again when you study fluid balance later in the course).

The plasma membrane of cells acts as a semi-permeable membrane. If red blood cells, for example, are placed in water, the water crosses the membrane to make the amount of water on both sides of it equal (see diagram 3.7). This means that the water moves into the cell causing it to swell. This can occur to such an extent that the cell actually bursts to release its contents. This bursting of red blood cells is called **haemolysis**. In a situation such as this when the solution on one side of a semi-permeable membrane has a lower concentration than that on the other side, the first solution is said to be **hypotonic** to the second.

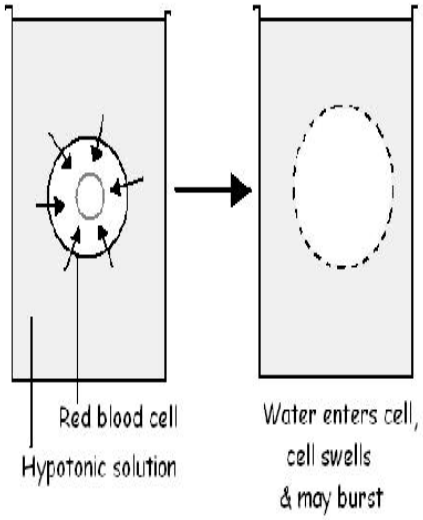


Diagram 3.7 - Osmosis in red cells placed in a hypotonic solution

Now think what would happen if red blood cells were placed in a salt solution that has a higher salt concentration than the solution within the cells (see diagram 3.8). Such a bathing solution is called a **hypertonic** solution. In this situation the "concentration" of water within the cells would be higher than that outside the cells. Osmosis (diffusion of water) would then occur from the inside of the cells to the outside solution, causing the cells to shrink.

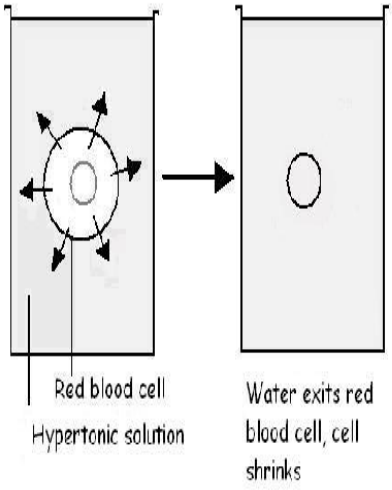


Diagram 3.8 - Osmosis in red cells placed in a hypertonic solution

A solution that contains 0.9% salt has the same concentration as body fluids and the solution within red cells. Cells placed in such a solution would neither swell nor shrink (see diagram 3.9). This solution is called an **isotonic**solution. This strength of salt solution is often called **normal saline** and is used when replacing an animal's body fluids or when

cells like red blood cells have to be suspended in fluid.

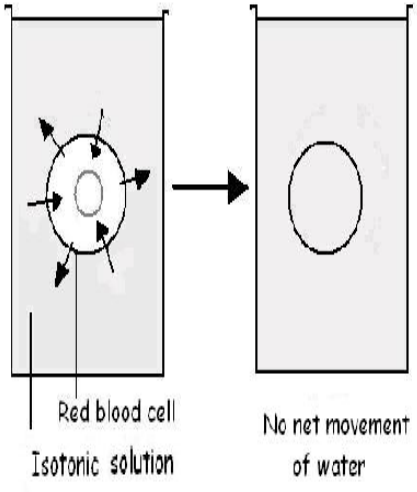


Diagram 3.9 - Red cells placed in an isotonic solution

Remember - osmosis is a special kind of diffusion. It is the diffusion of water molecules across a semi-permeable membrane. It is a completely passive process and requires no energy.

Sometimes it is difficult to remember which way the watermolecules move. Although it is not strictly true in a biological sense, many students use the phrase **"SALT SUCKS"** to help them remember which way water moves across the membrane when there are two solutions of different salt concentrations on either side.

As we have seen water moves in and out of the cell by osmosis. All water movement from the intestine into the blood system and between the blood capillaries and the fluid around the cells (tissue or extra cellular fluid) takes place by osmosis. Osmosis is also important in the production of concentrated urine by the kidney.

c) Active transport

When a substance is transported from a low concentration to a high concentration i.e. uphill against the concentration gradient, energy has to be used. This is called **active transport**.

Active transport is important in maintaining different concentrations of the ions sodium and potassium on either side of the nerve cell membrane. It is also important for removing valuable molecules such as glucose, amino acids and sodium ions from the urine.

d) Phagocytosis

Phagocytosis is sometimes called "cell eating". It is a process that requires energy and is used by cells to move solid particles like bacteria across the plasma membrane. Finger-like projections from the plasma membrane surround the bacteria and engulf them as shown in

diagram 3.10. Once within the cell, enzymes produced by the lysosomes of the cell (described later) destroy the bacteria.

The destruction of bacteria and other foreign substance by white blood cells by the process of phagocytosis is a vital part of the defense mechanisms of the body.

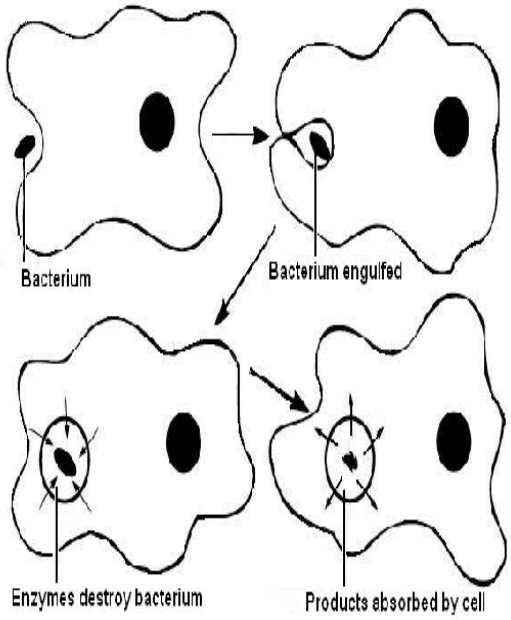


Diagram 3.10 - Phagocytosis

e) Pinocytosis

Pinocytosis or “cell drinking” is a very similar process to phagocytosis but is used by cells to move fluids across the plasma membrane. Most cells carry out pinocytosis (note the pinocytotic vesicle in diagram 3.3).

f) Exocytosis

Exocytosis is the process by means of which substances formed in the cell are moved through the plasma membrane into the fluid outside the cell (or extra-cellular fluid). It occurs in all cells but is most important in secretory cells (e.g. cells that produce digestive enzymes) and nerve cells.

Geological Eras

THE MIDDLE AGES OF THE EARTH

The story of the earth from the beginning of the Cambrian period to the present day was long ago divided by geologists into four great eras. The periods we have already covered--the Cambrian, Ordovician, Silurian, Devonian, Carboniferous, and Permian--form the Primary or Palaeozoic Era, to which the earlier Archaean rocks were prefixed as a barren and less interesting introduction. The stretch of time on which we now enter, at the

close of the Permian, is the Secondary or Mesozoic Era. It will be closed by a fresh upheaval of the earthand disturbance of life-conditions in the Chalk period, and followed by a Tertiary Era, in which the earth will approach its modern aspect. At its close there will be another series of upheavals, culminating in a great Ice-age, and the remaining stretch of the earth's story, in which we live, will form the Quaternary Era.

In point of duration these four eras differ enormously from each other. If the first be conceived as comprising sixteen million years--a very moderate estimate--the second will be found to cover less than eight million years, the third less than three million years, and the fourth, the Age of Man, much less than one million years; while the Archaean Age was probably as long as all these put together. But the division is rather based on certain gaps, or "unconformities," in the geological record; and, although the breaches are now partially filled, we saw that they correspond to certain profound and revolutionary disturbances in the face of the earth. We retain them, therefore, as convenient and logical divisions of the biological as well as the geological chronicle, and, instead of passing from one geological period to another, we may, for the rest of the story, take these three eras as wholes, and devote a few chapters to the chief advances made by living things in each era. The Mesozoic Era will be a protracted reaction between two revolutions: a period of low-lying land, great sea-invasions, and genial climate, between two upheavals of the earth. The Tertiary Era will represent a less sharply defined depression, with genial climate and luxuriant life, between two such upheavals.

The Mesozaic ("middle life") Era may very fitly be described as the Middle Ages of life on the earth. It by no means occupies a central position in the chronicle of life from the point of view of time or antiquity, just as the Middle Ages of Europe are by no means the centre of the chronicle of mankind, but its types of animals and plants are singularly transitional between the extinct ancient and the actual modern types. Life has been lifted to a higher level by the Permian revolution. Then, for some millions of years, the sterner process of selection relaxes, the warm bosom of the earthswarms again with a teeming and varied population, and a rich material is provided for the next great application of drastic selective agencies. To a poet it might seem that nature indulges each succeeding and imperfect type of living thing with a golden age before it is dismissed to make place forthe higher.

Geological Eras: Birds & Mammals

THE BIRD AND THE MAMMAL

These two types of organisms were the bird and the mammal. Both existed in the Jurassic, and the mammals at least had many representatives in the Triassic. In other words, they existed, with all their higher organisation, during several million
years without attainingpower. The mammals remained, during at least 3,000,000 years, a small and obscure caste, immensely overshadowed by the small-brained reptiles. The birds, while making more progress, apparently, than the mammals, were far outnumbered by the flying reptiles until the last part of the Mesozoic. Then there was another momentous turn of the wheel of fate, and they emerged from their obscurity to assume the lordship of the globe.

In earlier years, when some serious hesitation was felt by many to accept the new doctrine of evolution, a grave difficulty was found in the circumstance that new types--not merely new species and new genera, but new orders and even sub-classes--appeared in the geological record quite suddenly. Was it not a singular coincidence that in ALL cases the intermediateorganisms between one type and another should have wholly escaped preservation? The difficulty was generally due to an imperfect acquaintance with the conditions of the problem. The fossil population of a period is only that fraction of its living population which happened to be buried in a certain kind of deposit under water of a certain depth. We shall read later of insects being preserved in resin (amber), and we have animals (and even bacteria) preserved in trees from the Coal-forests. Generally speaking, however, the earthhas buried only a very minute fraction of its land-population. Moreover, only a fraction ofthe earth's cemeteries have yet been opened. When we further reflect that the new type of organism, when it first appears, is a small and local group, we see what the chances are of our finding specimens of it in a few scattered pages of a very fragmentary record of the earth's life. We shall see that we have discovered only about ten skeletons or fragments of skeletons of the men who lived on the earth before the Neolithic period; a stretch of some hundreds of thousands of years, recorded in the upper strata of the earth.

Whatever serious difficulty there ever was in this scantiness of intermediate types is amply met by the fact that every fresh decade of search in the geological tombs brings some to light. We have seen many instances of this-- the seed-bearing ferns and flower-bearing cycads, for example, found in the last decade--and will see others. But one of the most remarkable cases of the kind now claims our attention. The bird was probably evolved in the late Triassic or early Jurassic. It appears in abundance, divided into several genera, in the Chalk period. Luckily, two bird-skeletons have been found in the intermediate period, theJurassic, and they are of the intermediate type, between the reptile and the bird, which the theory of evolution would suggest. But for the fortunate accident of these two birds being embedded in an ancient Bavarian mud-layer, which happened to be opened, for commercial purposes, in the second half of the nineteenth century, critics of evolution--if there still were any in the world of science--might be repeating to-day that the transition from the reptile to the bird was unthinkable in theory and unproven in fact.

THE TERTIARY ERA

We have already traversed nearly nine-tenths ofthe story of terrestrial life, without counting thelong and obscure Archaean period, and still find ourselves in a strange and unfamiliar earth. With the close of the Chalk period, however, we take a long stride in the direction of the modern world. The Tertiary Era will, in the main, prove a fresh period of genial warmth and fertile low-lying regions. During its course our deciduous trees and grasses will mingle with the palms and pines over the land, our flowers will begin to brighten thelandscape, and the forms of our familiar birds and mammals, even the form of man, will be discernible in the crowds of animals. At its close another mighty period of selection will clear the stage for its modern actors.

A curious reflection is prompted in connection with this division of the earth's story into periods of relative prosperity and quiescence, separated by periods of disturbance. There

was--on the most modest estimate--a stretch of some fifteen million years between the Cambrian and the Permian upheavals. On the same chronological scale the interval between the Permian and Cretaceous revolutions was only about seven million years, and the Tertiary Era will comprise only about threemillion years. One wonders if the Fourth (Quaternary) Era in which we live will be similarly shortened. Further, whereas the earth returned after each of the earlier upheavals to what seems to have been its primitive condition of equable and warm climate, it has now entirely departed from that condition, and exhibits very different zones of climate and a succession of seasons in the year. One wonders what the climate of the earth will become long before the expiration of those tenmillion years which are usually assigned as the minimum period during which the globe will remain habitable.

It is premature to glance at the future, when we are still some millions of years from the present, but it will be useful to look more closely at the facts which inspire this reflection. From what we have seen, and shall further see, it is clear that, in spite of all the recent controversy about climate among our geologists, there has undeniably been a progressive refrigeration of the globe. Every geologist, indeed, admits "oscillations of climate," as Professor Chamberlin puts it. But amidst all these oscillations we trace a steady lowering of the temperature. Unless we put a strained and somewhat arbitrary interpretation on the facts of the geological record, earlier ages knew nothing of our division of the year into pronounced seasons and of the globe into very different climatic zones. It might plausibly be suggested that we are still living in the last days of the Ice-Age, and that the earth may be slowly returning to a warmer condition. Shackleton, it might be observed, found that there has been a considerable shrinkage of the south polar ice within the period of exploration. But we shall find that a difference of climate, as compared with earlier ages, was already evident in the middle of the Tertiary Era, and it is far more noticeable to-day.

Climatic Evolution

We do not know the causes of this climatic evolution-- the point will be considered more closely in connection with the last Ice-Age--but we see that it throws a flood of light on the evolution of organisms. It is one of the chief incarnations of natural selection. Changes in the distribution of land and water and in the nature of the land-surface, the coming of powerful carnivores, and other agencies which we have seen, have had their share in the onward impulsion of life, but the most drastic agency seems to have been the supervention of cold. The higher types of both animals and plants appear plainly in response to a lowering of temperature. This is the chiefadvantage of studying the story of evolution in strict connection with the geological record. We shall find that the record will continue to throw light on our path to the end, but, as we are now about to approach the most important era of evolution, and as we have now seen so much of the concrete story of evolution, it will be interesting to examine briefly some other ways of conceiving that story.

We need not return to the consideration of the leading schools of evolution, as described in a former chapter. Nothing that we have seen will enable us to choose between the Lamarckian and the Weismannist hypothesis; and I doubt if anything we are yet to see will prove more decisive. The dispute is somewhat academic, and not vital to a conception

of evolution. We shall, for instance, presently follow the evolution of the horse, and see four of its toes shrink and disappear, while the fifth toe is enormously strengthened. In the facts themselves there is nothing whatever to decide whether this evolutiontook place on the lines suggested by Weismann, or on the lines suggested by Lamarck and accepted by Darwin. It will be enough for us merely to establish the fact that the one-toed horse is an evolved descendant of a primitive five-toed mammal, through the adaptation of its foot to running on firm ground, its teeth and neck to feeding on grasses, and so on.

On the other hand, the facts we have already seen seem to justify the attitude of compromise I adopted in regard to the Mutationist theory. It would be an advantage in many ways if we could believe that new species arose by sudden and large variations (mutations) of the young from the parental type. In the case of many organs and habits it is extremely difficult to see how a gradual development, by a slow accentuation of small variations, is possible. When we further find that experimenters on living species can bring about such mutations, and when we reflect that there must have been acute disturbances in the surroundings of animals and plants sometimes, we are disposed to think that many a new species may have arisen in this way. On the other hand, while the palaeontological record can never prove that a species arose by mutations, it does sometimes show that species arise by very gradual modification. The Chalk period, which we have just traversed, affords a very clear instance. One of our chief investigators of the English Chalk, Dr. Rowe, paid particular attention to the sea-urchins it contains, as they serve well to identify different levels of chalk. He discovered, not merely that they vary from level to level, but that in at least one genus (Micraster) he could trace the organism very gradually passing from one species to another, without any leap or abruptness. It is certainly significant that we find such cases as this precisely where the conditions of preservation are exceptionally good. We must conclude that species arise, probably, both by mutations and small variations, and that it is impossible to say which class of species has been the more numerous.

Conceptions of Evolution

There remain one or two conceptions of evolution which we have not hitherto noticed, as it was advisable to see the facts first. One of these is the view--chiefly represented in this country by Professor Henslow--that natural selection has had no part in the creation of species; that the only two factors are the environment and the organism which responds to its changes. This is true enough in the sense that, as we saw, natural selection is not an action of nature on the "fit," but on the unfit or less fit. But this does not in the least lessen the importance of natural selection. If there were not in nature this body of destructive agencies, to which we apply the name natural selection, there would be little--we cannot say no--evolution. But the rising carnivores, the falls of temperature, etc., that we have studied, have had so real, if indirect, an influence on the development of life that we need not dwell on this.

Another school, or several schools, while admitting the action of natural selection, maintain that earlier evolutionists have made nature much too red in tooth and claw. Dr. Russel Wallace from one motive, and Prince Krapotkin from another, have insisted that the triumphs of war have been exaggerated, and the triumphs of peace, or of social co-

operation, far too little appreciated. It will be found that such writers usually base their theory on life as we find it in nature to-day, where the social principle is highly developed in many groups of animals. This is most misleading, since social co-operation among animals, as an instrument of progress, is (geologically speaking) quite a recent phenomenon. Nearly every group of animals in which it is found belongs, to put it moderately, to the last tenth of the story of life, and in some of the chief instances the animals have only gradually developed social life.* The first nine-tenths of the chronicle of evolution contain no indication of social life, except--curiously enough--in such groups as the Sponges, Corals, and Bryozoa, which are amongst the least progressive in nature. We have seen plainly that during the overwhelmingly greater part of the story of life the predominant agencies of evolution were struggle against adverse conditions and devouring carnivores; and we shall find them the predominant agencies throughout the Tertiary Era.

* Thus the social nature of man is sometimes quoted as one of the chief causes of his development. It is true that it has much to do with his later development, but we shall see that the statement that man was from the start a social being is not at all warranted by the facts. On the other hand, it may be pointed out that the ants and termites had appeared in the Mesozoic. We shall see some evidence that the remarkable division of labour which now characterises their life did not begin until a much later period, so that we have no evidence of social life in the early stages.

Rise of a new Era

It has seemed advisable to take this further glance at the general principles and current theories of evolution before we extend our own procedure into the Tertiary Era. The highest types of animals and plants are now about to appear on the stage of the earth; the theatre itself is about to take on a modern complexion. The Middle Ages are over; the new age is breaking upon the planet. We will, as before, first survey the Tertiary Era as a whole, with the momentous changes it introduces, and then examine, in separate chapters, the more important phases of its life.

It opens, like the preceding and the following era, with "the area of land large and its relief pronounced." This is the outcome of the Cretaceous revolution. Southern Europe andSouthern Asia have risen, and shaken the lastmasses of the Chalk ocean from their faces; the whole western fringe of America has similarly emerged from the sea that had flooded it. In many parts, as in England (at that time a part of the Continent), there is so great a gap between the latest Cretaceous and the earliest Tertiary strata that these newly elevated lands must evidently have stood out of the waters for a prolonged period. On their cooler plains the tragedy of the extinction of the great reptiles comes to an end. The cyeads and ginkgoes have shrunk into thin survivors of the luxuriant Mesozoic groves. The oak and beech and other deciduous trees spread slowly over the successive lands, amid the glare and thunder of the numerous volcanoes which the disturbance of the crust has brought into play. New forms of birds fly from tree to tree, or linger by the waters; and strange patriarchal types of mammals begin to move among the bones of the stricken reptiles.

But the seas and the rains and rivers are acting with renewed vigour on the elevated lands,

and the Eocene period closes in a fresh age of levelling. Let us put the work of a million years or so in a sentence. The southern sea, which has been confined almost to the limits of our Mediterranean by the Cretaceous upheaval, gradually enlarges once more. It floods the north-west of Africa almost as far as the equator; it covers most of Italy, Turkey, Austria, and Southern Russia; it spreads over Asia Minor, Persia, and Southern Asia, until it joins the Pacific; and it sends a long arm across the Franco-British region, and up the great valley which is now the German Ocean.

From earlier chapters we now expect to find a warmer climate, and the record gives abundant proof of it. To this period belongs the "London Clay," in whose thick and--to the unskilled eye--insignificant bed the geologist reads the remarkable story of what London was two or three million years ago. It tells us that a sea, some 500 or 600 feet deep, then lay over that part of England, and fragments of the life of the period are preserved in its deposit. The sea lay at the mouth of a sub-tropical river on whose banks grew palms, figs, ginkgoes, eucalyptuses, almonds, and magnolias, with the more familiar oaks and pines and laurels. Sword-fishes and monstrous sharks lived in the sea. Large turtles and crocodiles and enormous "sea-serpents" lingered in this last spell of warmth that Central Europe would experience. A primitive whale appeared in the seas, and strange large tapir-like mammals--remote ancestors of our horses and more familiar beasts--wandered heavily on the land. Gigantic primitive birds, sometimes ten feet high, waded by the shore. Deposits of the period at Bournemouth and in the Isle of Wight tell the same story of a land that bore figs, vines, palms, araucarias, and aralias, and waters that sheltered turtles and crocodiles. The Parisian region presented the same features.

THE EVOLUTION OF MAN

We have reserved for a closer inquiry thatorder of the placental mammals to which we ourselves belong, and on which zoologists have bestowed the very proper and distinguishingname of the Primates. Since the days of Darwin there has been some tendency to resent the term "lower animals," which man applies to his poorer relations. But, though there is no such thing as an absolute standard by which we may judge the "higher" or "lower" status of animals or plants, the extraordinary power which man has by his brain development attained over both animate and inanimate nature fully justifies the phrase. The Primate order is, therefore, of supreme interest as the family that gave birth to man, and it is important to discover the agencies which impelled some primitive member of it to enter upon the path which led to this summit of organic nature.

The order includes the femurs, a large and primitive family with ape-like features--the Germans call them "half-apes"--the monkeys, the man-like apes, and man.
This classificationaccording to structure corresponds with the successive appearance of the various families in the geological record. The femurs appear in the Eocene; the monkeys, and afterwards the apes, in the Miocene, the first semi-humanforms in the Pleistocene, though they must have been developed before this. It is hardly necessary to say that science does not regard man as a descendant of the known anthropoid apes, or these as descended from the monkeys. They are successive types or phases of development, diverging early from each other. Just as the succeeding horse-types of the record are not necessarily related

to each other in a direct line, yet illustrate the evolution of a type which culminates in the horse, so the spreading and branching members of the Primate group illustrate the evolution of a type of organism which culminates in man. The particular relationship of the various families, living and dead, will need careful study.

That there is a general blood-relationship, and that man is much more closely related to the anthropoid apes than to any of the lower Primates, is no longer a matter of controversy. In Rudolph Virchow there died, a few years ago, the last authoritative man of science to express any doubt about it. There are, however, non-scientific writers who, by repeating the ambiguous phrase that it is "only a theory," convey the impression to inexpert readers that it is still more or less an open question. We will therefore indicate a few of the lines of evidence which have overcome the last hesitations of scientific men, and closed the discussion as to the fact.

The very close analogy of structure between man and the ape at once suggests that they had a common ancestor. There are cases in which two widely removed animals may develop a similar organ independently, but there is assuredly no possibility of their being alike in all organs, unless by commoninheritance. Yet the essential identity of structure in man and the ape is only confirmed by every advance of science, and would of itself prove the common parentage. Such minor differences as there are between man and the higher ape--in the development of the cerebrum, the number of the teeth or ribs, the distribution of the hair, and so on--are quite explicable when we reflect that the two groups must have diverged from each other more than a million years ago

Structure of Man

Examining the structure of man more closely, we find this strong suggestion of relationship greatly confirmed. It is now well known that the human body contains a number of vestigial "organs"--organs of no actual use, and only intelligible as vestiges of organs that were once useful. Whatever view we take of the origin ofman, each organ in his frame must have a meaning; and, as these organs are vestigial and useless even in the lowest tribes of men, who represent primitive man, they must be vestiges of organs that were of use in a remote pre-human ancestor. The one fact that the ape has the same vestigial organs as man would, on a scientific standard of evidence, prove the common descent of the two. But these interesting organs themselves point back far earlier than a mixed ape-human ancestor in many cases.

The shell of cartilage which covers the entrance to the ear--the gristly appendage which is popularly called the ear--is one of the clearest and most easily recognised of these organs. The "ear" of a horse or a cat is an upright mobile shell for catching the waves of sound.The human ear has the appearance of being the shrunken relic of such an organ, and, when we remove the skin, and find seven generally useless muscles attached to it, obviously intended to pull the shell in all directions (as in the horse), there can be no doubt that the external ear is a discarded organ, a useless legacy from an earlier ancestor. In cases where it has been cut off it was found that the sense of hearing was scarcely, if at all, affected. Now we know that it is similarly useless in all tribes of men, and must therefore come from a pre-

human ancestor. It is also vestigial in the higher apes, and it is only when we descend to the lower monkeys and femurs that we see it approaching its primitive useful form. One may almost say that it is a reminiscence of the far-off period when, probably in the early Tertiary, the ancestors of the Primates took to the trees. The animals living on the plain needed acute senses to detect the approach of their prey or their enemies; the tree-dweller found less demand on his sense of hearing, the "speaking-trumpet" was discarded, and the development of the internal ear proceeded on the higher line of the perception of musical sounds.

We might take a very large number of parts of the actual human body, and discover that they are similar historical or archaeological monuments surviving in a modern system, but we have space only for a few of the more conspicuous.

The hair on the body is a vestigial organ, of actual use to no race of men, an evident relic of the thick warm coat of an earlier ancestor. It in turn recalls the dwellers in the primeval forest. In most cases--not all, because the wearing of clothes for ages has modified this feature--it will be found that the hairs on the arm tend upward from the wrist to the elbow, and downward from the shoulder to the elbow. This very peculiar feature becomes intelligible when we find that some of the apes also have it, and that it has a certain use in their case. They put their hands over their heads as they sit in the trees during ram, and in that position the sloping hair acts somewhat like the thatched roof of a cottage.

Natural Position of Standing

Again, it will be found that in the naturalposition of standing we are not perfectly flat-footed, but tend to press much more on the outer than on the inner edge of the foot. This tendency, surviving after ages of living on the level ground, is a lingering effect of the far-off arboreal days.

A more curious reminiscence is seen in the fact that the very young infant, flabby and powerless as it is in most of its muscles, is so strong in the muscles of the hand and arm that it can hang on to a stick by its hands, and sustain the whole weight of its body, for several minutes. Finally, our vestigial tail--for we have a tail comparable to that of the higher apes--must be mentioned. In embryonic development the tail is much longer than the legs, and some children are born with a real tail, which they move as the puppy does, according to their emotional condition. Other features of the body point back to an even earlier stage. The vermiform appendage--in which some recent medical writers have vainly endeavoured to find a utility-- is the shrunken remainder of a large and normal intestine of a remote ancestor. This interpretation of it would stand even if it were found to have a certain use in the human body. Vestigial organs are sometimes pressed into a secondary use when their original function has been lost. The danger of this appendage in the humanbody to-day is due to the fact that it is a blind alley leading off the alimentary canal, and has a very narrow opening. In the apethe opening is larger, and, significantly enough, it is still larger in the human foetus. When we examine some of the lower mammals we discover the meaning of it. It is in them an additional storage chamber in the alimentary system. It is believed that a change to a more digestible diet has made this additional chamber superfluous in the

Primates, and the system is slowly suppressing it.

Human Male

A much more interesting fact, but one less easy to interpret, is that the human male has, like the male ape, organs for suckling the young. That there are real milk-glands, usually vestigial, underneath the teats in the breast ofthe boy or the man is proved by the many known cases in which men have suckled the young. Several friends of the present writer have seen this done in India and Ceylon by male "wet-nurses." As there is no tribe of men or species of ape in which the male suckles the young normally, we seem to be thrown back once more upon an earlier ancestor. The difficulty is that we know of no mammal of which both parents suckle the young, and some authorities think that the breasts have been transferred to the male by a kind of embryonic muddle. That is difficult to believe, as no other feature has ever been similarly transferred to the opposite sex. In any case the male breasts are vestigial organs. Another peculiarity of the mammary system is that sometimes three, four, or five pairs of breasts appear in a woman (and several have been known even in a man). This is, apparently, an occasional reminiscence of an early mammal ancestor which had large litters of young and several pairs of breasts.

But there are features of the human body which recall an ancestor even earlier than the quadruped. The most conspicuous of these is the little fleshy pad at the inner corner of each eye. It is a common feature in mammals, and is always useless. When, however, we look lower down in the animal scale we find that fishes and reptiles (and birds) have a third eyelid, which is drawn across the eye from this corner. There is little room to doubt that the little fleshy vestige in the mammal's eye is the shrunken remainder of the lateral eyelid of a remote fish-ancestor.

Human Blood

The blood consists of cells, or minute disk-shaped corpuscles, floating in a watery fluid, or serum. It was found a few years ago, in the course of certain experiments in mixing the blood of animals, that the serum of one animal's blood sometimes destroyed the cells of the other animal's blood, and at other times did not. When the experiments were multiplied, it was found that the amount of destructive action exercised by one specimen of blood upon another depended on the nearness or remoteness of relationship between the animals. If the two are closely related, there is no disturbance when their blood is mixed; when they are not closely related, the serum of one destroys the cells of the other, and the intensity of the action is in proportion to their remoteness from each other. Another and more elaborate form of the experiment was devised, and the law was confirmed. On both tests it was found by experiment that the blood of man and of the anthropoid ape behaved in such a way as to prove that they were closely related. The blood of the monkey showed a less close relationship--a little more remote in the New World than in the Old World monkeys; and the blood of the femur showed a faint and distant relationship.

Miocene period

In the Miocene period we find a great expansion of the monkeys. These in turn enter the scene quite suddenly, and the authorities are reduced to uncertain and contradictory

conjectures as to their origin. Some think that they develop not from the femurs, but along an independent line from the Insectivores, or other ancestors of the Primates. We will not linger over these early monkeys, nor engage upon the hopeless task of tracing their gradual ramification into the numerous families of the present age. It is clear only that they soon divided into two main streams, one of which spread into the monkeys of America and the other into the monkeys of the Old World. There are important anatomical differences between the two. The monkeys remained in Central and Southern Europe until near the end of the Tertiary. Gradually we perceive that the advancing cold is driving them further south, and the monkeys of Gibraltar to-day are the diminished remnant of the great family that had previously wandered as far as Britain and France.

Evolvement of Human

The question whether an implement-using animal, which nearly all would agree to regard as in some degree human, wandered over what is now the South of England (Kent, Essex, Dorsetshire, etc.) as many hundred thousand years ago as this claim would imply, is certainly one of great interest. But there would be little use in discussing here thequestion of the "Eoliths," as these disputed implements are called. A very keen controversy is still being conducted in regard to them, and some of the highest authorities in England, France, and Germany deny that they show any trace of humanworkmanship or usage. Although they have the support of such high authorities as Sir J. Prestwich, Sir E. Ray Lankester, Lord Avebury, Dr. Keane, Dr. Blackmore, Professor Schwartz, etc., they are one of those controverted testimonies on which it would be ill-advised to rely in such a work as this.

We must say, then, that we have no undisputed traces of man in the Tertiary Era. The Tertiary implements which have been at various times claimed in France, Italy, and Portugal are equally disputed; the remains which were some years ago claimed as Tertiary in the United States are generally disallowed; and the recent claims from South America are under discussion. Yet it is the general feeling of anthropologists that man was evolved in the Tertiary Era. On the one hand, the anthropoid apes were highly developed by the Miocene period, and it would be almost incredible that the future human stock should linger hundreds of thousands of years behind them. On the other hand, when we find the first traces of man in the Pleistocene, this development has already proceeded so far that its earlier phase evidently goes back into the Tertiary. Let us pass beyond the Tertiary Era for a moment, and examine the earliest and most primitive remains we have of human or semi-human beings.

The first appearance of man in the chronicle of terrestrial life is a matter of great importance and interest. Even the least scientific of readers stands, so to say, on tiptoe to catch a first glimpse of the earliest known representative of our race, and half a century of discussion of evolution has engendered a very wide interest in the early history of man.*

* A personal experience may not be without interest in this connection. Among the many inquiries directed to me in regard to evolution I received, in one month, a letter from a negro in British Guiana and an extremely sensible query from an inmate of an English asylum for the insane! The problem that beset the latter of the two was whether the

Lemuranda preceded the Lemurogona in Eocene times. He had found a contradiction in the statements of two scientific writers.