Randall E. Hicks

MICROBIAL METABOLISM - Heterotrophy

Reaction	Electron Donor	Electron Acceptor	Carbon Source	ΔG° kcal/[mol]	Eh Range	Organisms
Aerobic Respiration						
$[CH_2O] + O_2 \rightarrow CO_2 + H_2O$	CH_2O	O_2	CH_2O	-114	+800 to +500	animals, algae, protozoa, fungi, & bacteria
Aerobic Chemoorganotrophy (Methane Oxidation)						
$[CH_4] + O_2 \rightarrow HCO_3^- + H_2O$	CH_4	O_2	CH_4	-57	+800 to +500	*Methylococcus* *Methylomonas* *Methylobacterium* *Methylocystis*
Anaerobic Respiration						
Denitrification						
$5[CH_2O] + 4NO_3^- \rightarrow 2N_2 + 4HCO_3^- + CO_2 + 3H_2O$	CH_2O H_2	NO_3^-	CH_2O	-107	+300 to -500	*Pseudomonas* *Thiobacillus* *Bacillus* *Spirillum* *Moraxella*
Manganese Reduction						
$[CH_2O] + 3CO_2 + H_2O + 3MnO_3 \rightarrow 2Mn^{++} + 4HCO_3^-$	CH_2O	MnO_2	CH_2O	-83	+400 to +100	
Iron Reduction						
$[CH_2O] + 7CO_2 + 4Fe(OH)_3 \rightarrow 4Fe^{++} + 8HCO_3^- + 3H_2O$	CH_2O	FeOH	CH_2O	-27	+400 to +100	*Bacillus* *Pseudomonas* *Proteus* *Clostridium* *Desulfovibrio*
Sulfate Reduction						
$2[CH_2O] + SO_4^{--} \rightarrow H_2S + 2HCO_3^-$	CH_2O	SO_4^{--}	CH_2O	-18	-100 to -400	*Desulfovibrio*
Methanogenesis						
$[HCO_3^-] + 4H_2 + H^+ \rightarrow CH_4 + 3H_2O$	CH_2O	CO_2	CH_2O	-32	-350 to -450	*Methanosarcina* *Methanobacterium*

Reaction	Electron Donor	Electron Acceptor	Carbon Source	ΔG° kcal/[mol]	Eh Range	Organisms
Acetogenesis						
$[2HCO_3^-] + 4H_2 + H^+ \rightarrow CH_3COOH + 2H_2O$	CH_2O	CO_2	CH_2O	-27		*Clostridium Acetobacterium*
Fermentation *(anaerobic)*						
Homolactic						
$6[CH_2O] \rightarrow 2[CH_3(CHOH)COOH] + 2H_2O$ *lactate*	CH_2O	CH_2O	CH_2O	-32		*Streptococcus Lactobacillus*
Heterolactic						
$6[CH_2O] \rightarrow CH_3(CHOH)COOH + CH_3(CH_2)OH + CO_2$ *lactate* *ethanol*	CH_2O	CH_2O	CH_2O	-16		*Leuconostoc Lactobacillus*
Ethanolic						
$6[CH_20] \rightarrow 2CH_3(CH_2)OH + 2CO_2 + 2\ H_2O$ *ethanol*	CH_20	CH_20	CH_20	-32		*Saccharomyces cerevisiae*
Mixed Acid						
$6[CH_2O] \rightarrow CH_3(CHOH)COOH + CH_3COOH + CH_3(CH_2)OH + CO_2 + H_2$ *lactate* *acetate* *ethanol*	CH_2O	CH_2O	CH_2O	-54		*Escherichia coli*
Propionic Acid						
$9[CH_2O] \rightarrow 2[CH_3(CH_2)COOH] + CH_3COOH + CO_2 + H_2O + 3H^+$ *propionic acid* *acetate*	CH_2O	CH_2O	CH_2O	-74		*Propionibacterium*
Butyric Acid						
$12[CH_2O] + 2H_2O \rightarrow CH_3(CH_2)_2COOH + 2(CH_3COOH) + 4CO_2 + 6H_2 + 3H^+$ *butyric acid* *acetate*	CH_2O	CH_2O	CH_2O	-57		*Clostridium Eubacterium Butyrivibrio*

MICROBIAL METABOLISM - Autotrophy

Reaction	Electron Donor	Electron Acceptor	Carbon Source	ΔG° kcal/[mol]	Eh Range	Organisms
Aerobic Photoautotrophy						
$[CO_2] + H_2O \xrightarrow{hv} CH_2O + O_2$	H_2O	NADP	CO_2	+114	+800 to +500	green plants cyanobacteria
Hydrogen Oxidation						
$[CO_2] + 6H_2O + 2O_2 \xrightarrow{hv} CH_2O + 5H_2O$	H_2	O_2 NAD	CO_2	+57	+800 to +500	*Hydrogenomonas*
Anaerobic Photoautotrophy						
$2[CO_2] + H_2S + 2H_2O \xrightarrow{hv} 2(CH_2O) + H_2SO_4$	H_2S	NADP	CO_2	+16		cyanobacteria *Chromatium*
$[CO_2] + 2H_2S \xrightarrow{hv} CH_2O + H_2O + 2S$	H_2S	NADP	CO_2	+16		*Chlorobium*
Chemoautotrophy *(aerobic)*						
Ammonia Oxidation						
$2CO_2 + 70NH_4 + 105O_2 \rightarrow 2(CH_2O) + 70NO_2^- + 72H_2O + 132H^+$	NH_4^+	O_2	CO_2	+66[N]	+800 to +500	*Nitrosomonas* *Nitrosococcus* *Nitrosospira* *Arthrobacter* *Aspergillus* *Nitrosopumilus*
Nitrification						
$CO_2 + 100NO_2^- + 50O_2 + H_2O \rightarrow CH_2O + 100NO_3^- + O_2$	NO_2^-	O_2	CO_2	+17[N]	+800 to +500	*Nitrobacter* *Nitrosococcus* *Nitrosospira*
Sulfur Oxidation						
$CO_2 + H_2S + O_2 + H_2O \rightarrow CH_2O + H_2SO_4$	H_2S $S°$, $S_2O_3^{--}$	O_2	CO_2	+50[S]	+800 to +500	*Thiobacillus* *Beggiatoa*

Reaction	Electron Donor	Electron Acceptor	Carbon Source	ΔG° kcal/[mol]	Eh Range	Organisms
Chemoautotrophy *(aerobic)*						
Iron Oxidation						
Acid pH						
$4Fe + 9O_2 + 10H_2O \rightarrow 4Fe(OH)_3 + 4SO_4^{--} + 8H^+$	Fe^{++}	O_2	CO_2	+29[Fe]	+800 to +500	*Thiobacillus ferooxidans*
Neutral pH						
$4\ FeCO_3 + O_2 + 6H_2O \rightarrow 4Fe(OH)_3 + 4CO_2$	Fe^{++}	O_2	CO_2	+40[Fe]	+800 to +500	*Gallionella* *Leptothrix* *Crenothrix* *Sphaerotilus*
Manganese Oxidation						
$2Mn^{++} + O_2 + 2H_2O \rightarrow MnO_2 + 2H^+$	Mn^{++}	O_2	CO_2	+7[Mn]	+800 to +500	*Gallionella* *Metallogenium* *Sphaerotilus* *Leptothrix* *Bacillus* *Pseudomonas* *Arthrobacter*