Ecology 1.018J/7.30 **Quiz 1** **October 2, 2008**

Please put your name on every page!

Space is provided for your answers; if you need more room, use the back of the ***same*** page.
This exam is worth 100 points, with an additional 6 points of bonus problems.
The number of points assigned to each question roughly corresponds to the amount of time you should spend answering it.

Equations that may come in handy	
$\Delta G_0' = -nF(\Delta E_0')$	n = # e^- transferred per mole of reductant
$\Delta E_0' = E_0'$(oxidizing agent) - E_0'(reducing agent)	F = Faraday constant (23 kcal V^{-1} mol^{-1})
$\Delta G' = \Delta G_o' + RT \ln ([C]^c[D]^d/[A]^a[B]^b)$	T = Temperature (K)
$aA + bB \rightarrow cC + dD$	R = gas constant (8.31 joules $degree^{-1}$ mol^{-1})

*A table of standard reduction potentials may be found on the last page of the exam.

1. (9 Points) As you know, a group of organisms catalyze the oxidation of N compounds using either organic or inorganic carbon as their carbon source:

$$NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^- \text{ (uses inorganic carbon)}$$

while others catalyze their reduction:

$$NO_3^- \rightarrow NO_2^- \rightarrow N_2O \rightarrow N_2 \text{ (uses organic carbon)}$$

(i) (2 Points) What are each of these processes called?
Nitrification (oxidation) carried out by nitrifying bacteria
Denitrification (reduction) carried out by denitrifying bacteria

(ii) (2 Points) What is the "metabolic classification" of organisms that carry each of these processes out? List the carbon source and the redox transformation of carbon for each of the processes.
nitrifying bacteria: chemosynthetic bacteria (aerobic autotrophs) oxidize ammonium and reduce CO2.
denitrifying bacteria: anaerobic respiration (heterotrophs) reduce nitrate and oxidize organic carbon

(iii) (5 Points) How can each group of microbes "make a living" by doing essentially opposite things? That is, how does each process benefit the organism that catalyzes it?
Nitrifying bacteria use energy from the oxidation of nitrogen compounds to reduce CO_2 to organic carbon, which they then use as their carbon source. Denitrifying bacteria get their energy and carbon from the organic compounds produced by autotrophs. They oxidize organic compounds to CO_2 for energy, using NO_3^- or NO_2^- as a final electron acceptor.

2. Answer the following questions "True" or "False" (1 Point Each).

___F___ The limiting factor for productivity in an ecosystem is always the element that is in lowest concentration.

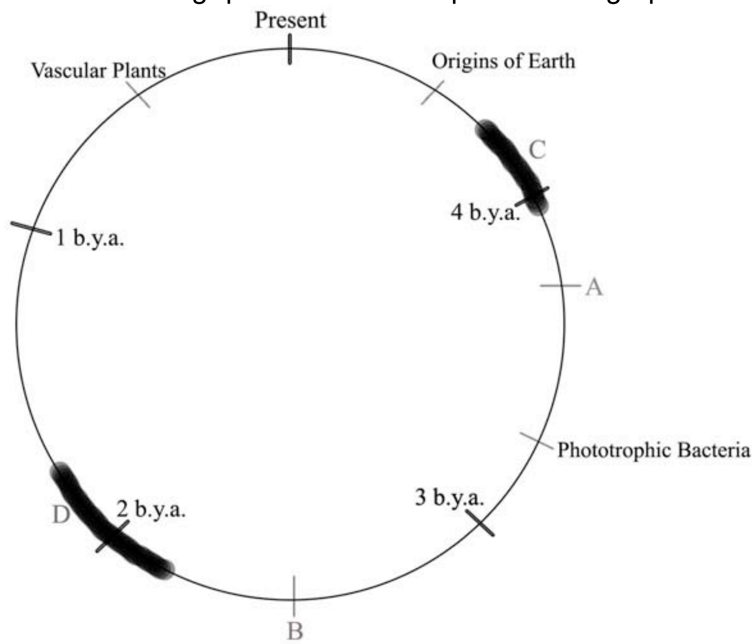
___T___ Net community production of an ecosystem can never be greater than net primary production.

____F__ N-limited lakes will often be very clear because nothing can grow in them since they are so nutrient poor.

____F__ Chlorophyll concentrations are maximal at the surface of the ocean where light intensity is greatest.

___T___ The amount of gross primary production in a forest is equal to the amount of carbon from CO_2 fixed by photosynthesis of plants and bacteria in the forest.

3. (14 Points) D. J. Des Marais diagrammed the history of the Earth as a clock in units of billions of years ago (b.y.a.) (*Science* 289: 1703(2000)). A simplified version of this clock is reproduced below. The following questions refer to parts of the graph labeled with letters.



(i) (1 Point) What appeared on Earth at “A”?
Life

(ii) (2 Points) What atmospheric event occurred at “B”? How did it affect life at that time?
The Great Oxygenation Event. Oxygen was toxic to many life forms, so they had to adapt.

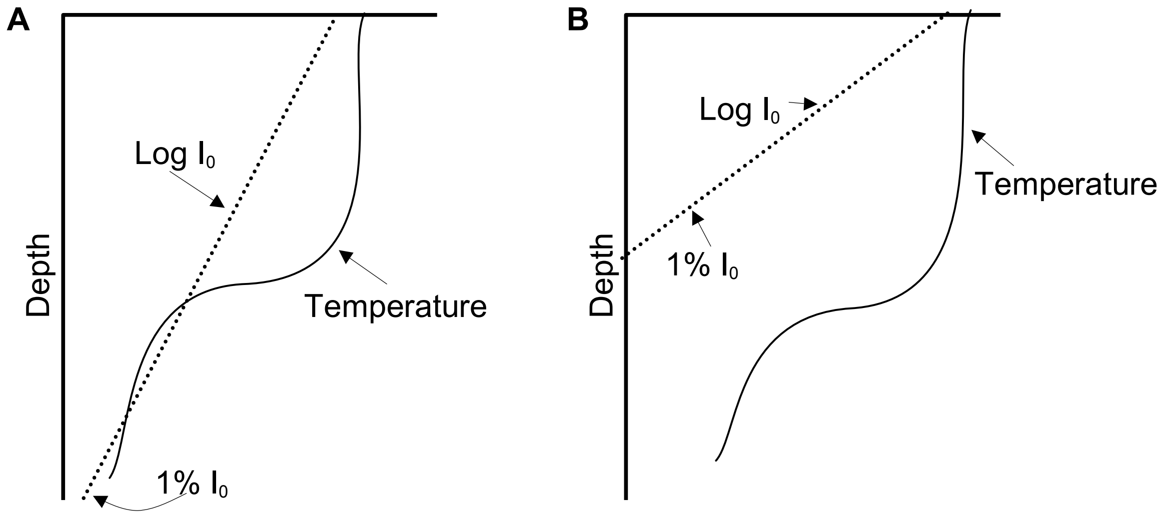
(iii) (2 Points) Describe the Earth’s atmosphere at the highlighted region “C”. What major gases were present?
The Earth’s atmosphere was reducing. Methane, carbon dioxide, reduced forms of nitrogen, etc., were present. Oxygen was absent.

(iv) (3 Points) Describe the Earth’s atmosphere at “D”. What factors led to the differences between the Earth’s atmosphere between “C” and “D”?
The Earth’s atmosphere was similar to today’s with ~21% oxygen. The differences were caused by the “great oxygenation event” and the emergence of photosynthesis.

(v) (1 Point) Draw, based on this approximate scale, when on this “clock” humans appeared on Earth.

(vi) (5 Points) Your friend, a geologist, wants your help investigating an ancient rock with curious banding and circular patterns. He has already demonstrated that the banding is not iron. What point on this graph represents the time the rock might be from? How would you test the origins of the patterning? What results would prove your hypothesis?
The rock might be from Point A, the origins of life. The banding could represent an ancient stromatolite fossil. You could test the biological origins of life by looking at stable isotope fractionation. Specifically, you could look at $\delta^{13}C$: if the ratio was lower than expected (i.e. the material is isotopically “lighter”), the material is probably of biological origin.

4. (11 Points) The graphs below describe the physical structure of two temperate lake ecosystems. I_0=incident light intensity on the water surface.



(i) (1 Point) Label z_c, the compensation depth.

(ii) (2 Points) Based on this information, which lake would you expect to produce the most phytoplankton and why?
Lake A would have the most phytoplankton because the cells never mix below the compensation depth, and thus photosynthesis is always greater than respiration.

(iii) (3 Points) Sketch on each of the graphs how you might expect the dissolved oxygen concentration to vary with depth, and why?.
It would be even in the mixed layer, and decrease below that. Probably more in the most productive lake, but you are going to have to be liberal in how you grade this.

(iv) (5 Points) Were these profiles measured in the summer or winter? Why? How would they differ if they had been measured six months earlier? (It may help you to diagram your response.)
The profiles were measured in the summer because a thermocline is evident. Thermoclines are thermal stratifications caused by warming of surface waters due to the absorption of sunlight. If the profiles were measured in the winter, light attenuation would be the same, but the thermal profile would be a straight line.

5. (10 Points) In your readings, Morton wrote: "All over the world, by day and night, animals and bacteria and fungi and the plants themselves are using the oxygen which photosynthesis spits out into the atmosphere to turn organic material back into carbon dioxide and water. In so doing, they regenerate the energy the plants stored away. The two processes come close to canceling each other out. Today, though, things are out of balance. Today is a spring day..."

   (i) (2 Points) Complete this thought with three sentences or more of your own to explain what is "out of balance".
   In spring, plants are growing, so plants must photosynthesize more than they respire in order to make biomass. There is a draw down in CO2 from the atmosphere as photosynthesis fixes more carbon from the atmosphere than respiration respires. This means that the whole cumminity is adding carbon (energy) in the spring, and the NCP will be positive.

   (ii) (2 Points) What are the animals, bacteria and fungi "using the oxygen" for?
   They are using oxygen as a terminal electron acceptor to oxidize organic carbon to use it as energy

   (iii) (2 Points) If the two processes Morton describes do "cancel each other out", can NPP still be positive? Justify your answer.
   Yes. NPP is GPP-Ra. This term could still be positive (the plants themselves could keep growing), even if the overall NCP is zero because of the respiration of heterotrophs.

   (iv) (2 Points) Over Earth's history, have these processes always canceled each other out? Explain your answer.
   No. The oxygenation of the Earth's atmosphere occurred because the process of photosynthesis far outstripped the process of respiration on the global scale leading to an increase in oxygen in the atmosphere and leading to organic carbon being stored below ground in the form of "ancient photosynthetically fixed carbon"

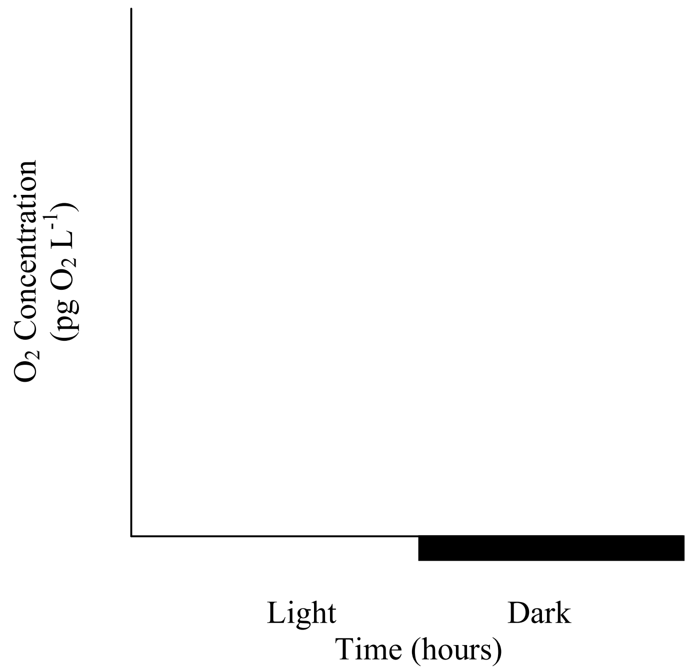
   (v) (2 Points) Morton talks about "Eating the Sun." Explain what he means by this.
   He means that photosynthesis uses light energy to convert CO2 into reduced organic carbon compounds (sugars) which are either used by the plants own respiration or used as the energy source in heterotrophic respiration, including our own. This means that the energy used for the life of heterotrophs originally came in the form of light from the Sun.

6. (17 Points) Inspired by Priestley's experiment involving a mouse, a plant, and a glass jar, you decide to build a self-sustaining closed system containing goldfish and aquatic plants.

(i) (3 Points) What roles do the plants and fish play in your mini-ecosystem? How do they depend on one another?

The plants are the primary producers (autotrophs) , fixing CO2 and releasing oxygen. The fish are the Heterotrophs, consuming O2 to break down the products of the plants. The two organisms complement each other by cycling carbon and oxygen back and forth between them.

(ii) (6 Points) Before you seal off the system, you decide to do some tests to make sure your system will be balanced, i.e. the mix of fish and plants is adequate. You do this by temporarily placing the different components of your system into sealed containers and measuring the O_2 concentration for three hours in the light and three hours in darkness. On the axes below, sketch 3 graphs of the change in O_2 over time that you expect to see for the aquatic plants alone, the goldfish alone, and the aquatic plants and goldfish combined. Assume you are using sterile water.



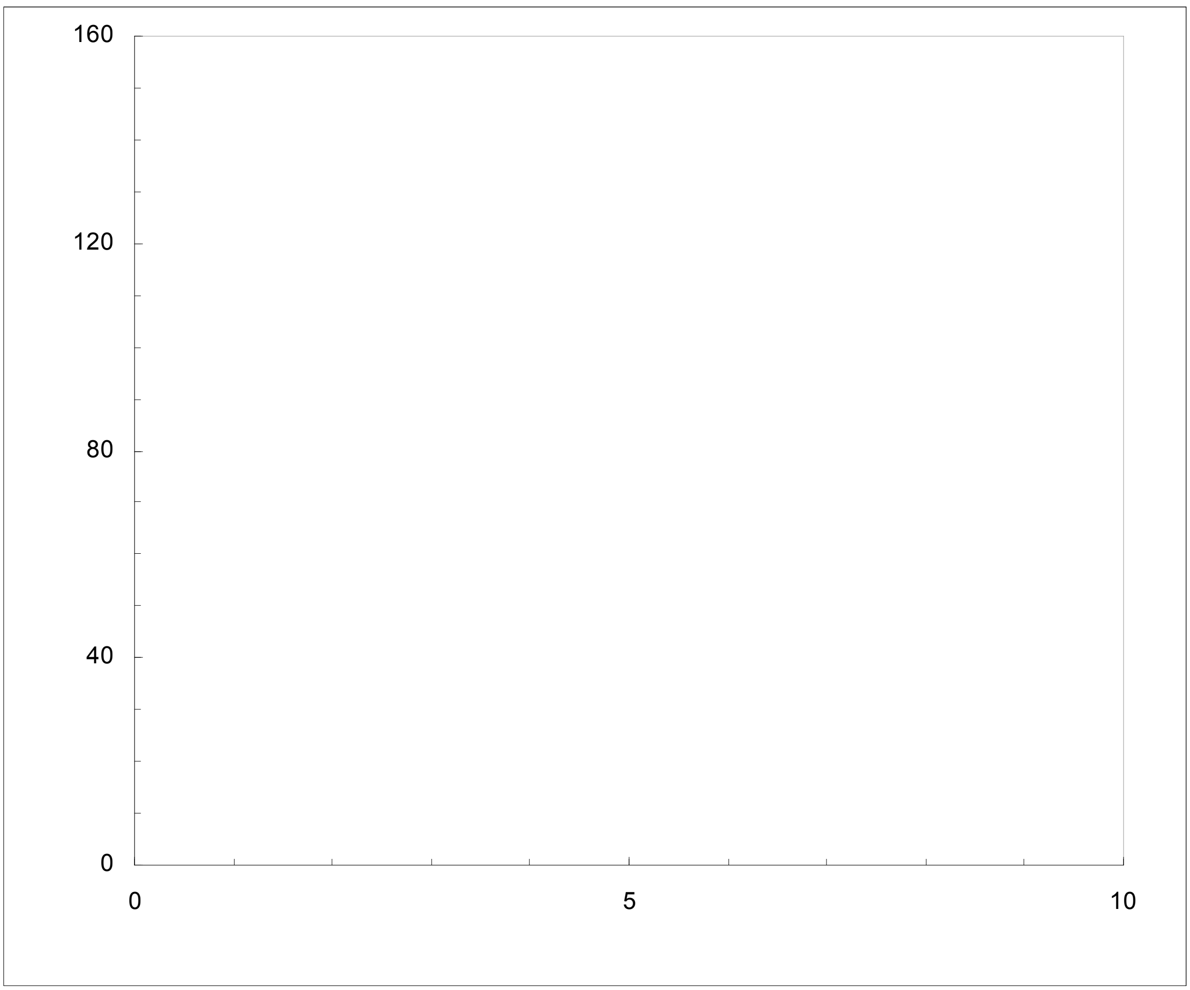
(iii) (6 Points) Explain the features of your graphs.

(iv) (2 Points) You decide you are ready to assemble the final system, but you are very tired from all of your problem sets and accidentally fill the container with water from the Charles River and leave it in the dark overnight. The next day, though your plant looks healthy, your fish is floating upside down. You know the water does not have anthropogenic toxins in it, because you just read a water quality report from the MDC. What do you hypothesize as the cause of death of the fish and why?

The Charles River water had a lot of organic matter and microbes decomposing it. The microbes used up all the oxygen and the fish suffocated.

7. (16 Points) You are a limnologist studying several lakes in northern Ontario. The lakes have little input of nutrients from streams. You measure the concentrations of nitrate and phosphate every two months, and generate the following data. All units are in μg/L concentration. Using the graph paper provided below may help you answer the question.

	Trout Lake		Big Lake		Lake Balance	
	NO_3^-	PO_4^{3-}	NO_3^-	PO_4^{3-}	NO_3^-	PO_4^{3-}
January	149	8	140	10	143	9
March	113	6	113	9	128	8
May	97	5	41	4	63	4
July	37	1	5	2	31	2
September	51	2	26	3	16	1
November	133	7	83	7	92	6



(i) (6 Points) Which lake is limited by the availability of P? By the availability of N? Explain your answer.
P-limited: Trout Lake – because the intercept is on the y axis… indicating that when P runs out, there is still N in the lake.
N-limited: Big Lake – because the intercept is the P axis
The Redfield Ratio for N:P is 16:1. Whenever the ratio exceeds 16 (as in Trout Lake), phosphorous is limiting. When the ratio is less than 16, nitrogen is limiting.

(ii) (4 Points) In which lake do you expect more blue-green algae (cyanobacteria)? Why?
More cyanobacteria would be present in Big Lake because it is N-limited. Cyanobacteria are capable of fixing nitrogen, so they would have a competitive advantage over other algae in a nitrogen-limited system. (See in-class example of Lake Washington).

(iii) (3 Points) A resort-house development is proposed to be built around Lake Balance leading to the use of large numbers of septic systems around the lake. (Septic systems leach nitrogenous compounds into the groundwater, and the groundwater ultimately carries them to the lake). Would Lake Balance start to look more like Trout Lake or Big Lake over time?
Lake Balance would start to look more like Trout Lake because Trout Lake is P-limited. The septic systems are leaching nitrogen-bearing compounds into the water, making Lake Balance enriched in nitrogen with respect to phosphorous.

(iv) (3 Points) The development goes ahead, and the concentrations of NO_3 in Lake Balance skyrocket. At the same time, the housing developments around the lake began to leach sewage into the lake, increasing its P supply. What might happen to the oxygen concentrations in the deep waters of Lake Balance over time and why? What is this process called?
Oxygen concentrations will decline, especially in the deep waters of the lake. The added nutrients cause blooms of algae, which increase the primary productivity of the lake. When the algae die, they sink towards the bottom and are decomposed by heterotrophs, which consume oxygen as they decompose the organic carbon produced by the algae. This is Cultural Eutrophication,

Bonus (1 Point): To mitigate the effects of the added nitrate from sewage coming from the new homes surrounding Lake Balance, the local wastewater treatment authority proposes an innovative solution. Rather than trying to install a sewer system across the entire, remote area, they propose using denitrifying bacteria to convert the nitrate in groundwater to nitrogen gas. They set up an anaerobic ground system and test it. Initially they find that there are fast rates of denitrification, but these rates soon slow down. There is still a lot of nitrate to be reduced and the environment is still anaerobic. What would you recommend adding to the system to help spur further denitrification?
Organic carbon

8. (8 Points) Given the following data from an Experimental Forest, answer the following questions. Show your work and units.

Total vegetative biomass	80,000 kcal m^{-2}
Detritus and organic matter in soil	120,000 kcal m^{-2}
Total Gross Primary Productivity	20,000 kcal m^{-2} yr^{-1}
Total Plant Respiration	5,000 kcal m^{-2} yr^{-1}
Total Community Respiration	9,000 kcal $m^{-2}yr^{-1}$

(i) (2 Points) What is the net primary productivity of the forest?
NPP = GPP – R_A = 20,000 – 5,000 = 15,000 kcal m^{-2} yr^{-1}

(ii) (2 Points) What is the net community production?
NCP = GPP – R_A – R_H = 20,000 – 9000 = 11,000 kcal m^{-2} yr^{-1}

(iii) (2 Points) What is the mean residence time of carbon in the vegetative biomass?
MRT = biomass / NPP = 80,000/15,000 = 5.3 years

(iv) (2 Points) Is this a fully mature forest? Explain your answer.
no. NCP > 0

9. (8 Points) You are a microbe and you go to the store where they are having a sale on elemental sulfur. You are thinking about buying some elemental sulfur to consume to make energy. There's plenty of sulfur, but you need to buy something to go with it. All that's left at the store besides sulfur is nitrate (NO_3^-) and succinate. You do have the recipe (i.e. genes) to convert NO_3^- to N_2 gas and to convert S to SO_4^{2-}. You also have a recipe to convert S to H_2S and succinate to fumarate. Assume you can buy and react one mole of each in standard conditions. Should you buy the NO_3^- or the succinate if your goal is to maximize the amount of energy produced from one mole of sulfur?

1) SO_4^{2-} + 8H+ +6e- -> S^0 + $4H_2O$ -0.20V
2) NO^{3-} + 6H++ 6 e- -> $1/2N_2$ + $3H_2O$ +0.75V
3) fumarate+ 2 H+ +2e→ succinate = +0.031V
4) S + 2 H+ +2e- -> H2S -0.243 V

For the coupled sulfur oxidation and denitrification:
dE=0.75-(-0.20)= 0.95 E
dG=-8*93.67*0.95= -711.892 kj/mol

For the coupled sulfur reduction and fumarate oxidation
dE=-0.243-(0.031)= -0.274 E
dG=-2*93.67*-0.274= 51.33kJ/mol

You should buy the nitrate.

Bonus Problem (up to 5 points):

The Peak District Moorlands in the United Kingdom store 20 million tonnes of carbon, almost half of the carbon stored in the soils of the entire United Kingdom (the Moorlands are only 8% of the land area). In pristine condition, these peatlands can store an additional 13,000 tonnes of carbon per year.

(i) Given this rate of productivity, how long did it take for the Peatlands to sequester this much carbon?
20,000,000 tonnes C / 13,000 tonnes C yr^{-1} = 1538 years

(ii) What is the effective residence time of the carbon that makes it into long-term storage in the peatland if no disturbance occurs? (Note: this is not a calculator problem!)
Theoretically, infinite: the net community productivity is stored in peat indefinitely.

(iii) The Peak District Moorlands store carbon because they are saturated with water. Based on your knowledge of terminal electron acceptors and their efficiencies, why would this inhibit/slow respiration?
Oxygen is the best electron acceptor, but in a saturated wetland anaerobic conditions prevail. Therefore, organisms experience slower rates of respiration because they grow more slowly using “poorer” metabolic pathways.

(iv) One prediction of climate change models is a reduction in rainfall in England. This would transform the Moorlands into a carbon source, emitting up to 381,000 tonnes of carbon per year. How many years would it take to respire all the carbon stored in the Peak District Moorlands?
20,000,000 tonnes C / 381,000 tonnes C yr^{-1} = 52.5 years!!!!

Table 1.

Standard reduction potential (E_0') values (at 25°C and pH 7)

Half-Reaction			E_o' (V)
1/2 O_2 + 2 H^+ + 2 e^-	⇒	H_2O	+0.816
Fe^{3+} + e^-	⇒	Fe^{2+}	+0.771
NO_3^- + 5 H^+ + 6 e^-	⇒	½ N_2 + 3 H_2O	+0.75
NO_3^- + 2 H^+ + 2 e^-	⇒	NO_2^- + H_2O	+0.421
NO_3^- + 10 H^+ + 8 e^-	⇒	NH_4^+ + 3 H_2O	+0.36
NO_2^- + 8 H^+ + 6 e^-	⇒	NH_4^+ + 2 H_2O	+0.34
CH_3OH + 2 H^+ + 2 e^-	⇒	CH_4 + H_2O	+0.17
fumarate + 2 H^+ + 2 e^-	⇒	succinate	+0.031
2 H^+ + 2 e^-	⇒	H_2 (pH 0)	+0.00
oxaloacetate + 2 H^++ 2 e^-	⇒	malate	-0.166
CH_2O + 2 H^+ + 2 e^-	⇒	CH_3OH	-0.18
pyruvate + 2 H^+ + 2 e^-	⇒	lactate	-0.185
acetaldehyde + 2 H^+ + 2 e^-	⇒	ethanol	-0.197
SO_4^{2-} + 8 H^+ + 6 e^-	⇒	S + 4 H_2O	-0.20
SO_4^{2-} + 10 H^+ + 8 e^-	⇒	H_2S + 4 H_2O	-0.21
FAD + 2 H^+ + 2 e^-	⇒	$FADH_2$	-0.219
CO_2 + 8 H^+ + 8 e^-	⇒	CH_4 + 2 H_2O	-0.24
S + 2 H^+ + 2 e^-	⇒	H_2S	-0.243
N_2 + 8 H^+ + 6 e^-	⇒	2 NH_4^+	-0.28
NAD^+ + H^+ + 2 e^-	⇒	NADH	-0.320
$NADP^+$ + H^+ + 2 e^-	⇒	NADPH	-0.324
2 H^+ + 2 e^-	⇒	H_2 (pH 7)	-0.414
CO_2 + 4 H^+ + 4 e^-	⇒	1/6 glucose + H_2O	-0.43
Fe^{2+} + 2 e^-	⇒	Fe	-0.85

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