

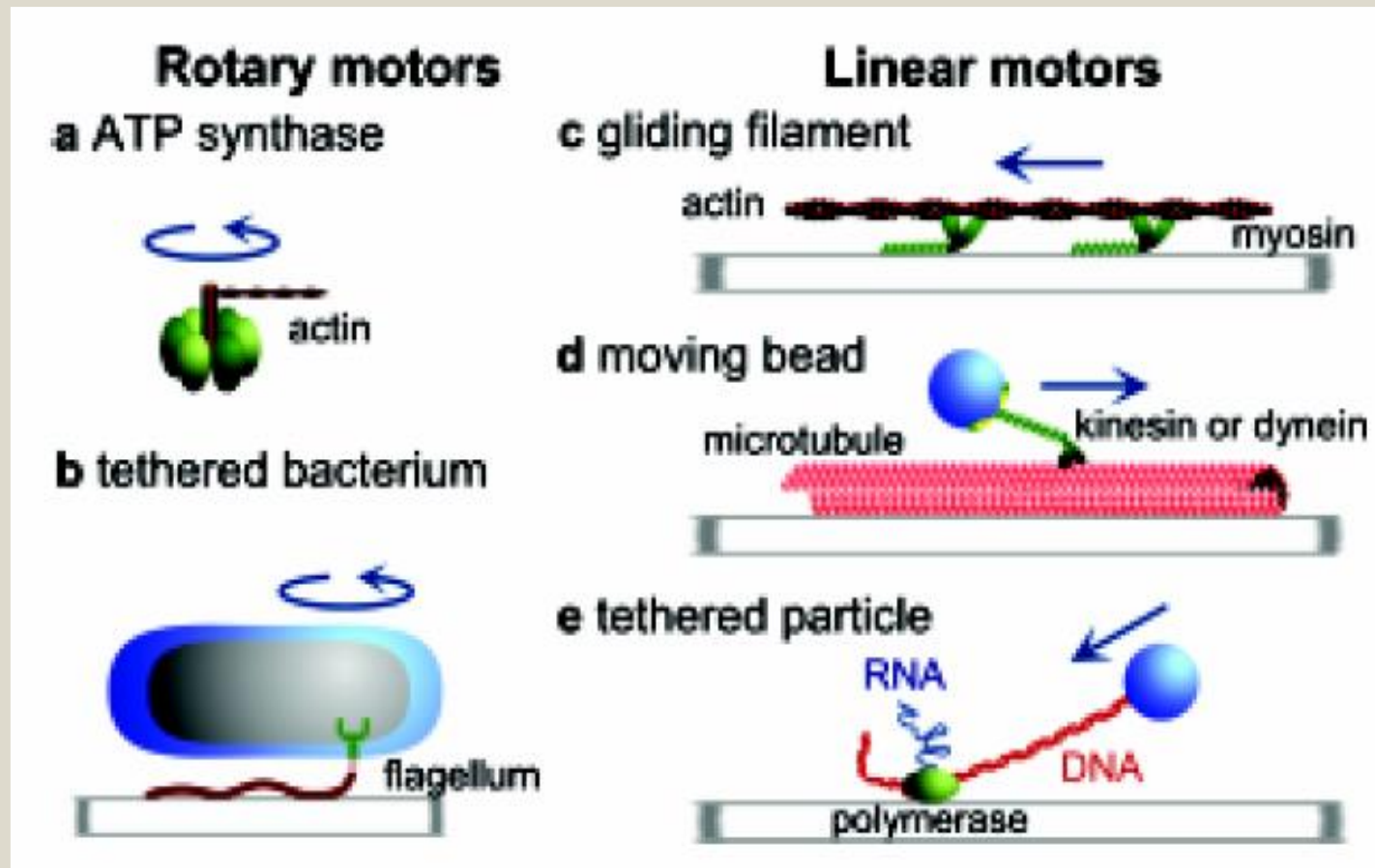
Unit 4 Mechanochemistry

- Molecular Machines/Motors
- Properties of ATP-based Protein Molecular Machines
 - The F₀F₁-ATP Synthase Motors
 - Coupling and Coordination of Motors
- The Bacterial Flagellar Motor
 - Flagellar motor structure
- Cytoskeleton
- Bioremediation
- Biosensors

Molecular Machines/Motors

- *Molecular machines can be defined as devices that can produce useful work through the interaction of individual molecules at the molecular scale of length.*
- *A convenient unit of measurement at the molecular scale would be a nanometer. Hence, molecular machines also fall into the category of nanomachines.*
- *As our knowledge and understanding of these numerous machines continues to increase, we now see a possibility of using the natural machines, or creating synthetic ones from scratch, by mimicking nature.*

Different types of molecular machines. These machines used by nature for force generation and motion. *They convert chemical energy into mechanical force via conformational changes.*



- Most of the natural machinery is built from proteins.
- These findings help unravel the mysteries associated with the molecular machinery and pave the way for the production and application of these miniature machines in various fields, including medicine, space exploration, electronics and military.
- *We divide the molecular machines into three broad categories—protein based, DNA-based, and chemical molecular motors.*

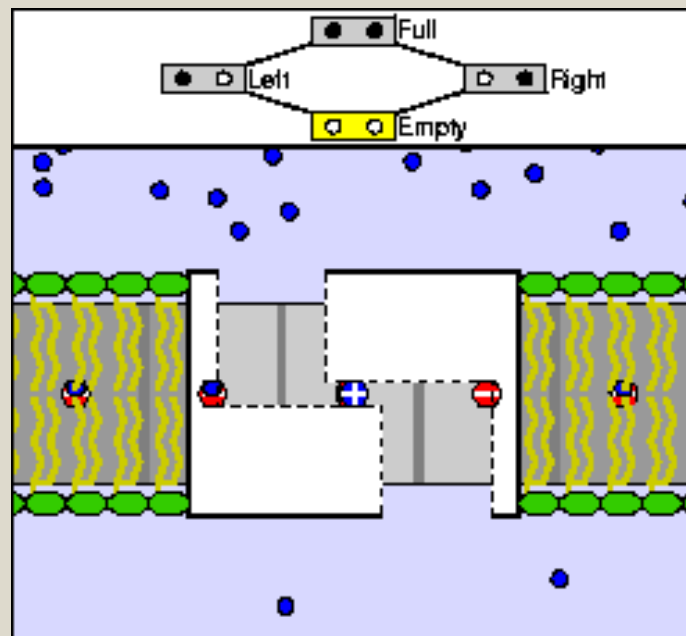
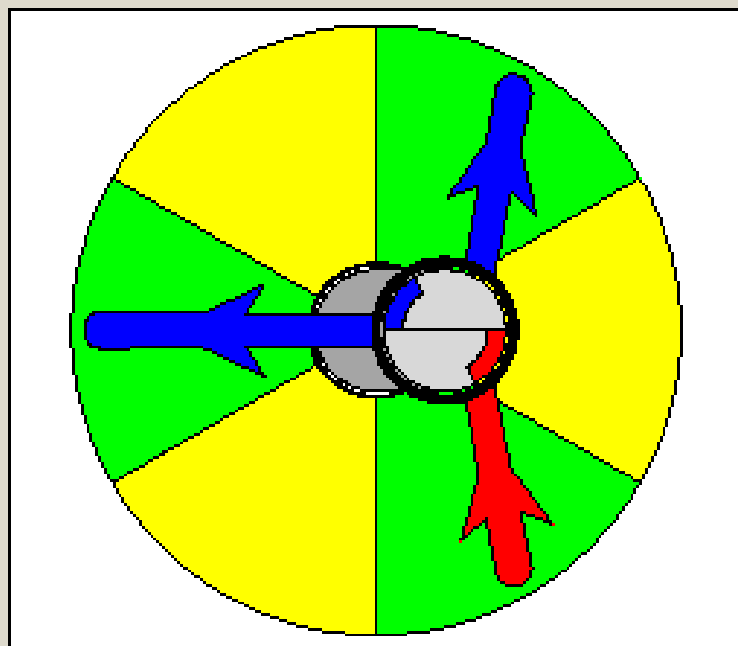
Properties of ATP-based Protein Molecular Machines

- *Two form the F₀F₁-ATP synthase, and the third one is the bacterial flagellar motor.*
- **The protein-based molecular motors rely on an energy-rich molecule known as adenosine triphosphate (ATP),**
- **The machines described in this section, the F₀F₁-ATPase, the kinesin, myosin, and dynein superfamily of protein molecular machines, and bacteria flagellar motors all depend, directly or indirectly, on ATP for their input energy.**
- **These machines have now been segregated out of their natural environment and are seen as energy conversion devices to obtain forces, torques, and motion.**
- **One disadvantage associated with ATP dependence is that the ATP creation machinery itself could be many times heavier and bulkier than the motors, thereby making it more complex.**
- **These machines perform best in their natural environment, and in the near future it may be possible to have them as a part of biomimetic molecular machinery.**

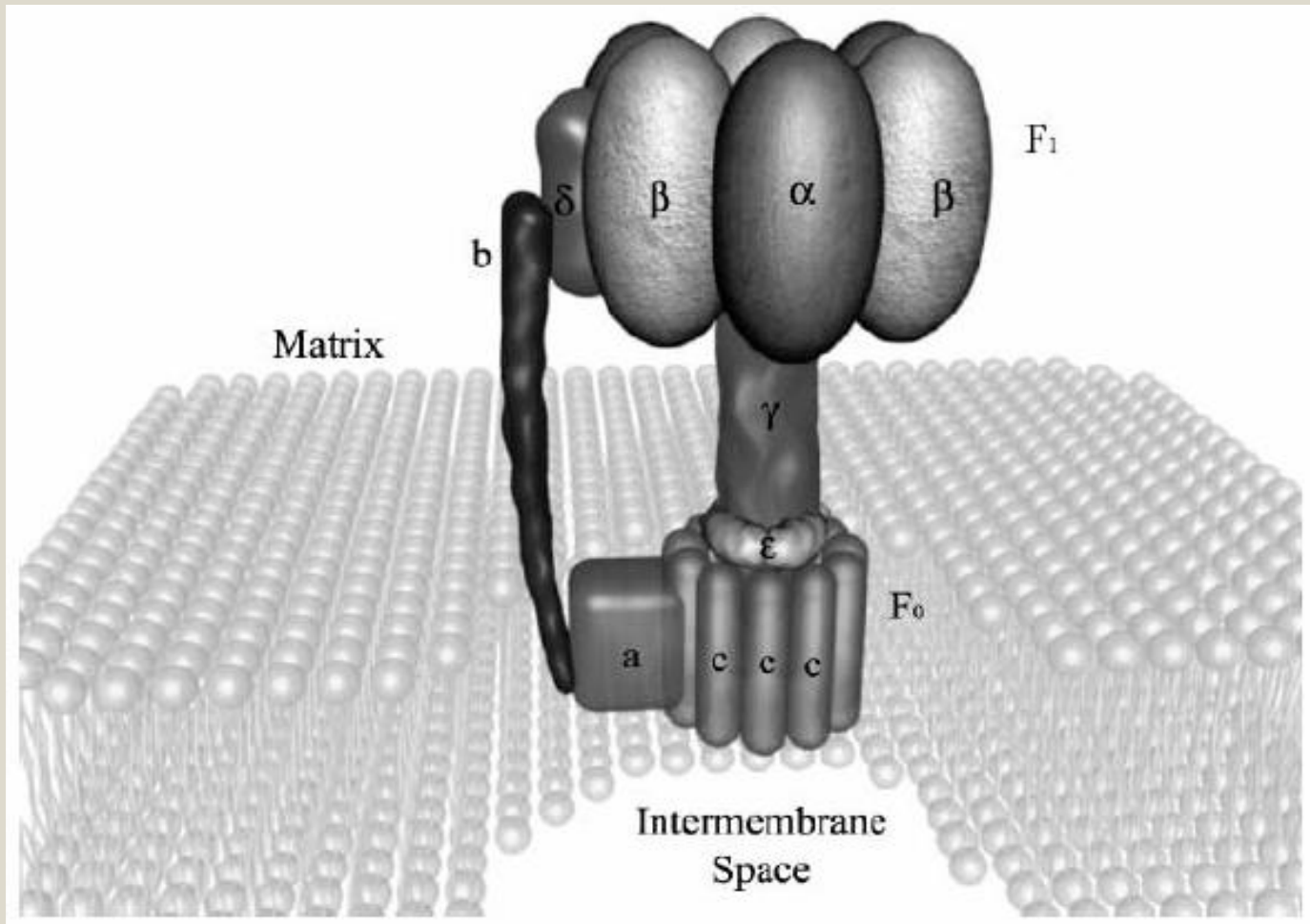
The F₀F₁-ATP Synthase Motors

- ATP is regarded as the energy currency of biological systems.
- When this currency is utilized (i.e., the energy of the molecule that is used to drive a biological process), the terminal anhydride bond in the ATP molecule has to be split. This leaves adenosine diphosphate (ADP) and a phosphate ion (Pi) as the products, which are recombined to form ATP by a super efficient enzyme motor assembly called the F₀F₁-ATP synthase (F₀F₁-ATPase).
- ATP synthase is present inside the mitochondria of animal cells, in plant chloroplasts, in bacteria, and some other organisms.

- ATP synthase consists of two portions: **a membrane-spanning portion, Fo**, comprising the ion channel, and **a soluble portion, F1**, containing three catalytic sites.
- Both Fo and F1 are reversible rotary motors --- perhaps the smallest motors known to science. Fo uses the transmembrane electrochemical gradient to generate a rotary torque to drive ATP synthesis in F1 or, when driven backwards by the torque generated in F1, to pump ions uphill against their transmembrane electrochemical gradient.
- F1 generates a rotary torque by hydrolyzing ATP at its three catalytic sites or, when turned backwards by the torque generated in Fo, as a synthesizer of ATP.

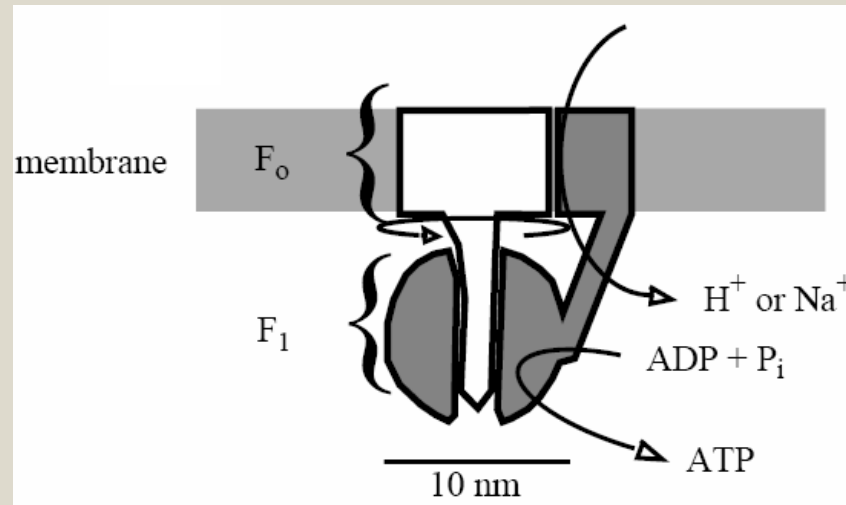


The F₀F₁-ATPase motors. The F₀ motor is embedded in the inner mitochondrial membrane of the mitochondria. F₀ is typically composed of a , b , and c subunits as shown. The F₁ motor is the soluble region composed of three α -, three β -, one each of γ -, δ - and ϵ -subunits.



Coupling and Coordination of Motors

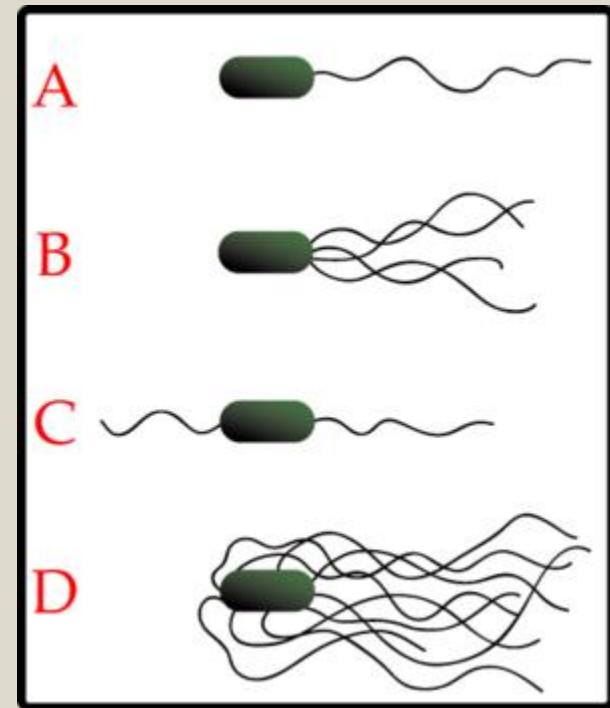
- The ATP synthase is actually a combination of two motors functioning together, the hydrophobic transmembrane F₀-ATPase motor and the globular F₁-ATPase motor



The F₀F₁-ATPase contains two rotary motors: the membrane-bound F₀, driven by the flux of ions across a membrane, and the soluble F₁, driven by ATP hydrolysis. These two motors are coupled by sharing a common motor, drawn in white, and a common stator, drawn dark. The figure shows the F₀F₁-ATPase operating as an ATP-synthase. Rotation of F₀ driven by ion flux drives F₁ in reverse, causing it to synthesize ATP from ADP and inorganic phosphate.

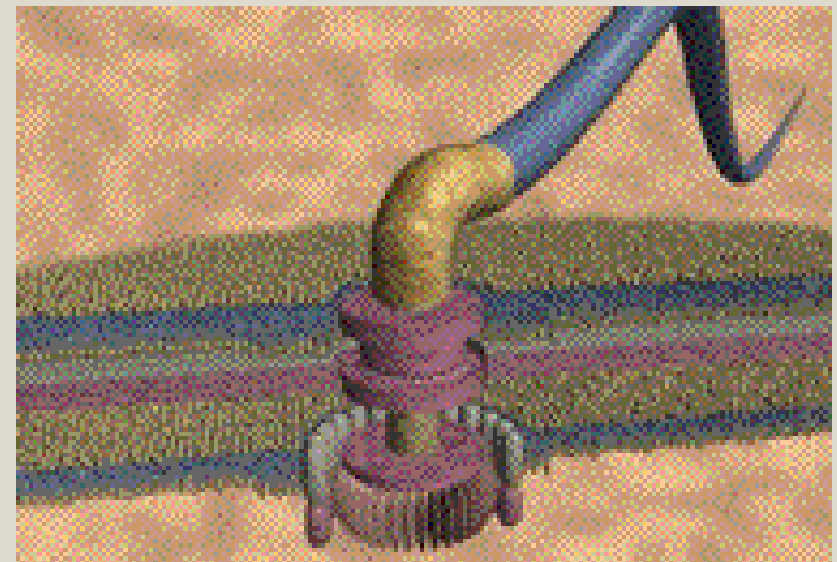
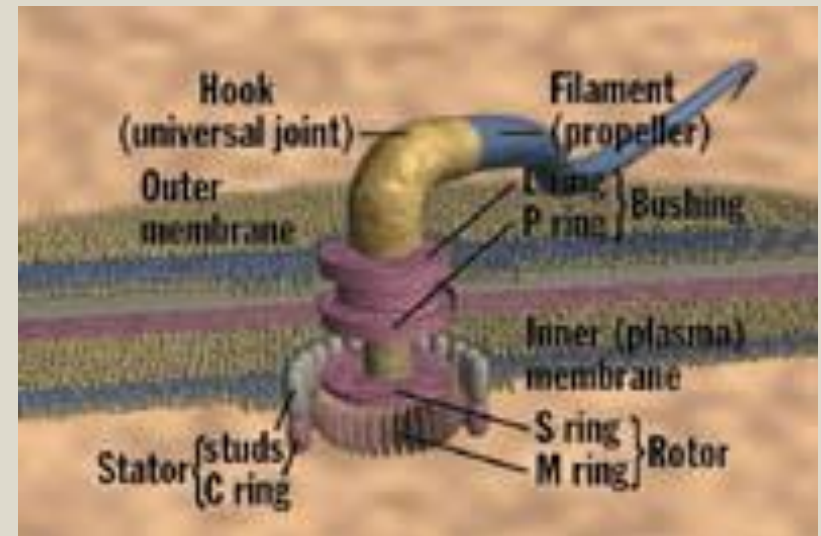
The Bacterial Flagellar Motor

- A flagellum (plural: flagella) is a long, slender projection from the cell body, composed of microtubules and surrounded by the plasma membrane.
- In small, single-cell organisms they may function to propel the cell by beating in a whip-like motion; in larger animals, they often serve to move fluids along mucous membranes such as the lining of the trachea.
- The bacterial flagellar motor is a nanotechnological marvel, no more than 50 nm in diameter, built from about 20 different kinds of parts.



Examples of bacterial flagella arrangement schemes. A-Monotrichous; B-Lophotrichous; C-Amphitrichous; D-Peritrichous

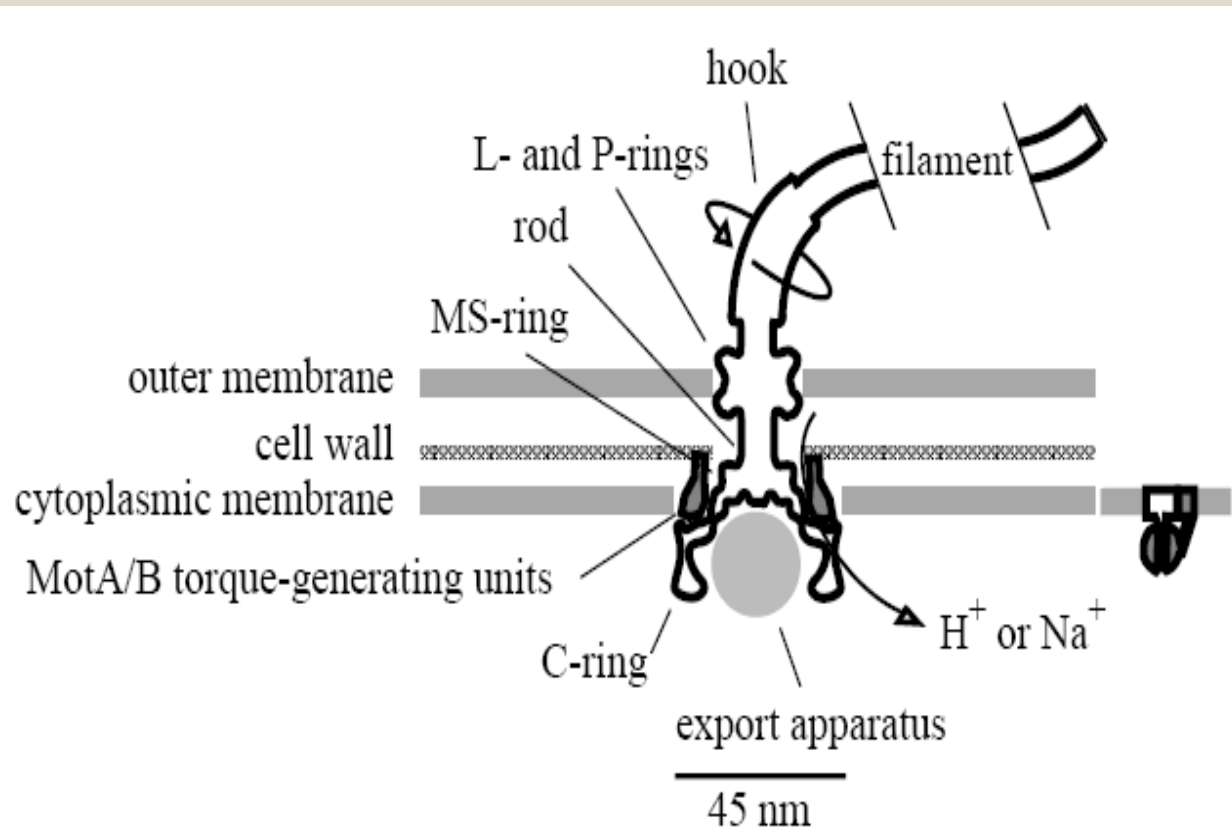
- It spins clockwise (CW) or counterclockwise (CCW) at speeds on the order of 100 Hz, driving long thin helical filaments that enable cells to swim.
- Peritrichously flagellated cells (*peri*, around; *trichos*, hair), such as *Escherichia coli*, execute a random search, moving steadily at about 30 diameters per second, now in one direction, now in another.
- Steady motion requires CCW rotation. Receptors near the surface of the cell count molecules of interest (sugars, amino acids, dipeptides) and control the direction of flagellar rotation.
- If a leg of the search is deemed favorable, it is extended, i.e., the motors spin CCW longer than they otherwise would. This bias enables cells to actively find regions in their environment where life is better.



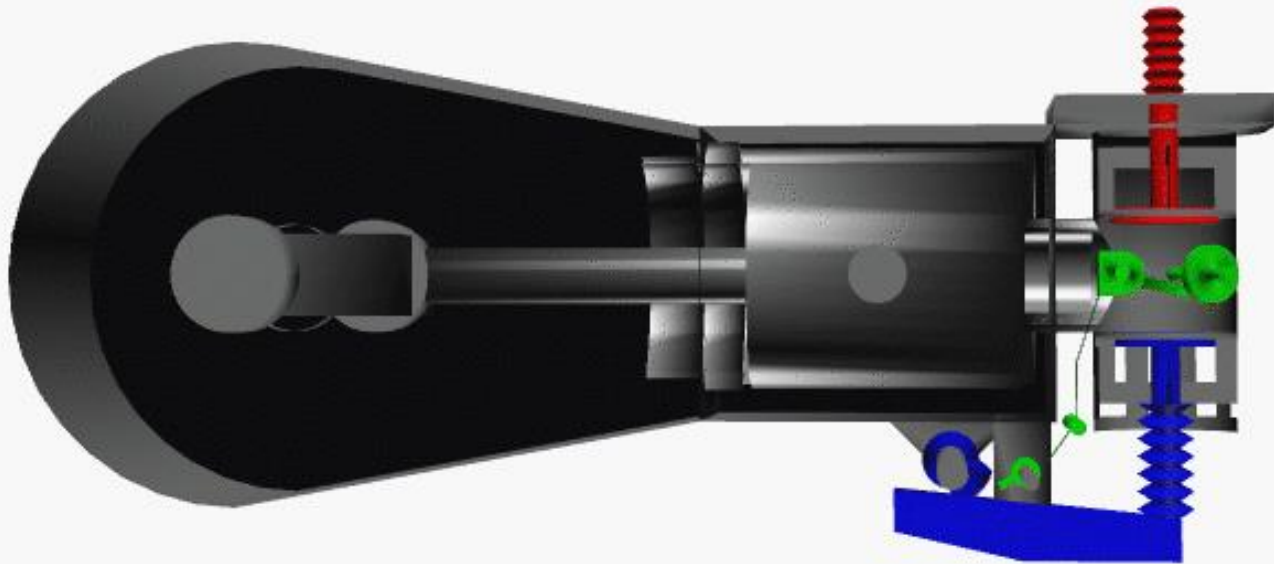
- Thus, the flagellar motor is the output organelle of a remarkable sensory system, the components of which have been honed to perfection by billions of years of evolution.
- A number of bacterial species in addition to *E. coli* depend on flagella motors for motility: e.g., *Salmonella enterica* serovar, Typhimurium (*Salmonella*), *Streptococcus*, *Vibrio* spp., *Caulobacter*, *Leptospira*, *Aquaspirillum serpens*, and *Bacillus*.
- The rotation of flagella motors is stimulated by a flow of ions through them, which is a result of a build-up of a transmembrane ion gradient. There is no direct ATP-involvement; however, the proton gradient needed for the functioning of flagella motors can be produced by ATPase.

Flagellar motor structure

- **Bacterial flagella are the only biological structures known that use rotation for the purpose of locomotion.**
- **Flagella consist of a rotary motor embedded in the cell envelope connected to an extracellular helical propeller. The motor is powered by the flow of ions down an electrochemical gradient across the cytoplasmic membrane into the cell.**
- **The ions are typically H^+ (protons), although certain marine and alkalophilic species have motors driven by Na^+ .**
- **The electrochemical gradient (protonmotive force or sodium motive force) consists of a transmembrane voltage and a concentration difference across the membrane, both of which are maintained by various metabolic processes.**
- **The rotor shown in white (Figure 5), consists of a series of rings spanning the cell envelope and is attached via the flexible hook to the helical propeller or filament. The stator is a ring of particles in the cytoplasmic membrane, containing the proteins MotA and MotB, and anchored to the peptidoglycan cell**



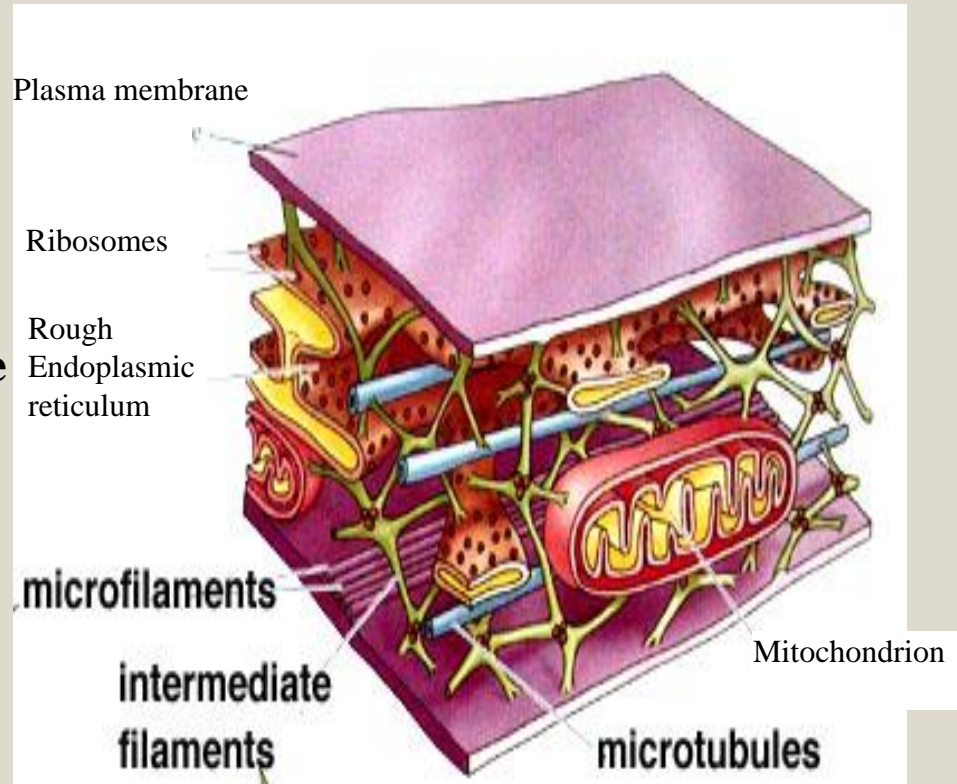
The bacterial flagellar motor. The rotor, drawn in white, consists of a series of rings that span the cell envelope and are attached to the extracellular hook and filament. The stator consists of a ring of torque-generating units containing the proteins MotA and MotB and anchored to the cell wall. Ions flowing through the motor generate torque by means of unknown interactions between the rotor and stator in the vicinity of the C-ring. The F₀F₁-ATPase is also shown, to the same scale.



The fuel/air intake system **red**, the electrical system **green**, and the exhaust system **blue**

Cytoskeleton: Microtubules, Microfilaments, and Intermediate filaments

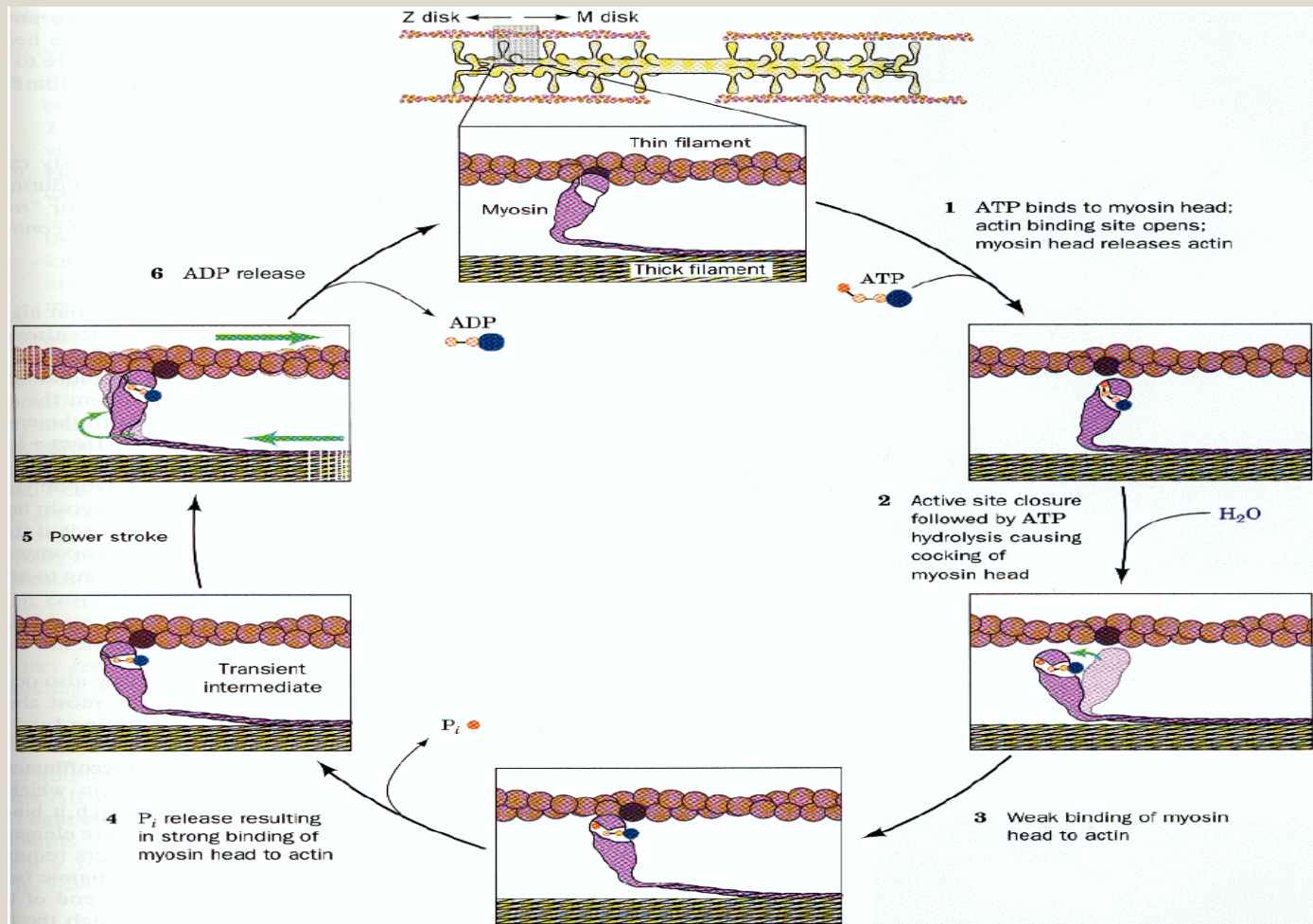
- Cytoskeleton gives the cell shape, structure, and physical organization
- Motor proteins can rearrange the structural elements, or move cell components around the cytoskeleton.
- The cytoskeleton is in constant state of change depending on the requirements of the cell.
- 3 major structural elements of the cytoskeleton
- Microtubules - hollow, rigid cylindrical tubes made from tubulin subunits
- Microfilaments - solid, thinner structures made of actin
- Intermediate filaments - tough, ropelike fibers made of a variety of related proteins



The Myosin Linear Motor

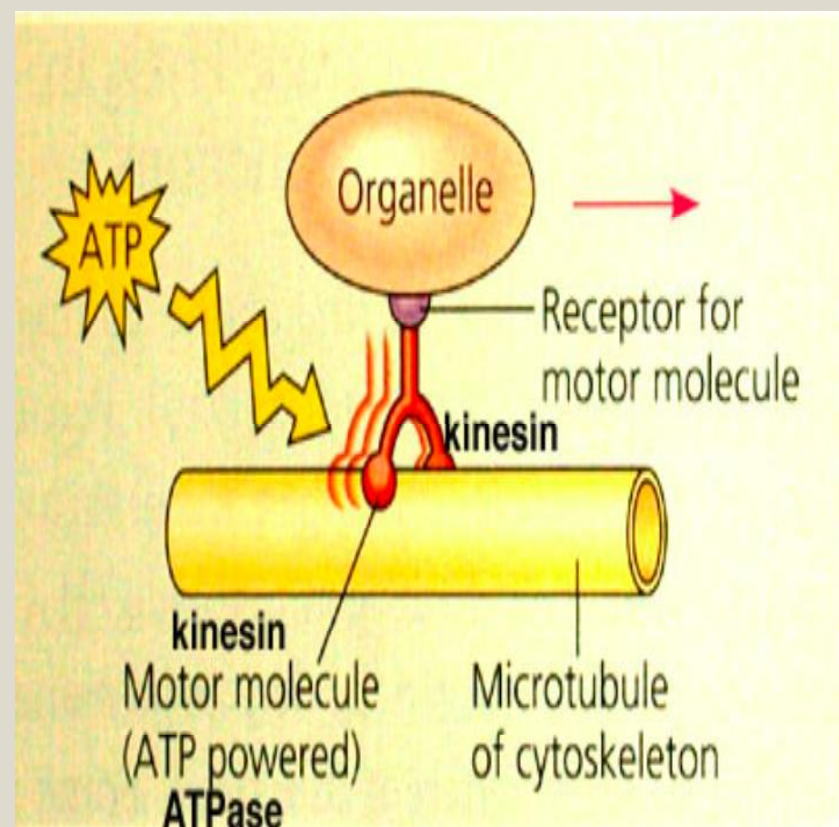
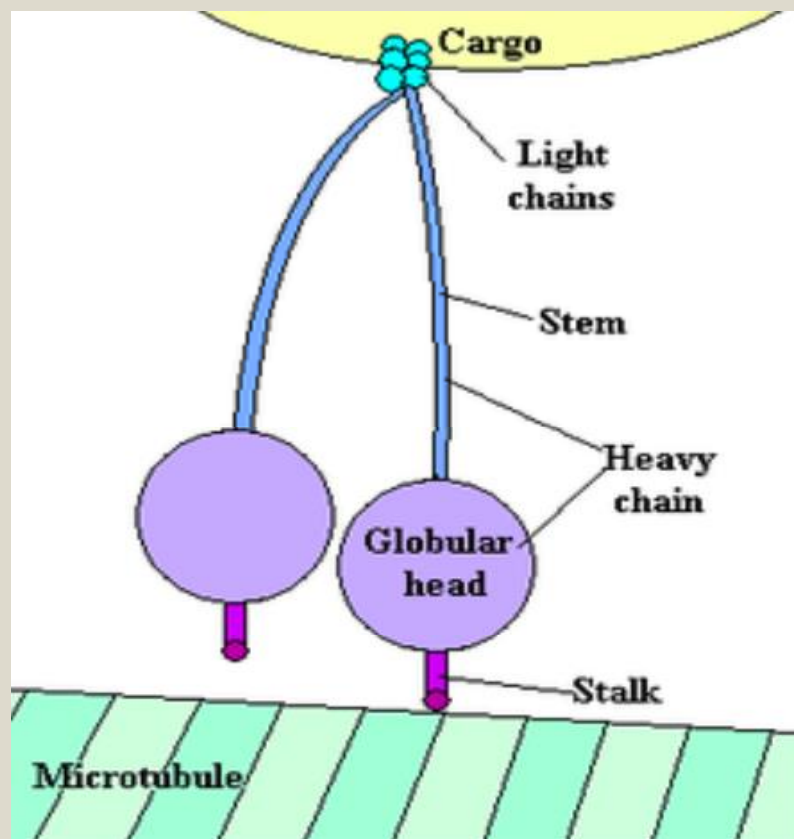
- **Myosin is a diverse superfamily of motor proteins.**
- **Myosin-based molecular machines transport cargoes along actin filaments, the two-stranded helical polymers of the protein actin that are about 5–9 nm in diameter. They do this by hydrolyzing ATP and utilizing the released energy.**
- **In addition to transport, they are also involved in the process of force generation during muscle contraction, wherein thin actin filaments and thick myosin filaments slide past each other.**
- **Myosin molecules were first seen (in the late 1950s) through electron microscope protruding out from thick filaments and interacting with the thin actin filaments. Since that time, ATP has been known to play a role in myosin-related muscle movement along actin; however, the exact mechanism was unknown, until it was explained in 1971.**

Myosin cross-bridge model of contraction. Myosin uses the energy released from ATP hydrolysis to move along actin.



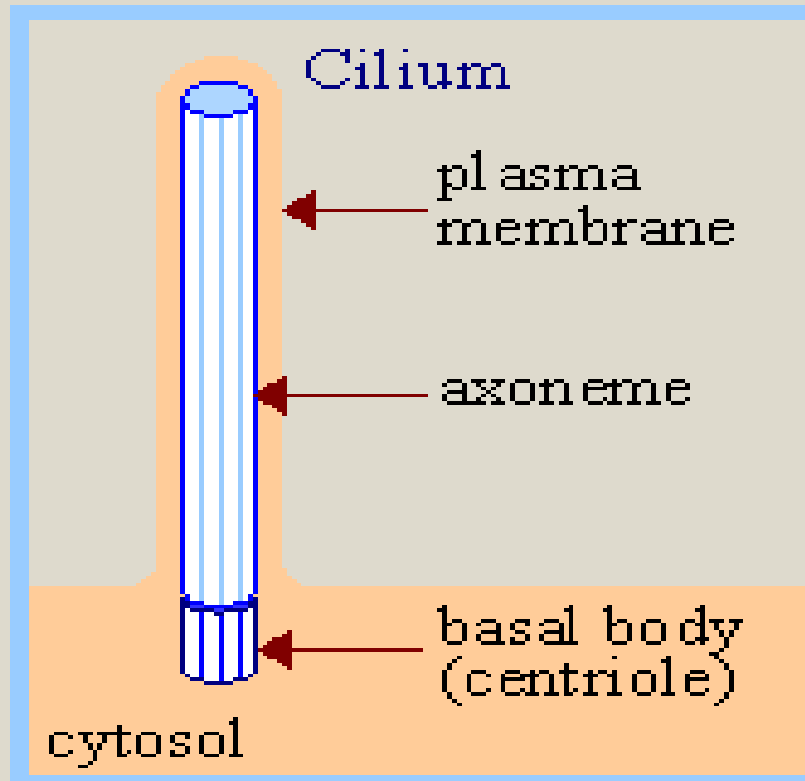
The Kinesin Linear Motor

- **The kinesin and dynein families of proteins are involved in cellular cargo transport along microtubules, in contrast to myosin, which transports along actin.**
- **Microtubules are 25-nm diameter tubes made of protein tubulin and are present in the cells in an organized manner.**
- **Microtubules have polarity; one end being the plus (fast-growing) end while the other end is the minus (slow-growing) end.**
- **Kinesins move from the minus end to the plus end of the microtubule, whereas dyneins move from the plus end to the minus end.**
- **Microtubule arrangement varies in different cell systems. In nerve axons, they are arranged longitudinally such that their plus ends point away from the cell body and into the axon.**
- **In epithelial cells, their plus ends point toward the basement membrane.**
- **They extend radially out of the cell center in fibroblasts and macrophages with the plus end protruding outward.**
- **Similar to myosin, kinesin is also an ATP-driven motor.**
- **One unique characteristic of the kinesin family proteins is their processivity; they bind to microtubules and literally walk on it for many enzymatic cycles before detaching.**



The Dynein Motor

- **The dynein superfamily of proteins was discovered in 1965.**
- **Dyneins exist in two isoforms: cytoplasmic and axonemal.**
- **Cytoplasmic dyneins are involved in cargo movement, whereas axonemal dyneins are involved in producing bending motions of cilia and flagella.**
- **Because dynein is a larger and more complex structure than other motor proteins, its mode of operation is not as well known. However, electron microscopy and image processing was used to show the structure of a flagellar dynein at the start and end of its power stroke, which gives some insight into its possible mode of force generation.**



Cilia and flagella have a core **axoneme**, a complex of microtubules and associated proteins.

Bioremediation

Definition: Use of living organisms to transform, destroy or immobilize contaminants

Goal: Detoxification of the parent compound(s) and conversion to products that are no longer hazardous to human health and the environment.

Sources of Contamination

- Industrial spills and leaks
- Surface impoundments
- Storage tanks and pipes
- Landfills
- Burial areas and dumps
- Injection wells

Why use Bioremediation?

- No additional disposal costs
- Low maintenance
- Does not create an eyesore
- Capable of impacting source zones and thus, decreasing site clean-up time

Microorganisms

- **Aerobic bacteria:**

- Examples include: *Pseudomonas*, *Alcaligenes*, *Sphingomonas*, *Rhodococcus*, and *Mycobacterium*
- Shown to degrade pesticides and hydrocarbons; alkanes and polyaromatics
- May be able to use the contaminant as sole source of carbon and energy.

- **Methanotrophs:**

- Aerobic bacteria that utilize methane for carbon and energy
- Methane monooxygenase has a broad substrate range
 - active against a wide range of compounds (e.g. chlorinated aliphatics such as trichloroethylene and 1,2-dichloroethane)

- **Anaerobic bacteria:**

- Not used as frequently as aerobic bacteria
- Can often be applied to bioremediation of polychlorinated biphenyls (PCBs) in river sediments, trichloroethylene (TCE), and chloroform

- **Fungi:**

- Able to degrade a diverse range of persistent or toxic environmental pollutants

Forms of Bioremediation

- **In situ Bioremediation**

- Bioventing
- In situ biodegradation
- Biostimulation
- Biosparging
- Bioaugmentation
- Natural Attenuation

- **Ex situ Bioremediation**

- Land farming
- Composting
- Biopiles
- Bioreactors

- **Phytoremediation**

- Phytoextraction or phytoaccumulation
- Phytodegradation or phytotransformation
- Phytostabilization
- Rhizodegradation
- Rhizofiltration

In Situ Bioremediation

- **Bioventing**

- One of the most common approaches in soil
- Supply air and nutrients via wells
- Takes advantage of indigenous microorganisms

- **In situ biodegradation**

- Supply air and nutrients by circulating aqueous solutions through contaminated soils or groundwater

- **Biosparging**

- Injection of air below the water table → increases groundwater oxygen concentrations and mixing in saturated zone

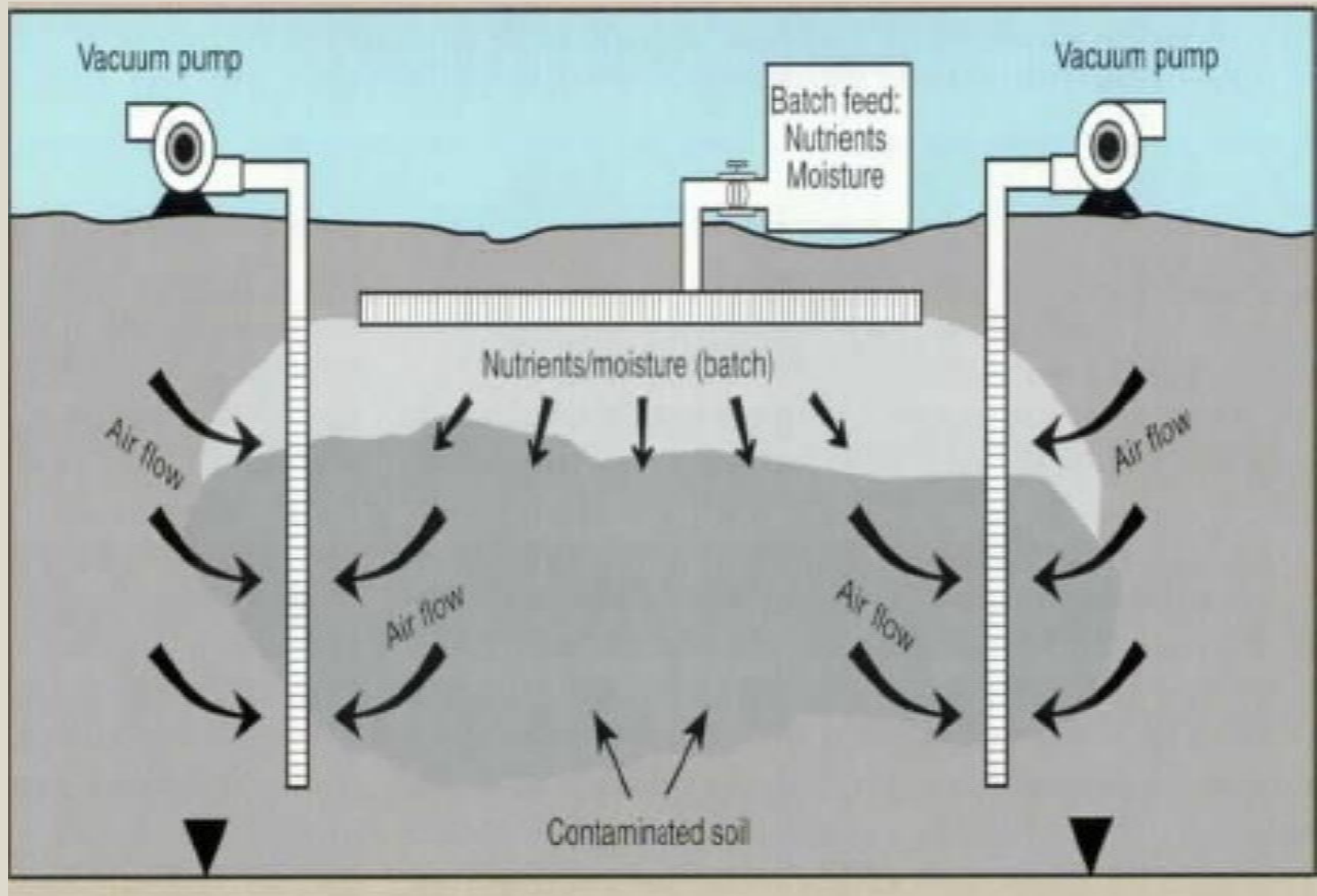
- **Bioaugmentation**

- Addition of indigenous or exogenous microorganisms
- Limits to use: competition and necessity

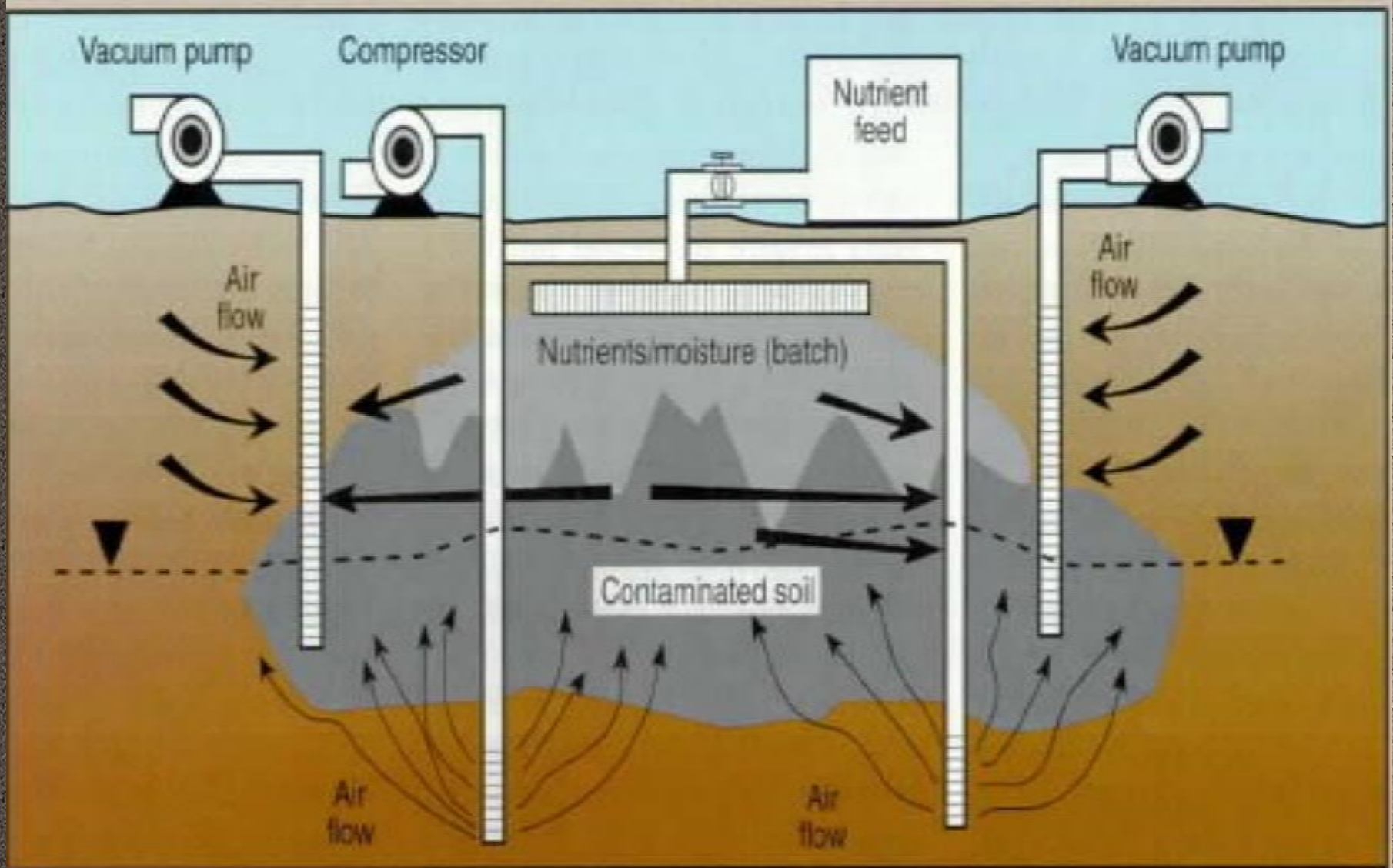
- **Biostimulation**

- **Natural Attenuation or Intrinsic Bioremediation**

Bioventing



Biosparging



Five Steps of In Situ Bioremediation

1. Site investigation
2. Treatability studies
3. Recovery of free product and removal of the contamination source
4. Design and implementation of the in situ bioremediation system
5. Monitoring and performance evaluation of the in situ bioremediation system

Ex situ Bioremediation

Land farming

- Contaminated soil is excavated and spread over land
- Soil is periodically tilled to improve aeration
- Remediation due to indigenous microorganisms, as well as chemical and physical processes
- Generally limited to the superficial 10–35 cm of soil
- Can reduce monitoring and maintenance costs

Composting

- Combines contaminated soil with nonhazardous organic amendants (e.g. manure or agricultural wastes)

Biopiles

- Combination of landfarming and composting
- Control physical losses of contaminants

Bioreactors

- Soil and water pumped up from a contaminated plume and processed through an engineered containment system
- Degradation in a bioreactor is generally greater than *in situ* because the contained environment is more controllable and predictable

Phytoremediation

- **Phytoextraction or phytoaccumulation**

- Plants used to accumulate contaminants in the roots and aboveground biomass
- Can be a relatively low cost option for a large area
- Results in biomass that must be properly disposed of or reused

- **Phytotransformation or phytodegradation**

- Uptake of contaminants and transformation to more stable, less toxic, or less mobile forms
- Eg. metal chromium can be reduced from hexavalent to less mobile (and non-carcinogenic) trivalent chromium

- **Phytostabilization**

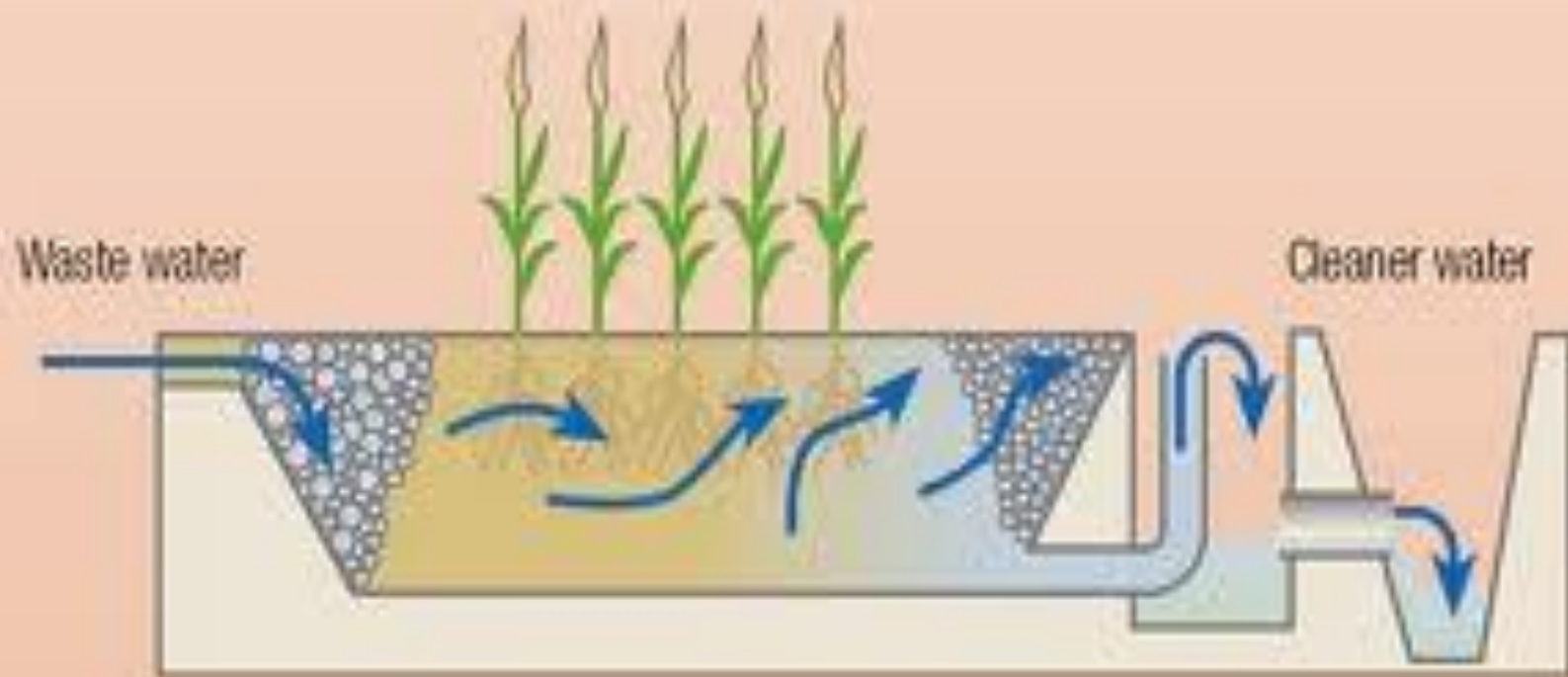
- Mobility and migration of contaminants are reduced through sorption onto or into the plant

- **Rhizodegradation**

- Breakdown of contaminants through activity of the rhizosphere

- **Rhizofiltration**

- Water remediation technique
- Used to reduce contamination in natural wetlands and estuary areas.



Overview of phytoremediation applications.

Technique	Plant mechanism	Surface medium
Phytoextraction	Uptake and concentration of metal via direct uptake into the plant tissue with subsequent removal of the plants	Soils
Phytotransformation	Plant uptake and degradation of organic compounds	Surface water, groundwater
Phytostabilization	Root exudates cause metal to precipitate and become less available	Soils, groundwater, mine tailing
Phytodegradation	Enhances microbial degradation in rhizosphere	Soils, groundwater within rhizosphere
Rhizofiltration	Uptake of metals into plant roots	Surface water and water pumped
Phytovolatilization	Plants evapotranspire selenium, mercury, and volatile hydrocarbons	Soils and groundwater
Vegetative cap	Rainwater is evapotranspired by plants to prevent leaching contaminants from disposal sites	Soils

Mechanism of Bioremediation

- Conversion of contaminants to mineralized (e.g. CO₂, H₂O, and salts) end-products via biological mechanisms
- Biotransformation refers to a biological process where the end-products are not minerals.
- Biodegradation involves the process of extracting energy from organic chemicals via oxidation of the organic chemicals

How Microbes Use the Contaminant

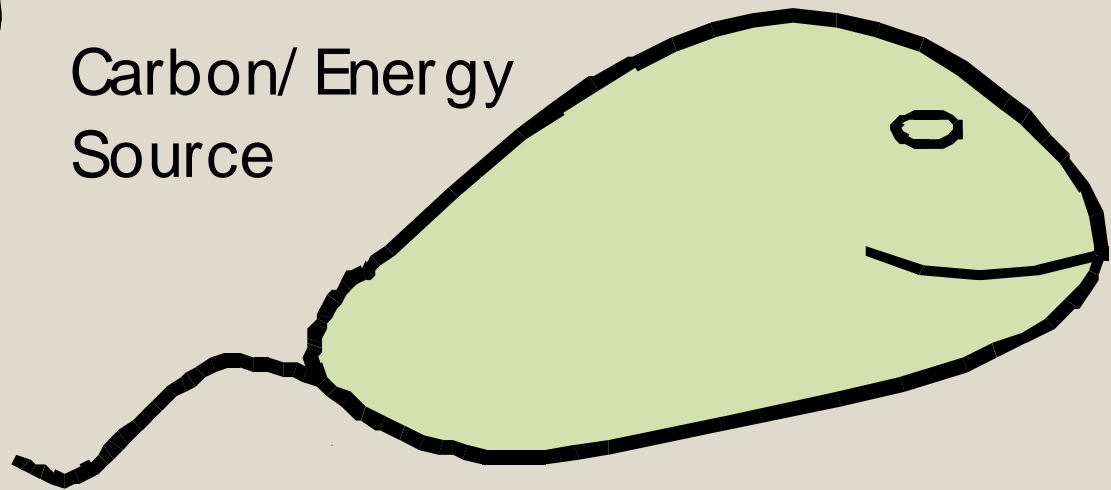
- Contaminants may serve as:
 - Primary substrate
 - enough available to be the sole energy source
 - Secondary substrate
 - provides energy, not available in high enough concentration
 - Cometabolic substrate
 - fortuitous transformation of a compound by a microbe relying on some other primary substrate

Requirements for Microbial Growth



Electron Acceptor
(O_2 , NO_3^- , SO_4^{2-} , et c.)

Carbon/ Energy
Source



Environmental
Conditions
(Temp, pH, Eh)

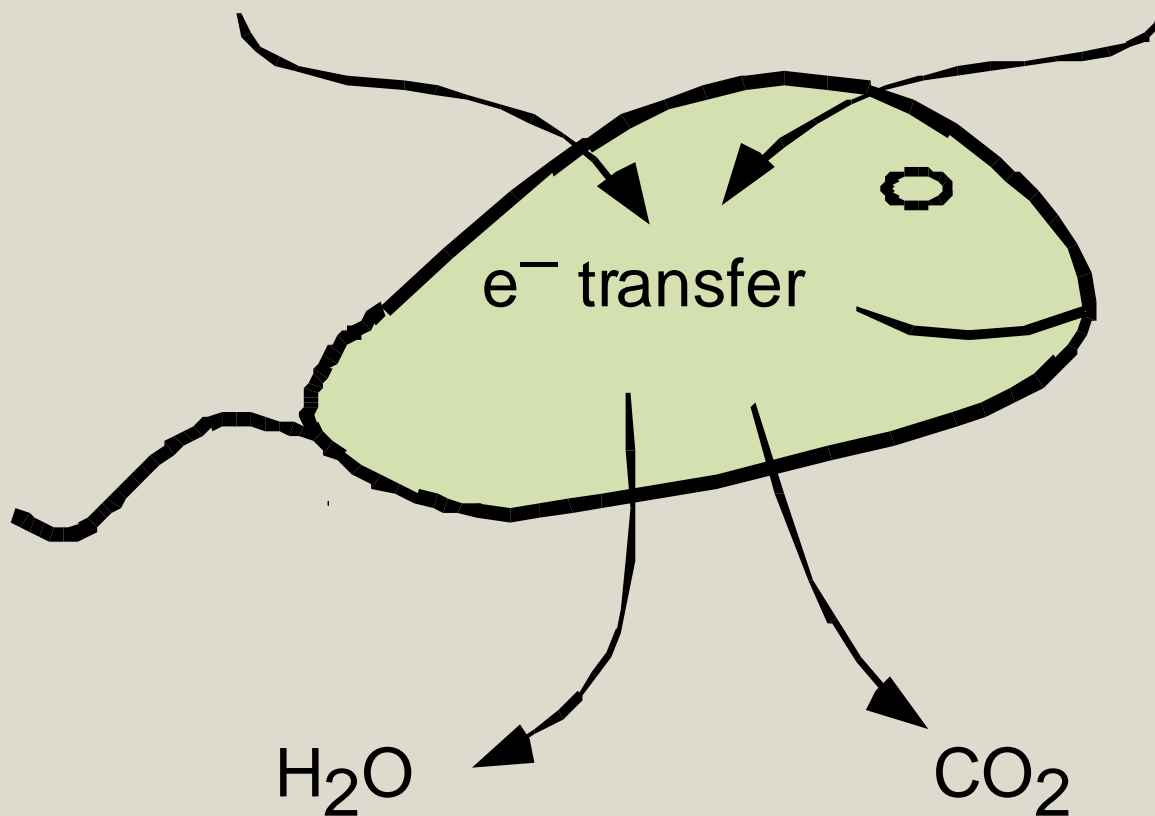
Nutrients (N, P)

Trace Elements

Electron Exchange

Electron Acceptor
(O_2 , NO_3^- , SO_4^{2-} , etc.)

Carbon/Energy Source
Electron Donor



Aerobic vs Anaerobic biodegradation

Aerobic biodegradation

- If oxygen is the terminal electron acceptor, the process is called aerobic biodegradation

Anaerobic biodegradation

- All other biological degradation processes are classified as anaerobic biodegradation

Environmental Factors

Environmental conditions affecting degradation.

Parameters	Condition required for microbial activity	Optimum value for an oil degradation
Soil moisture	25–28% of water holding capacity	30–90%
Soil pH	5.5–8.8	6.5–8.0
Oxygen content	Aerobic, minimum air-filled pore space of 10%	10–40%
Nutrient content	N and p for microbial growth	C:N:P = 100:10:1
Temperature (°C)	15–45	20–30
Contaminants	Not too toxic	Hydrocarbon 5–10% of dry weight of soil
Heavy metals	Total content 2000 ppm	700 ppm
Type of soil	Low clay or silt content	

Summary

Summary of bioremediation strategies.

Technology	Examples	Benefits	Limitations	Factors to consider
<i>In situ</i>	<i>In situ</i> bioremediation Biosparging Bioventing Bioaugmentation	Most cost efficient Noninvasive Relatively passive Natural attenuation processes Treats soil and water	Environmental constraints Extended treatment time Monitoring difficulties	Biodegradative abilities of indigenous microorganisms Presence of metals and other inorganics Environmental parameters Biodegradability of pollutants Chemical solubility Geological factors Distribution of pollutants
<i>Ex situ</i>	Landfarming Composting Biopiles	Cost efficient Low cost Can be done on site	Space requirements Extended treatment time Need to control abiotic loss Mass transfer problem Bioavailability limitation	See above

BIOSENSOR

What is a Biosensor?

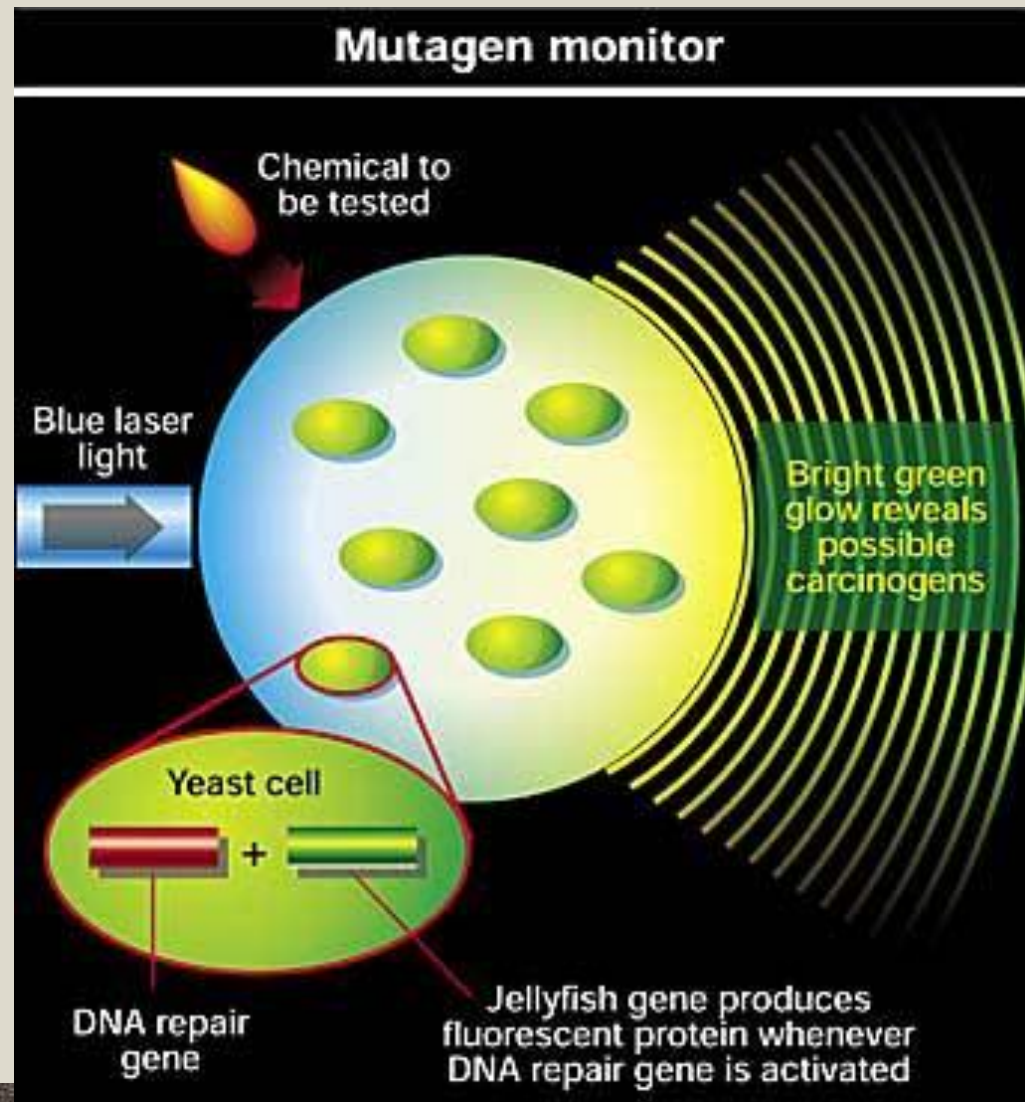
A biosensor is a self-contained integrated device that is capable of providing specific quantitative or semi-quantitative analytical information using a biological recognition element which is in direct spatial contact with a transduction element (IUPAC, 1996)



1) Biosensor \neq Bioanalytical system

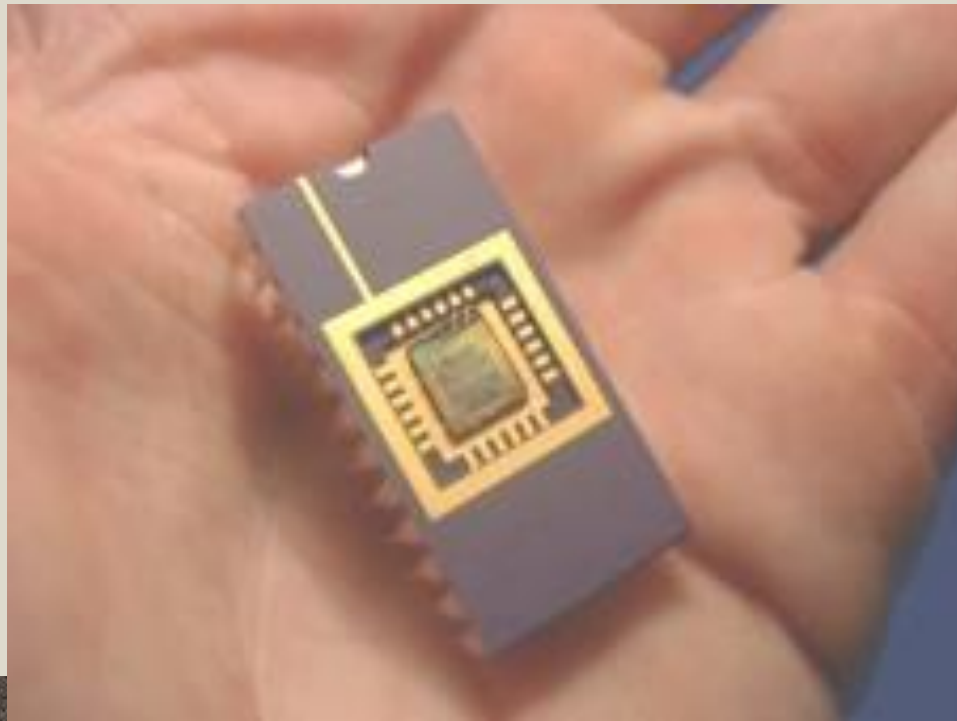
2) An enzyme electrode is a biosensor

“Biosensor” – Any device that uses specific biochemical reactions to detect chemical compounds in biological samples.

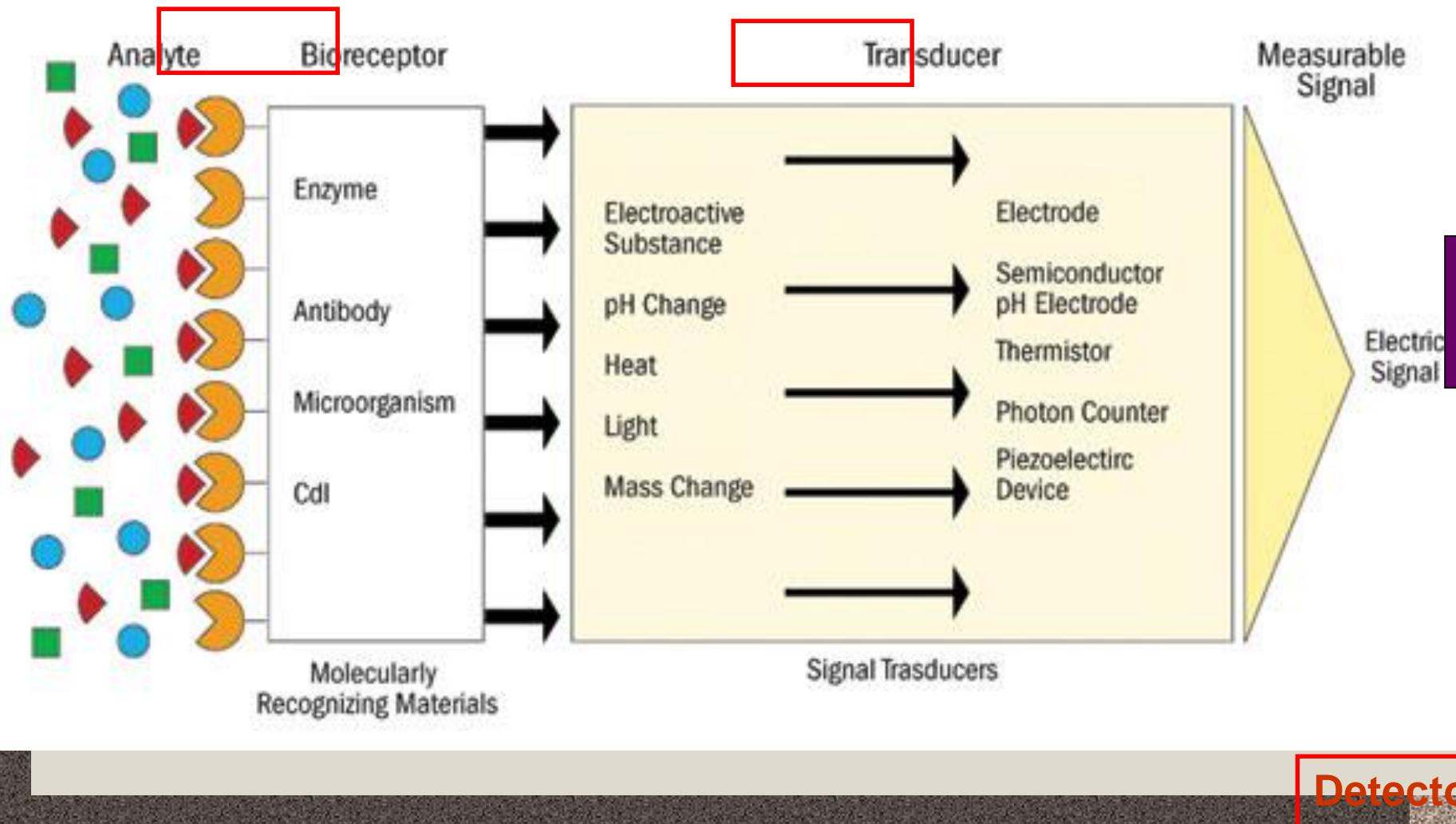


Current Definition

A sensor that integrates a biological element with a physiochemical transducer to produce an electronic signal proportional to a single analyte which is then conveyed to a detector.



Components of a Biosensor



History of Biosensors

- **1916** **First report on immobilization of proteins : adsorption of invertase on charcoal** **activated**
- **1922** **First glass pH electrode**
- **1956** **Clark published his definitive paper on the oxygen electrode.**
- **1962** **First description of a biosensor: an amperometric enzyme electrode for (Clark)** **glucose**
- **1969** **Guilbault and Montalvo – First potentiometric biosensor:urease on an ammonia** **immobilized electrode to detect urea**

History of Biosensors

- 1970 Bergveld – ion selective Field Effect Transistor (ISFET)
- 1975 Lubbers and Opitz described a fibre-optic sensor with immobilised indicator to measure carbon dioxide or oxygen.
- 1975 First commercial biosensor (Yellow springs Instruments glucose biosensor)
- 1975 First microbe based biosensor, First immunosensor
- 1976 First bedside artificial pancreas (Miles)
- 1980 First fibre optic pH sensor for in vivo blood gases (Peterson)
- 1982 First fibre optic-based biosensor for glucose
- 1983 First surface plasmon resonance (SPR) immunosensor
- 1984 First mediated amperometric biosensor: ferrocene used with glucose oxidase for glucose detection

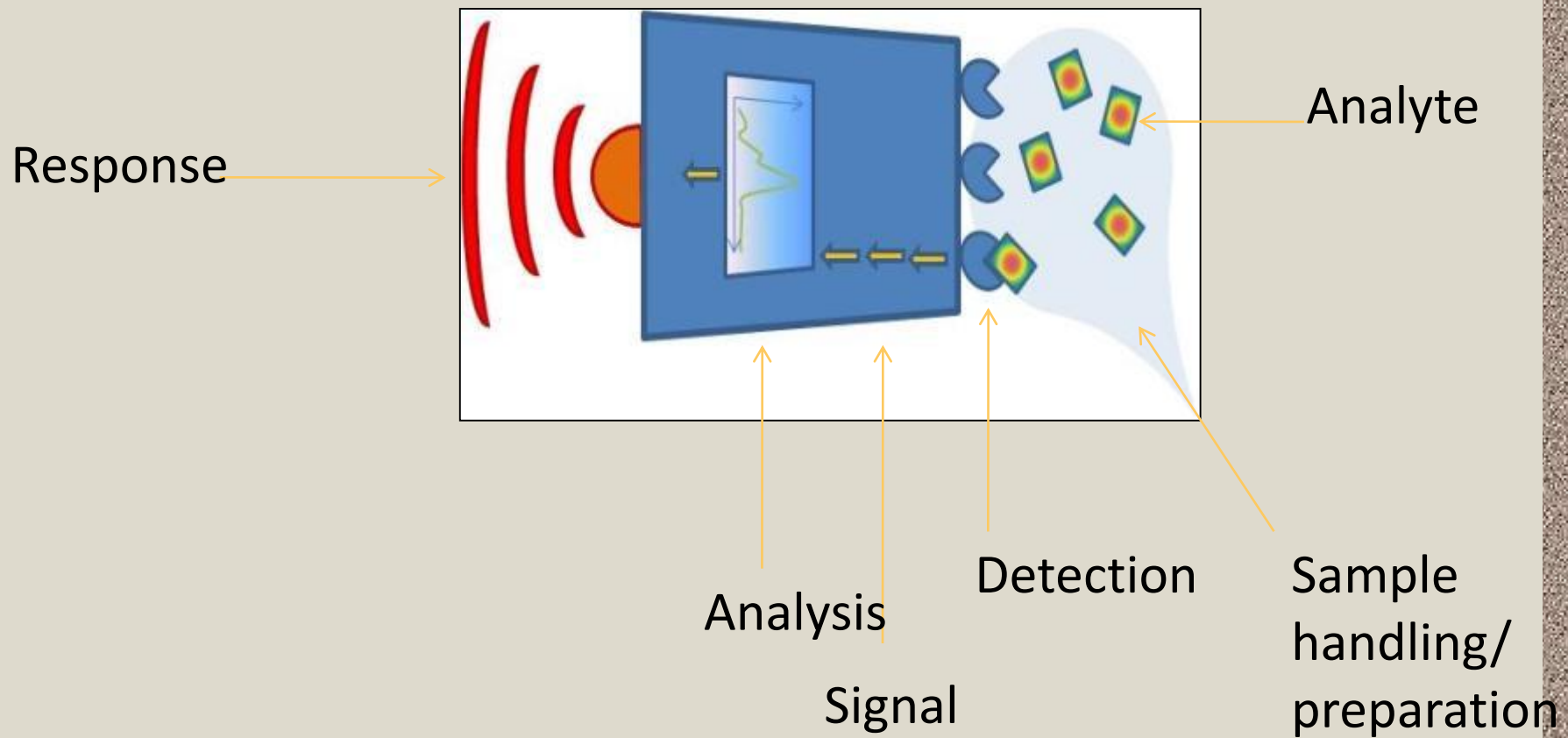
History of Biosensors

- **1987** **Blood-glucose biosensor launched by MediSense ExacTech**
- **1990** **SPR based biosensor by Pharmacia BIACore**
- **1992** **Hand held blood biosensor by i-STAT**
- **1996** **Launching of Glucocard**
- **1998** **Blood glucose biosensor launch by LifeScan FastTake**
- **1998** **Roche Diagnostics by Merger of Roche and Boehringer mannheim**
- **Current** **Quantom dots, nanoparicles, nanowire, nanotube, etc**

Basic Characteristics of a Biosensor

- 1. LINEARITY** Linearity of the sensor should be high for the detection of high substrate concentration.
- 2. SENSITIVITY** Value of the electrode response per substrate concentration.
- 3. SELECTIVITY** Chemicals Interference must be minimised for obtaining the correct result.
- 4. RESPONSE TIME** Time necessary for having 95% of the response.

Biosensor



Biosensor

1. The Analyte (What do you want to detect)

Molecule - Protein, toxin, peptide, vitamin, sugar, metal ion

2. Sample handling (How to deliver the analyte to the sensitive region?)

*(Micro) fluidics - Concentration increase/decrease),
Filtration/selection*

Biosensor

❖3. Detection/Recognition

(How do you specifically recognize the analyte?)

4. Signal

(How do you know there was a detection)

Example of biosensors



Pregnancy test

Detects the hCG protein in urine.



Glucose monitoring device (for diabetes patients)

Monitors the glucose level in the blood.

Example of biosensors

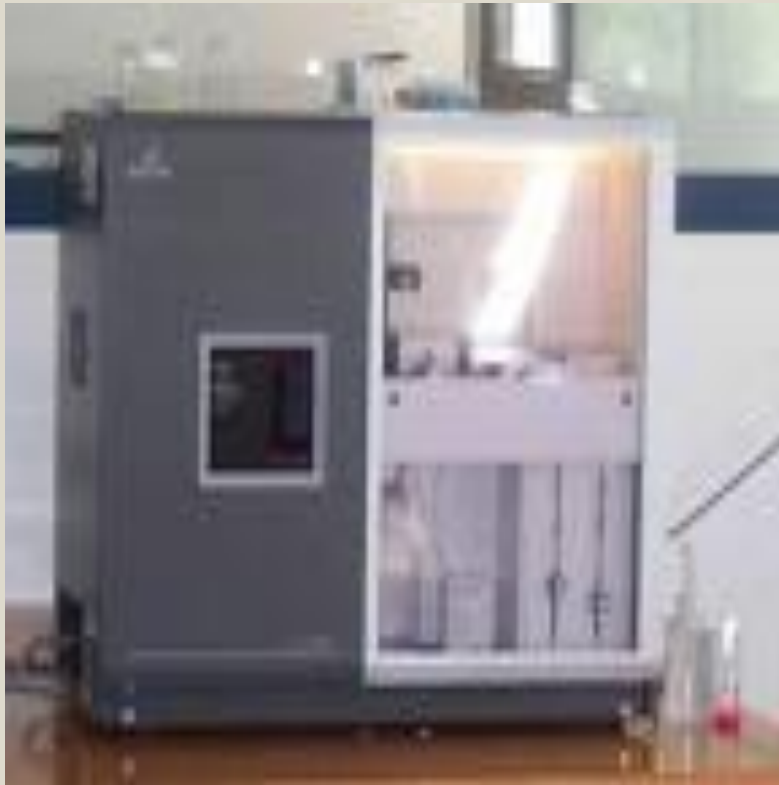


**Infectious disease
biosensor from RBS**



Old time coal miners' biosensor

Research Biosensors



Biacore Biosensor platform

Typical Sensing Techniques for Biosensors

- ✓ **Fluorescence**
- ✓ **DNA Microarray**
- ✓ **SPR Surface plasmon resonance**
- ✓ **Impedance spectroscopy**
- ✓ **SPM (Scanning probe microscopy, AFM, STM)**
- ✓ **QCM (Quartz crystal microbalance)**
- ✓ **SERS (Surface Enhanced Raman Spectroscopy)**
- ✓ **Electrochemical**

Types of Biosensors

- 1. Calorimetric Biosensor**
- 2. Potentiometric Biosensor**
- 3. Amperometric Biosensor**
- 4. Optical Biosensor**
- 5. Piezo-electric Biosensor**

Piezo-Electric Biosensors

Piezo-electric devices use gold to detect the specific angle at which electron waves are emitted when the substance is exposed to laser light or crystals, such as quartz, which vibrate under the influence of an electric field.

The change in frequency is proportional to the mass of absorbed material.

Electrochemical Biosensors

- **For applied current: Movement of e^- in redox reactions detected when a potential is applied between two electrodes.**

Potentiometric Biosensor

- **For voltage: Change in distribution of charge is detected using ion-selective electrodes, such as pH-meters.**

Optical Biosensors

- Colorimetric for color

Measure change in light adsorption

- Photometric for light intensity

Photon output for a luminescent or fluorescent process can be detected with photomultiplier tubes or photodiode systems.

Calorimetric Biosensors

If the enzyme catalyzed reaction is exothermic, two thermistors may be used to measure the difference in resistance between reactant and product and, hence, the analyte concentration.

Electrochemical DNA Biosensor

- **Steps involved in electrochemical DNA hybridization biosensors:**
 - **Formation of the DNA recognition layer**
 - **Actual hybridization event**
 - **Transformation of the hybridization event into an electrical signal**

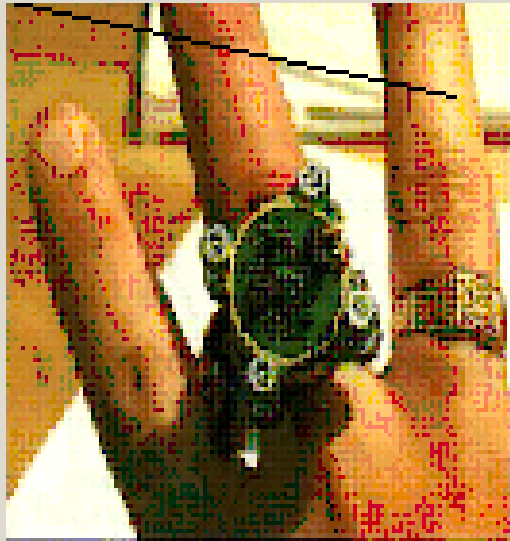
DNA biosensor

Motivated by the application to clinical diagnosis and genome mutation detection

Types DNA Biosensors

- Electrodes
- Chips
- Crystals

Wearable Biosensors



Smart Shirt

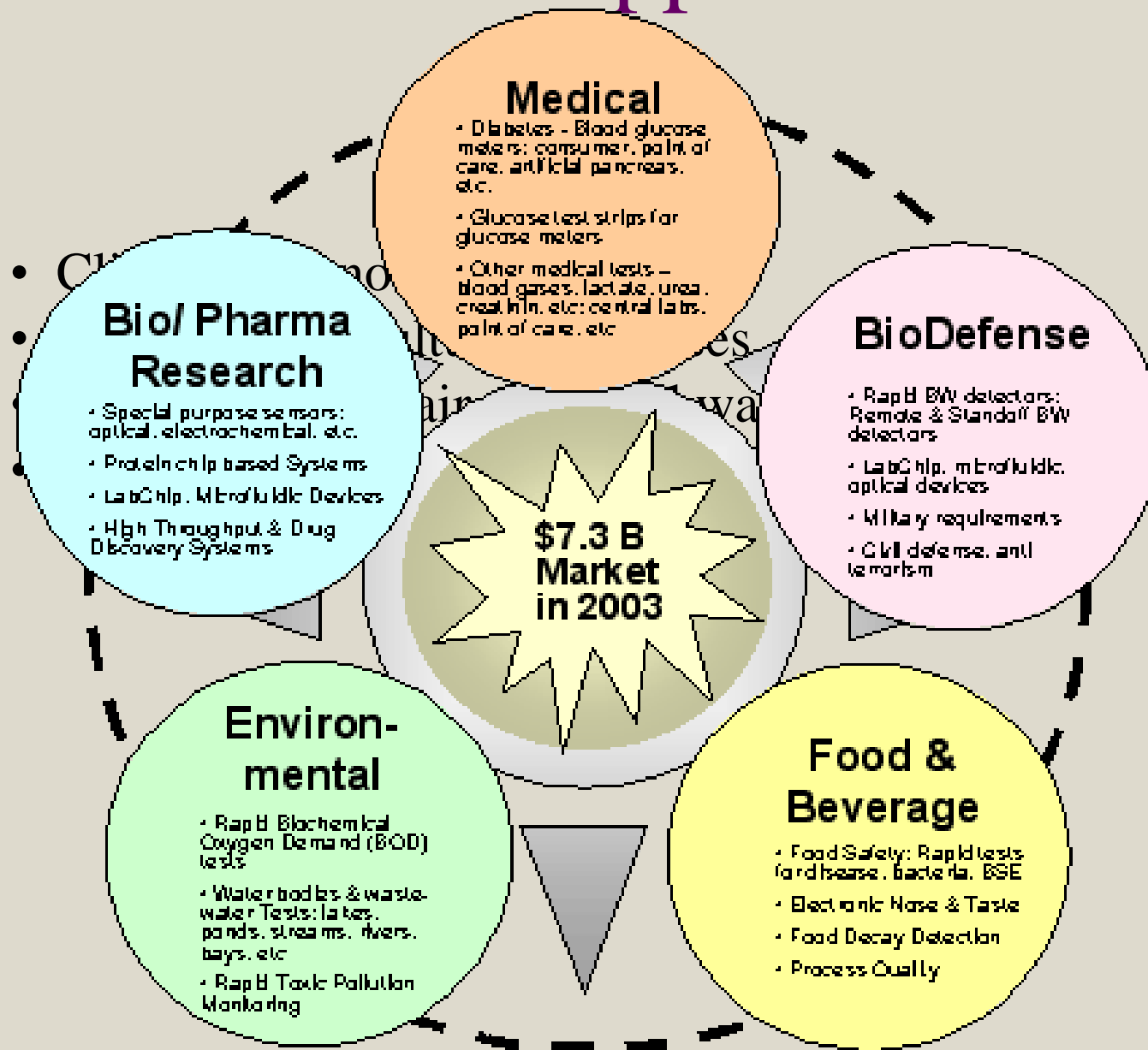
Ring Sensor



Biosensors on the Nanoscale

- ❑ Molecular sheaths around the nanotube are developed that respond to a particular chemical and modulate the nanotube's optical properties.
- ❑ A layer of olfactory proteins on a nanoelectrode react with low-concentration odorants (SPOT-NOSED Project). Doctors can use to diagnose diseases at earlier stages.
- ❑ Nanosphere lithography (NSL) derived triangular Ag nanoparticles are used to detect streptavidin down to one picomolar concentrations.
- ❑ The School of Biomedical Engineering has developed an anti-body based piezoelectric nanobiosensor to be used for anthrax, HIV hepatitis detection.

Potential Applications



Application of Biosensor

- ❖ **Food Analysis**
- ❖ **Study of biomolecules and their interaction**
- ❖ **Drug Development**
- ❖ **Crime detection**
- ❖ **Medical diagnosis (both clinical and laboratory use)**
- ❖ **Environmental field monitoring**
- ❖ **Quality control**
- ❖ **Industrial Process Control**
- ❖ **Detection systems for biological warfare agents**
- ❖ **Manufacturing of pharmaceuticals and replacement organs**

- **Biosensors play a part in the field of environmental quality, medicine and industry mainly by identifying material and the degree of concentration present**