Chemolithotrophy

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Introduction

- Chemoautotrophs includes those *Bacteria* as well as *Archaea*, obtain their energy from the oxidation of reduced inorganic compounds such as hydrogen, ammonia, nitrite, sulfide, elemental sulfur, hydrogen and Fe(II) ions.

- They are thus able to grow without any organic compounds and without light. Such microorganisms are called chemolithotrophs or chemoautotrophs.

- Processes mediated by chemolithotrophic prokaryotes include nitrification (the formation of nitrate from ammonia), production of sulfuric acid from sulfide and elemental sulfur, and the formation of methane from hydrogen and carbon dioxide.
- Chemolithotrophy is widespread in the two domains of prokaryotes: the *Bacteria* and the *Archaea*

- Nitrification, or the oxidation of ammonia via nitrite to nitrate by chemolithotrophic bacteria, is a key process in the global nitrogen cycle.
- Two types of anaerobic chemolithotrophs oxidize hydrogen with carbon dioxide as electron acceptor: methanogens and homoacetogens, producing methane and acetate, respectively.
- Chemolithotrophs participate in the biogeochemical cycles of certain metals (iron, manganese) and metalloids (arsenic).

Name	Examples	Source of energy and electrons	Respiration electron acceptor
Methanogens	Archaea	H_2 (hydrogen) → H_2O (water) + e^-	CO_2 (carbon dioxide)
Carboxydotrophic bacteria	*Carboxydothermus hydrogenoformans*	carbon monoxide (CO) → carbon dioxide (CO_2) + e^-	H_2O (water) → H_2 (hydrogen)
Anammox bacteria	Planctomycetes	NH_3 (ammonia) → N_2 (nitrogen) + e^-[19]	NO_2^- (nitrite)[19]
Thiobacillus denitrificans	*Thiobacillus denitrificans*	S^0 (sulfur) → SO_4^{2-} (sulfate) + e^-[20]	NO_3^- (nitrate)[20]
Chemotrophic purple sulfur bacteria	Halothiobacillaceae	S^{2-} (sulfide) → S^0 (sulfur) + e^-	O_2 (oxygen) → H_2O (water)
Sulfur-oxidizing bacteria	Chemotrophic Rhodobacteraceae and Thiotrichaceae	S^0 (sulfur) → SO_4^{2-} (sulfate) + e^-	O_2 (oxygen) → H_2O (water)
Iron bacteria	*Acidithiobacillus ferrooxidans*	Fe^{2+} (ferrous iron) → Fe^{3+} (ferric iron) + e^-[15]	O_2 (oxygen) → H_2O (water)[15]
Nitrosifying bacteria	*Nitrosomonas*	NH_3 (ammonia) → NO_2^- (nitrite) + e^-[16]	O_2 (oxygen) → H_2O (water)[16]
Nitrifying bacteria	*Nitrobacter*	NO_2^- (nitrite) → NO_3^- (nitrate) + e^-[17]	O_2 (oxygen) → H_2O (water)[17]
Aerobic hydrogen bacteria	*Cupriavidus metallidurans*	H_2 (hydrogen) → H_2O (water) + e^-[18]	O_2 (oxygen) → H_2O (water)[18]
Sulfate-reducing bacteria: Phosphite bacteria	*Desulfotignum phosphitoxidans*	PO_3^{3-} (phosphite) → PO_4^{3-} (phosphate) + e^-	Sulfate (SO_4^{2-})
Sulfate-reducing bacteria: Hydrogen bacteria	*Desulfovibrio paquesii*	H_2 (hydrogen) → H_2O (water) + e^-[18]	Sulfate (SO_4^{2-})[18]

Sulfate-reducing bacteria

- Sulfate-reducing bacteria are those bacteria and archaea. that can obtain energy by oxidizing organic compounds or molecular hydrogen (H_2) while reducing sulfate (SO_4^{2-}) to hydrogen sulfide (H_2S).
- In a sense, these organisms "breathe" sulfate rather than oxygen in a form of anaerobic respiration.
- Sulfate-reducing bacteria can be traced back to 3.5 billion years ago and are considered to be among the oldest forms of microorganisms.

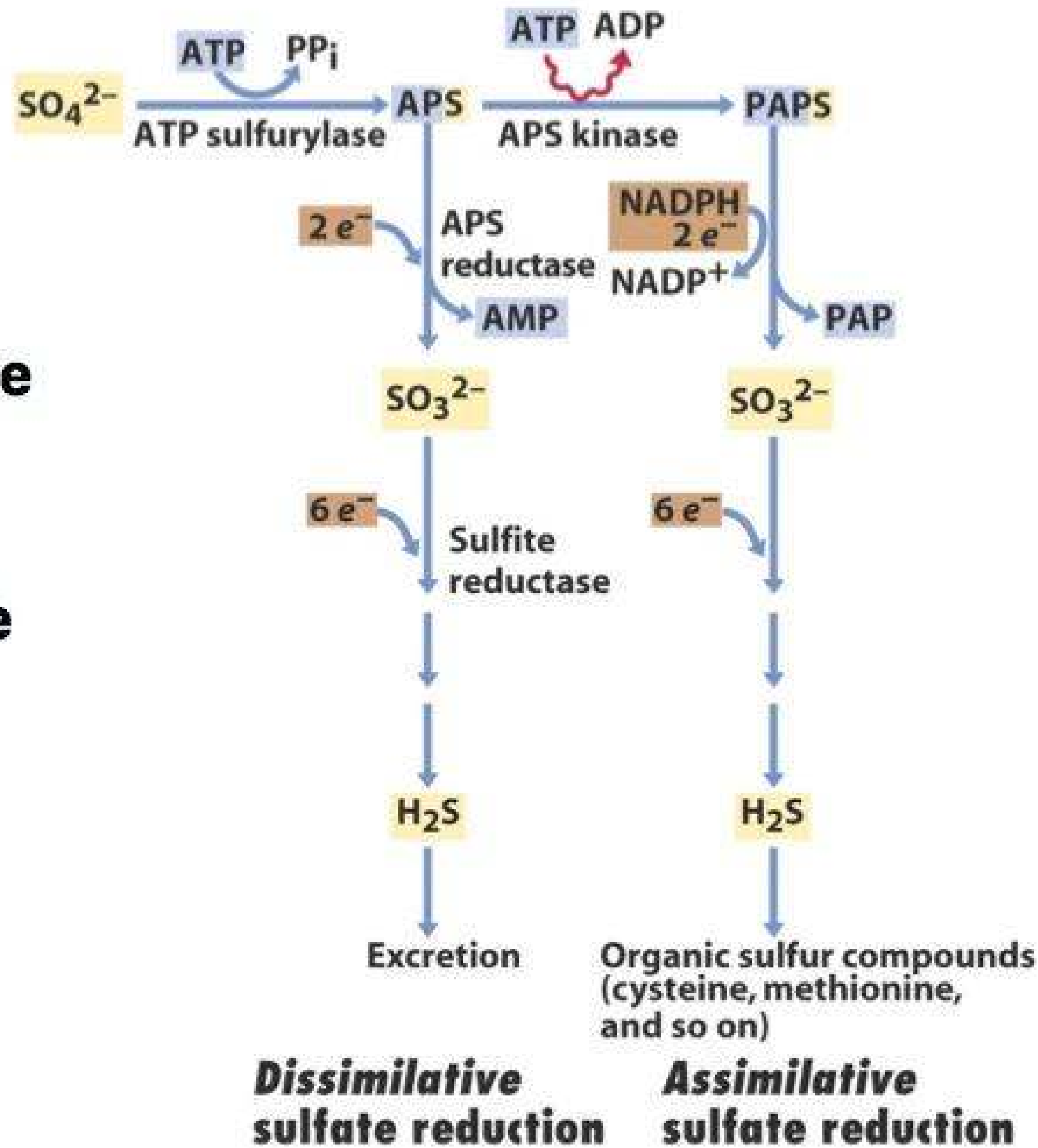
Process of Sulfate Reduction

- Assimilatory Sulfate Reduction
- Reduce small amount of sulfate to synthesis cell component

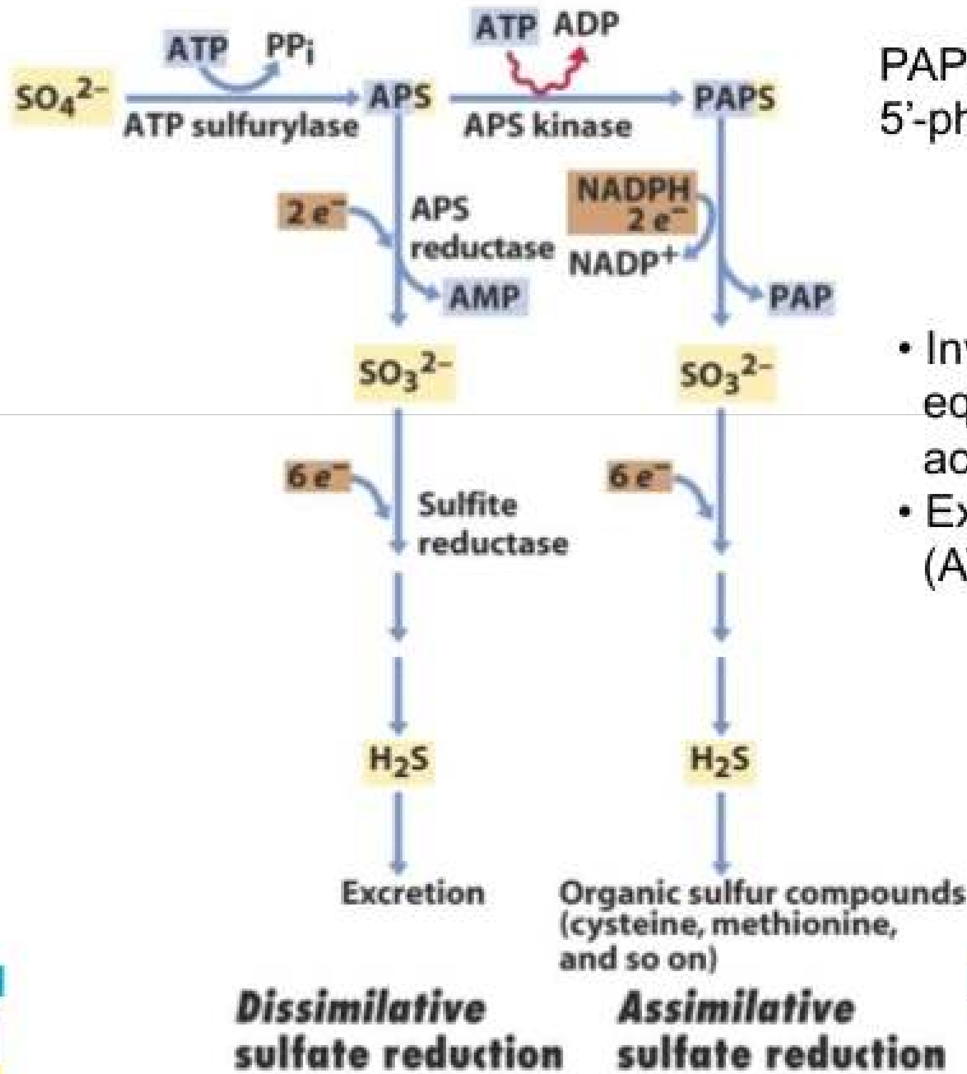
- Dissimilatory Sulfate Reduction
- Reduce large amount of sulfure to obtain energy, resulting sulfide as waste.

costs: 1 ATP for dissimilatory sulfate reduction

costs: 2 ATP for assimilatory sulfate reduction



Assimilatory sulfate reduction



PAPS = phosphoadenosine 5'-phosphosulfate

- Investment of 3 ATP equivalents for sulfate activation
- Expensive process (ATP, reducing equivalents)

TUDelft

Iron Oxidizing Bacteria

- Iron bacteria are bacteria that live and multiply by oxidizing dissolve ferrous iron.
- They are known to grow and proliferate in water containing as low as 0.1 mg/l of iron.
- When oxygen not present

H_2O + Fe_2O_3 - - - - - - - - - - 2Fe $(OH)_2$ + O_2

water Iron oxide Iron hydroxide oxygen

when oxygen absent

2 Fe $(OH)_2$ + O_2 - - - - - - - - - H_2O + Fe_2O_3

Iron Hydroxide oxygen water Iron oxide

- Bacteria known to feed on iron include Thiobacillus ferrooxidans and Leptospirillum ferrooxidans.

$H_2O + Fe_2O_3 \rightarrow 2Fe(OH)_2 + O_2$

(water) + (Iron[III] oxide) → (Iron[II] hydroxide) + (oxygen)

$2Fe(OH)_2 + O_2 \rightarrow H_2O + Fe_2O_3$

(Iron[II] hydroxide) + (oxygen) → (water) + (Iron[III] oxide)

denitrification	$2NO_3^- + 10e^- + 12H^+ \rightarrow N_2 + 6H_2O$	500 ~ 200
manganese IV reduction	$MnO_2 + 2e^- + 4H^+ \rightarrow Mn^{2+} + 2H_2O$	400 ~ 200
iron III reduction	$Fe(OH)_3 + e^- + 3H^+ \rightarrow Fe^{2+} + 3H_2O$	300 ~ 100
sulfate reduction	$SO_4^{2-} + 8e^- + 10H^+ \rightarrow H_2S + 4H_2O$	0 ~ −150
fermentation	$2CH_2O \rightarrow CO_2 + CH_4$	−150 ~ −220

Methanogenic Bacteria

- Anaerobic bacteria
- Able to obtain energy from growth by oxidizing compound of H_2 with the formation of methane gas.
- Habitat – Pond, lack, marine, sediment, rumen of cattle, anaerobic sludge.

- Examples –
- Methanobacterium thermoautotrophicum
- Gram Positive, Non motile
- Methanobacterium ruminatium
- Gram negative, short rod, motile
- Methanosarcina barkeri
- Gram positive, cocci, in cluster, non motile
- Methanospirillium hungate
- Gram negative, curved rod, long filament