Resources for energy production
Dissimilation of nutrients

- **Bioenergetics: the study of energy in organisms**
  - Energy flows into, through and out of cells
  - Nutrients are used to generate energy but these nutrients do not form cell components – dissimilation
- **Sources of energy and its use in microorganisms**
- **Utilisation of redox power in microorganisms**
  - **N**icotinamide **A**denine **D**inucleotide (phosphate)
- **Utilisation of high energy phosphate bonds in microorganisms**
  - **A**denosine **T**ri**P**hosphate
  - Mechanisms to generate ATP in microorganisms

Sources of energy for microorganisms

Cells may capture energy from external sources via

- **Respiration and fermentation**
  - Catabolism of organic compounds: Oxidation
  - Lithotrophy of inorganic compounds: Oxidation
- **Photosynthesis** (photophosphorylation in sunlight)

Free energy $\triangle G^o$ (KJ mole^{-1})

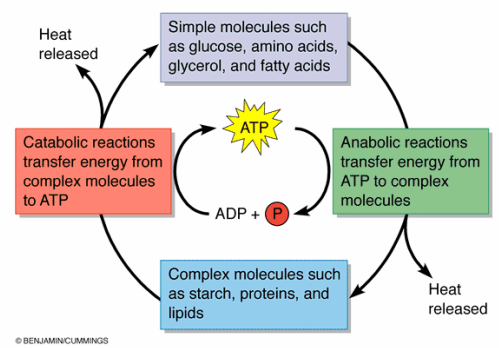
- **Negative $\triangle G^o$ released in exergonic reactions,**
  - spontaneous, energy releasing reactions in the breakdown of bonds
    e.g. catabolism, oxidation, electron transport chains (ETCs) in respiration, lithotrophy and photophosphorylation
- **Positive $\triangle G^o$ absorbed in endergonic reactions,**
  - input of energy to form chemical bonds
    e.g. anabolism (reduction of organic compounds in biosynthesis), flagella motion, nutrient transport through plasma membranes

Use of energy in microorganisms

1. **Cells transfer captured energy by**
   - phosphorylation (dehydration) of metabolites *e.g.* glucose and AMP/ADP
     » dehydration
   - reduction of NAD/NADP → NADH + H or NADPH + H
     » during catabolism, photosynthesis, lithotrophy
2. **Cell stores energy as**
   - ATP, ADP, "high energy" phosphorylated compounds, (storage polymers)
3. **In anabolism, the cell uses energy to form organic chemical bonds by**
   - de-phosphorylation (hydrolysis) of ATP, ADP, "high energy" phosphorylated compounds
   - oxidation of NADH + H+ or NADPH + H+ → NAD or NADP

Use of energy in microorganisms 2

4. **To biosynthesize**
   - sugars, polysaccharides, amino acids, peptides, proteins, RNA, DNA, fatty acids, glycerol, lipids → cell components, storage compounds



Nicotinamide Adenine Dinucleotide (P)

- Associated with proton and electron/energy transfer during redox reactions in cell *viz.* dehydrogenation
  - Freely diffusable in cytoplasm between associated enzymes
  - Associated enzymes - 'dehydrogenases'
- Energy captured as 'reducing power' by
  - $NAD^+ \rightarrow NADH + H^+$ (reduction) in catabolism, lithotrophy
  - $NADP^+ \rightarrow NADPH + H^+$ in photosynthesis
- Cycles between being
  - reduced during oxidation of substrates during catabolism and lithotrophy, or photosynthesis
  - oxidised during reduction of substrates during anabolism, or of respiratory electron transport chain components

Utilisation of 'reducing power' in microorganisms

Coupled redox reactions transfer reducing power energy from

- Catabolism of organic nutrient compounds
- photosynthetic harvesting of light energy via NADH/NADPH
- Lithotrophic oxidation of inorganic compounds

Directly

- via $NAD^+/NADH+H^+$ from catabolism (Glycolysis) or lithotrophy
- via $NADP^+/NADPH+H^+$ from photosynthesis

Indirectly

- Through redox coupled reactions of components in electron transport chains from
  - Light energy captured initially by chlorophyll (photosynthesis)
  - Oxidative energy captured by initially NADH (respiration or lithotrophy)

Utilisation of high energy phosphate bonds in microorganisms: Adenosine TriPhosphate (ATP)

- Related energy storage compounds:

  ATP ←→ ADP + Pi ←→ AMP + Pi
- Hydrolysis (addition of H_2O) of ATP and/or ADP in reactions transfers energy from high energy phosphate bond to
  - new organic bond
  - use in movement or nutrient transport
- Other, but not all, PO_4~lated compounds may also transfer energy in reactions
  e.g. glucose-6-phosphate

Mechanisms to generate ATP in microorganisms

Phosphorylation (addition of Pi; dehydration process)

1. Substrate Level Phosphorylation

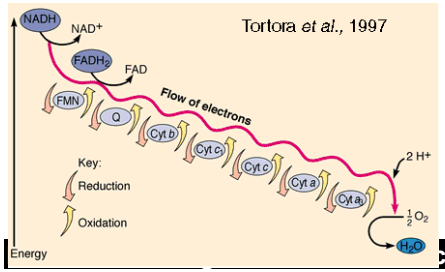
- Part of catabolic pathways close to internal plasma membranes
- Pre-phosphorylated organic compound is oxidised
  Transfer of energy as ~P
  - to AMP → ADP or ADP → ATP
  - directly from pre-phosphorylated organic substrate
    - *e.g.* glycolysis and TCA cycle; fermentation
- ADP/ATP immediately available for energy transfer in anabolic reactions
  - Major source of energy from fermentation
  - Minor source of energy from glycolysis and TCA cycle

2. Oxidative Phosphorylation

Chemiosmotic Mechanism of ATP generation

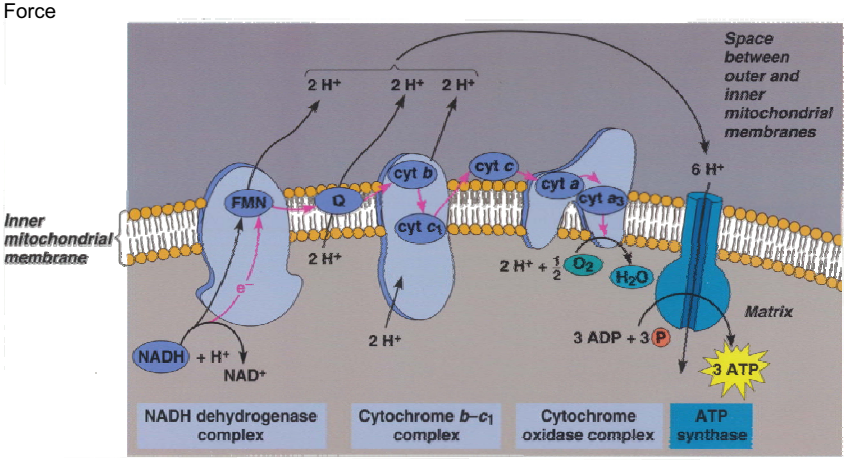
Two structures within plasma membranes of prokaryotes; mitochondria in eukaryotes:

a. Electron Transport Chains (ETC)
(a series of respiratory or lithotrophic redox couples and their enzymes)



- electrons and protons donated to ETC from NADH + H^+ from catabolism (respiration) or direct oxidation of inorganic compounds (lithotrophy)
- electrons are sequentially accepted by redox couples to final acceptor outside membrane *e.g.* O_2, NO_3

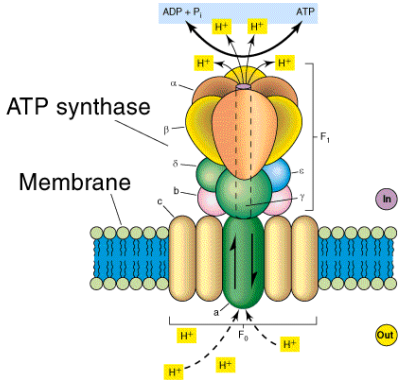
- transfer of H^+ from inside membrane to outside generates proton gradient, the Proton Motive Force



Electron transport and chemiosmotic generation of ATP (Tortora *et al.*, 1997)

b. Membrane bound ATPase (enzyme) at F_0/F_1 site

- Controlled re-entry of protons at site energises phosphorylation of ADP with Pi.
- major source of ATP from glycolysis; 1 ATP per 2 H^+



P/O ratio
3 ATP in eukaryotes
1 to 3 in bacteria (varies with components of ETC)

P = PO_4 incorporation into ATP
O = oxygen uptake (number of electron pairs down the ETC)

3. Photophosphorylation

- Energy from light transferred to both $NADP^+$ and ADP via electron transport chain in thylakoid membranes, attached to inside of plasma membranes of phototrophic prokaryotes (chloroplasts/ eukaryotes)
- Two types:

a. Anoxygenic (cyclic) Photophosphorylation

- found in green and purple sulphur and non-sulphur bacteria
- cyclic electron donated from component of ETC and returns to ETC
- ADP phosphorylated directly from photosynthesic ETC

b. Oxygenic (non-cyclic) Photophosphorylation

- found in cyanobacteria and algae
- electron donated to ETC from oxidation of water, releasing O_2
  - (finally accepted by NADP and reduced to NADPH)
  - ADP phosphorylated directly from ETC of photosynthesis