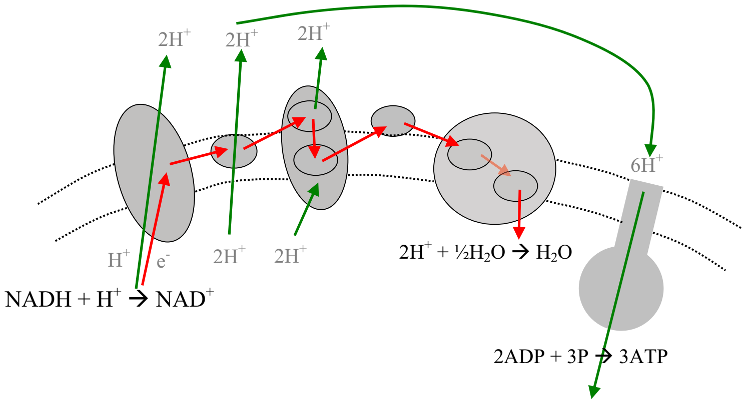
Aerobic/Anaerobic Respiration

Respiration

Generation of Proton Motive Force (via catalytic reactions) created by the transfer of protons across the plasma membrane to the exterior, and transfer of electrons in an electron transport chain to an external terminal electron acceptor



The physical chemistry of electron transfer

Oxidation-reduction (redox) reactions

Electron donor; becomes oxidized

$H_2 \rightarrow 2e^- + 2H^+$ (oxidation half-reaction)

needs to be coupled with a reduction half-reaction *e.g.*

$½O_2 + 2e^- + 2H^+ \rightarrow H_2O$ (reduction half-reaction)

Electron acceptor; becomes reduced

Redox

Reduction potential (E_o')

The tendency to become either reduced or oxidized

At pH 7

E_o' for $H_2 \rightarrow 2e^- + 2H^+$ is –0.421 volts

E_o' for $½O_2 + 2e^- + 2H^+ \rightarrow H_2O$ is +0.816 volts

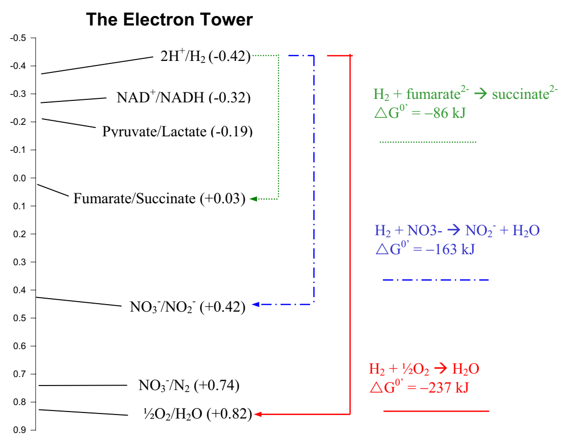
Redox couples

oxidized form • reduced form

Couple	$E^{o}{}'$
$2H^+/H_2$	-0.421 V
$½O_2/H_2O$	+0.816 V

The more negative the E_o' the more the tendency to donate electrons
The positive the E_o' the more the tendency to accept electrons

$\triangle G^{0}{}'$ (free energy) and E_o'



- Strong reductants at the top of the tower
- Strong oxidants at the bottom of the tower
- Electron transfer moves exergonically from more negative to more positive *Eo'* couples

Electron transport chains in microbes

Series of linked redox couples move electrons from compounds with more negative E_o' to those with less negative E_o'

- **Found the plasma membrane of prokaryotes and mitochondria of eukaryotes**
- **Contain**
  - Primary electron donor *e.g.* NADH
  - Flavoproteins, cytochromes, ferredoxins, quinones (redox couples)
  - NADH dehydrogenases and electron transfer enzymes
  - Terminal electron acceptor *e.g.* O_2; NO_3^-

Electron transport chains in microbes 2

- **Transport e^- and H^+ between energy sources and energy storage or biosynthesis**
  - Respiratory ETC: from catabolism to oxidative phosphorylation of ADP
  - Photosynthetic ETC: from light source to phosphorylation of ADP and/or oxidation of $NADP^+$ to NADPH
  - Lithotrophic ETC: from inorganic compounds to reduce NAD^+ to NADH
- **Movement of protons and electrons/ATP production**
  - Electron and protons may enter ETC at different stages from *e.g.* NADH, FADH, lactate
  - Protons excreted at various stages of chain
  - Electrons transferred to external acceptors via oxidases/reductases creates Proton Motive Force to phosphorylate ADP

Respiratory Electron Transport Chains

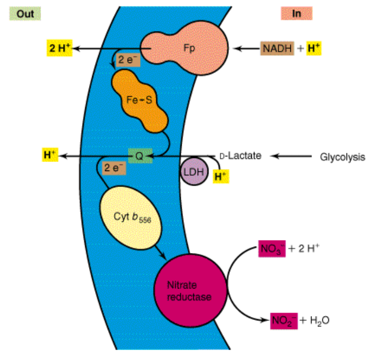
- **Two types of respiration**
  - **Aerobic:** When only O_2 is the external, terminal electron acceptor
  - **Anaerobic:** External, terminal e^- acceptors other than O_2

Aerobes and anaerobes using respiration

- **Aerobes**
  - Only O_2 as terminal, external e^- acceptor
  - have cytochrome oxidase as terminal enzyme in the ETC
  - need to protect cell against oxidation by superoxide (O_2^-), H_2O_2, hydroxyl radicals (by-products of reduction of O_2 to H_2O in respiration)
    - superoxide dismutase, catalase, peroxidase
- **Facultative anaerobes and strict anaerobes**
  - Have other than O_2 as terminal, external e^- acceptor
  - Have no cytochrome oxidase; other terminal enzyme
    - *e.g.* nitrate reductase, nitrite reductase
- **Various kinds of anaerobic respiration processes**
  - Various external terminal electron acceptors
    - nitrate, sulphate, CO_2 , fumarate
  - Reducing power differentials: more negative = more anaerobic

Anaerobic respiration with nitrate reduction

- **Nitrate**
  - assimilated to organic N by aerobic heterotrophs under aerobic conditions
    - *e.g.* into amino acids and used for growth
  - dissimilated by denitrifying bacteria for energy
    - used for energy production in respiration to form nitrite and products returned to environment
- **Dissimilatory nitrate reductase**
  - enzyme biosynthesis repressed by O_2, synthesised under anoxia
- **Further reduction of NO_2^- by series of various nitrogen reductases in different bacteria**
  - Denitrification in soil, water, effluent
    $NO_2^- \rightarrow N_2O \rightarrow NH_3 \rightarrow N_2$
  - Nitrogen lost to organisms for assimilation



Anaerobic Respiration:
Other terminal electron acceptors

- **Sulphate**
  - oxidised to organic S compounds *e.g.* methionine, (assimilation) concurrently with
  - reduction (dissimilation) to sulphite, H_2S generates ATP
  - Specialised electron transport chains
  - electrons donated from acetate, H_2, lactate, not glycolysis and TCA cycle
- **Organic electron acceptors**
  - CO_2 reduced in methanogens to methane and in homoacetogens to acetate
  - Fumarate → succinate; trimethylamine oxide → trimethylamine
- **Nutrient cycling in the environment**
  - Reduction of nutrients is anaerobic part of biogeochemical cycles of elements

Energy Production from Respiration

- **Proton/Oxygen (P/O) ratios**
  - moles of ATP per atom of O_2 utilised (aerobes)
  - also relates to moles of ATP per 2 protons excreted by ETC
  - depends on stage at which protons/electrons enter ETC
  - often P/O ratio = 3 (aerobes) but may only be 1 - 2 in strict anaerobes and facultative anaerobes
- **Calculations based on oxidation of NADH + H^+ via aerobic respiration:**
  - $2e^-$ transferred through ETC to ½O_2 (1 atom O)
  - 3 × $2H^+$ excreted for each transfer of electron pair
  - $2H^+$ + ½O_2 → H_2O external to membrane
  - $3H^+$ used to produce 3 ATP; $3H^+$ released to environment

Energy Production from Catabolism

- **Substrate level phosphorylation of ADP**
  - ADP + Pi → ATP directly during oxidation of organic substrate
  - Of lesser importance as source of energy in respiratory dependent micoorganisms
  - Occurs in
    - EMP, Entner-Doudoroff, Phosphoketolase Pathways not Pentose Phosphate Pathway
    - TCA cycle with GDP → GTP / ADP → ATP
- **Oxidative Phosphorylation of ADP: Respiration**
  - ATP generated from Proton Motive Force
  - Of greater importance as source of energy in respiratory dependent microorganisms
  - Occurs as a result of all glycolytic pathways and TCA cycle (NADH + H/FADH + H)

Energy Production from Catabolism 2

- **ATP yield from aerobic catabolism of one glucose molecule**
  Based on P/O ratio = 3 for NADH; 2 for $FADH_2$ (in oxidative phosphorylation)

Glycolytic pathway	
Substrate level phosphorylation	2 ATP
Oxidative phosphorylation with 2 NADH	6 ATP
2 pyruvate to 2 acetyl-CoA	
Oxidative phosphorylation with 2 NADH	6 ATP
Tricarboxylic acid cycle	
Substrate level phosphorylation (GTP)	2 ATP
Oxidative phosphorylation with 6 NADH	18 ATP
Oxidative phosphorylation with 2 $FADH_2$	4 ATP
Total aerobic yield	**38 ATP**

Identification of various respiratory types

- **(Cytochrome) Oxidase test**
  - **Positive reaction** identifies organisms which use aerobic respiration
- **Nitrate reductase test**
  - **Positive reaction** identifies organisms which use nitrate as terminal electron acceptor in anaerobic respiration
- **Catalase test**
  - **Positive reaction** identifies organisms which are facultatively anaerobic, *i.e.* tolerate O_2, or use aerobic respiration
- **Organisms not using nitrate or oxygen**
  - are negative for (cytochrome) oxidase and nitrate reductase
  - may be positive or negative for catalase
- **Catalase negative organisms**
  - may still be O_2 tolerant
  - may be aerobes, facultative or strict anaerobes