CANADIAN CHEMISTRY CONTEST

CHEMISTRY

TOPIC QUESTIONS

King

CANADIAN CHEMISTRY OLYMPIAD | OLYMPIADE DE CHIMIE DU CANADA

4. Electrochemistry

KingCh

2) Which of the following statements are TRUE about reactions 1 and 2?
Reaction 1: N_2 (g) + $3H_2$ (g) → $2NH_3$ (g)
Reaction 2: NaOH (aq) + HCl (aq) → H_2O (l) + NaCl (aq)

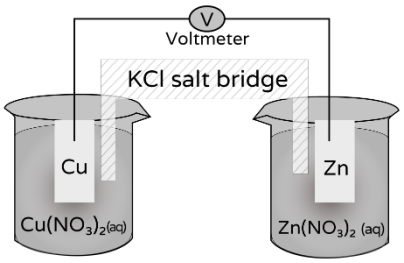
i) Reaction 1 is a redox reaction
ii) Reaction 2 is a redox reaction
iii) Hydrogen is the reducing agent in both reaction 1 and 2
iv) One of the products in each reaction has a bond angle of < 109.5°

A) i, ii and iii B) i, ii and iv C) ii and iv
D) i and iv E) i, ii, iii and iv

22) Consider the following galvanic cell for Questions 22-24

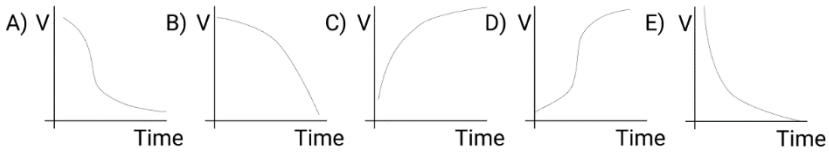
$$E^o_{Cu^{2+}/Cu} = +0.34\ V$$

$$E_{Zn^{2+}/Zn} = -0.76\ V$$



Which of the statements is true about $[Cl^-]$ at the anode and the cathode after the cell has operated for 5 minutes?
A) $[Cl^-] = 0\ M$ in both half cells.
B) Both half cells contain $[Cl^-] = 0.1\ M$ due to diffusion.
C) $[Cl^-]$ is greatest at the cathode. A precipitate forms at the anode.
D) $[Cl^-]$ is greatest at the cathode as the ions migrate to make the cell work.
E) $[Cl^-]$ is greatest at the anode as ions move to neutralize the charge difference.

23) If the anode and cathode were connected with a wire with constant resistance, which would be the expected graph of voltage of the cell vs. time?



24) Assuming no energy is lost in the system, how much work can the cell do at 298 K if there are 2 mols of $^{2+}$ at the cathode and 2 mols of $^{2+}$ at the anode? The potential of the cell is 1.10 V .

A) 1.10 J B) 2.20 J C) 106.15 kJ D) 212.3 kJ E) 424.5 kJ

CCC 2021

5) In which of the following substances does sulfur have the lowest oxidation state?

A) S_8 B) $Na_2S_2O_3$ C) Na_2SO_4 D) H_2S E) SO_2

15) Given the following standard reduction potentials.

$Cu^{2+} + 2\ e^- \rightarrow Cu$	$E^o = 0.34$ V
$Al^{3+} + 3\ e^- \rightarrow Al$	$E^o = -1.66$ V
$Na^+ + e^- \rightarrow Na$	$E^o = -2.71$ V

Which of the following statement(s) is/are true?

I. Na is the most easily oxidized
II. Cu is the best reducing agent.
III. Cu^{2+} cannot be spontaneously reduced by Al
IV. Na^+ has a greater attraction for electrons than Al^{3+}

A) I only B) I and II only C) I, II and III only
D) II and IV only E) I, III, and IV only

CCC 2020

11) Given the following electrochemical cell data:

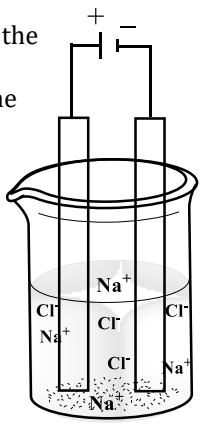
Cell 1 $Cd(s) \mid Cd^{2+}(1.0M) \parallel Cu^{2+}(1.0M) \mid Cu(s)$ $E^o = +0.74$ V
Cell 2 $Zn(s) \mid Zn^{2+}(1.0\ M) \parallel Cu^{2+}(1.0\ M) \mid Cu(s)$ $E^o = +1.10$ V
Cell 3 $Zn(s) \mid Zn^{2+}(1.0\ M) \parallel Cd^{2+}(1.0\ M) \mid Cd(s)$

Determine the standard cell potential for Cell 3.

A) – 0.36 V B) 0.36 V C) –1.84 V
D) –0.18 V E) 0.18 V

CCC 2019

21) 96.5% of water available on Earth is sea water. Desalination of seawater could provide a solution to the global fresh water crisis. There are many challenges that chemists face in achieving desalination. Given the half reactions below and the setup of the electrolytic cell to the right, what would happen with an applied potential difference from the power source?



$Na^+(aq) + e^- \rightarrow Na(s)$	$E° = -2.71$ V
$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$	$E° = -0.83$ V
$O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$	$E° = +1.23$ V
$Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$	$E° = +1.36$ V

A) With 1.35 V, the cell produces Na at the cathode and Cl_2 at the anode
B) With 1.35 V, the cell produces Na at the anode and Cl_2 at the cathode
C) With 4.07 V, the cell produces Na at the cathode and Cl_2 at the anode
D) With 2.06 V, the cell produces H_2 at the anode and H_2O at the cathode
E) With 2.06 V, the cell produces H_2 at the cathode and O_2 at the anode

CCC 2018

7) Artificial photosynthesis involves splitting water with solar energy. This clean energy reaction is: $2\ H_2O\ (l) \rightarrow 2\ H_2\ (g) + O_2\ (g)$

Which of the following statements about the splitting of water is **incorrect**:

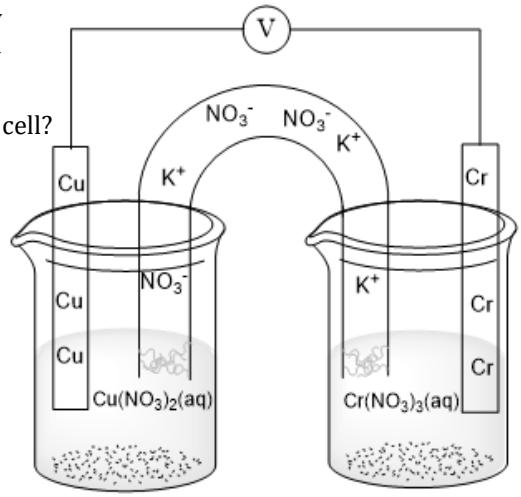
A) The oxidation state of hydrogen in water is +1
B) The oxidation state of hydrogen gas is 0
C) Water is the oxidizing and reducing agent
D) The oxidation state of oxygen in water is – 1
E) The oxygen atoms are oxidized in this process

25) Given the following half reactions and galvanic cell diagram

$K^+\ (aq) + e^- \rightarrow K\ (s)$ $\quad E° = -2.93$ V
$Cu^{2+}\ (aq) + 2e^- \rightarrow Cu\ (s)$ $\quad E° = +0.34$ V
$Cr^{3+}\ (aq) + 3e^- \rightarrow Cr\ (s)$ $\quad E° = -0.74$ V

what is the theoretical potential of the cell?

A) 0.40 V B) 1.08 V
C) 1.85 V D) 2.19 V
E) 2.50 V



CCC 2017

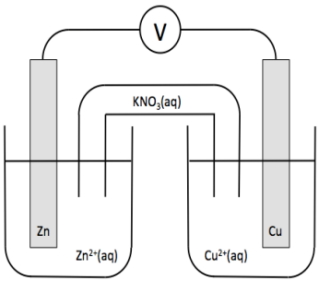
16) The transition metal rhenium (Re), is among the rarest elements in the earth's crust. The precursor to the pure metal, ammonium perrhenate, is produced during the refinement of molybdenum ores. The principal application of rhenium is as an alloy with nickel, used in jet engine components. Consider the unbalanced chemical equation for the hydrogen reduction of ammonium perrhenate:

$$\_\_\ NH_4ReO_4 + \_\_\ H_2 \longrightarrow \_\_\ Re + \_\_ H_2O + \_\_\ NH_3$$

Assume the oxidation number of nitrogen in the reactants and products is unchanged. Determine the **sum** of the smallest integer coefficients for the stoichiometrically balanced chemical equation.

A) 5 B) 14 C) 18 D) 20 E) 21

22) For the cell depicted, the half-reactions are:



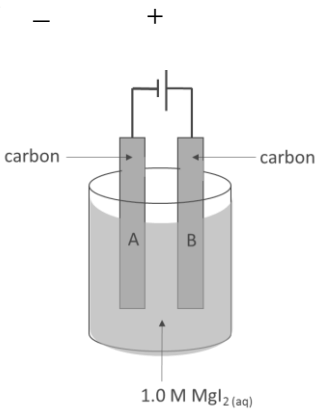
$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$ $\quad E^\circ = -0.76$ V
$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ $\quad E^\circ = +0.34$ V

Which of the following is true for the *spontaneous* cell reaction?

A) Zn is the anode; the electron flow is from anode to cathode; anions migrate through the salt bridge from the Zn/Zn^{2+} to the Cu/Cu^{2+} half-cell and cations migrate in the opposite direction.
B) Zn is the cathode; the electron flow is from anode to cathode; anions migrate through the salt bridge from the Zn/Zn^{2+} to the Cu/Cu^{2+} half-cell and cations migrate in the opposite direction.
C) Zn is the anode; the electron flow is from cathode to anode; anions migrate through the salt bridge from the Zn/Zn^{2+} to the Cu/Cu^{2+} half-cell and cations migrate in the opposite direction.
D) Zn is the cathode; the electron flow is from anode to cathode; cations migrate through the salt bridge from the Zn/Zn^{2+} to the Cu/Cu^{2+} half-cell and anions migrate in the opposite direction.
E) Zn is the anode; the electron flow is from anode to cathode; cations migrate through the salt bridge from the Zn/Zn^{2+} to the Cu/Cu^{2+} half-cell and anions migrate in the opposite direction.

CCC 2016

21. Which of the following statements about the electrolysis of a solution of magnesium iodide, as depicted in the diagram, is **false**?
A) If the negative and positive terminals of the cell are reversed, magnesium would begin to plate on electrode B.
B) The reaction is non-spontaneous without an applied power source.
C) An acid-base indicator could be used to detect a product formed at electrode A.
D) I_2 forms at the anode.
E) A gas is formed at the cathode.



$I_2(s) + 2\,e^- \rightarrow 2\,I^-(aq)$ $\quad E^\circ = +0.54$ V
$Mg^{2+}(aq) + 2\,e^- \rightarrow Mg(s)$ $\quad E^\circ = -2.37$ V
$O_2(g) + 4\,H^+(aq) + 4e^- \rightarrow 2\,H_2O(l)$ $\quad E^\circ = +1.23$ V
$2H_2O(l) + 2\,e^- \rightarrow H_2(g) + 2\,OH^-(aq)$ $\quad E^\circ = -0.83$ V

7. Assuming the oxidation number of chlorine is – 1, the oxidation numbers of iodine and antimony in the compound $[ICl_2]^+[SbCl_6]^-$ are respectively

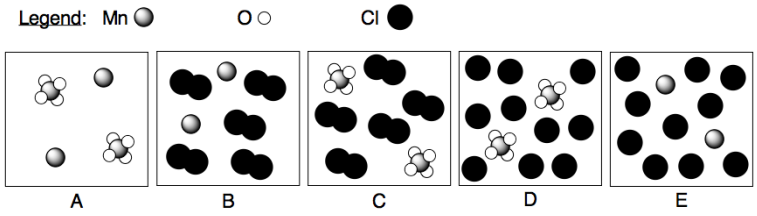
A) +2 and +6 B) +2 and +5 C) +1 and +7
D) +3 and+5 E) +3 and +7

23. Consider the following half-cell reactions in aqueous, acid conditions:

$Cl_2(aq) + 2e^- \rightleftharpoons 2Cl^-(aq)$ $\quad E° = +1.36$ V

$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$ $\quad E° = +1.49$ V

Assuming correct stoichiometric ratios of reactants, which of the following represents the *products* from the *spontaneous* cell reaction? (H^+ *and* H_2O *have been omitted for clarity*)



CCC 2015

19. A galvanic cell is created for the following reaction:

$Zn_{(s)} + 2\ Cu^{2+} \rightarrow Zn^{2+} + 2\ Cu_{(s)}$ $\quad E°_{cell} = 1.10$ V, $\Delta H°$ −217 kJ/mol

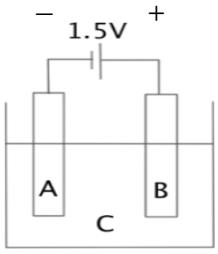
A light bulb is connected to the cell and allowed to glow until it dies out. Doubling the mass of the electrodes and volumes of solutions will have which of the following effects?

I. The light bulb will glow twice as bright.
II. Twice as much heat will be generated.
III. The light bulb will glow twice as long.

A) II only B) I and II C) I and III D) II and III E) I, II, and III

20. To create a nickel–plated electrode using a 1.5 V battery, what are the most appropriate choices for A, B, and C in the diagram of the electrolytic cell below?

$Ni^{2+} + 2\ e^- \rightarrow Ni$ $\quad E° = -0.25$ V
$Cu^{2+} + 2\ e^- \rightarrow Cu$ $\quad E° = +0.34$ V
$Al^{3+} + 3\ e^- \rightarrow Al$ $\quad E° = -1.66$ V



	A	B	C
A)	Ni	Cu	$CuSO_4$
B)	Ni	Cu	$NiSO_4$
C)	Cu	Ni	$NiSO_4$
D)	Ni	Al	$Al_2(SO_4)_3$
E)	Al	Ni	$NiSO_4$

CCC 2014

21. The thiosulfate ion $S_2O_3^{2-}$ has a structure in which a central sulfur atom forms four single bonds to one terminal S atom and three O atoms. The two non-equivalent S atoms have two different oxidation states. The oxidation state of the **central** S atom is:

A. +6 B. +5 C. +4 D. +2 E. –2

23. When an object is silver plated, cyanide ions are added to the electrolyte to keep the silver ions in solution as a soluble silver cyanide complex. The **unbalanced** oxidation and reduction half-reactions are given below:

Oxidation: $CN^-(aq) + Ag(s) \rightarrow Ag(CN)_2^-(aq)$
Reduction: $O_2(g) + 4H^+(aq) \rightarrow 2H_2O(l)$

In acidic solution, the balanced chemical reaction is:

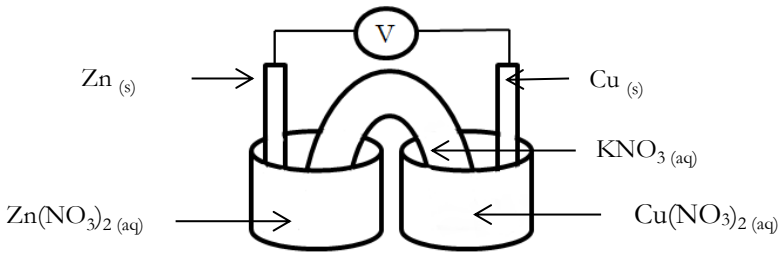
A) $8CN^-(aq) + 4Ag(s) + O_2(g) + 4H^+(aq) \rightarrow 4Ag(CN)_2^-(aq) + 2H_2O(l)$
B) $2CN^-(aq) + Ag(s) + O_2(g) + 4H^+(aq) \rightarrow Ag(CN)_2^-(aq) + 2H_2O(l)$
C) $4CN^-(aq) + 2Ag(s) + O_2(g) + 4H^+(aq) \rightarrow 2Ag(CN)_2^-(aq) + 2H_2O(l)$
D) $2CN^-(aq) + Ag(s) + ½\ O_2(g) + 2H^+(aq) \rightarrow Ag(CN)_2^-(aq) + H_2O(l)$
E) $6CN^-(aq) + 3Ag(s) + ½O_2(g) + 2H^+(aq) \rightarrow 3Ag(CN)_2^-(aq) + H_2O(l)$

Use the following Standard Reduction Potentials for questions 24 and 25

$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$	$E° = +1.23$ V
$Ag^+ + e^- \rightarrow Ag$	$E° = +0.80$ V
$Cu^{2+} + 2e^- \rightarrow Cu$	$E° = +0.34$ V
$SO_4^{2-} + 4H^+ + 2e^- \rightarrow H_2O + H_2SO_3$	$E° = +0.20$ V
$Zn^{2+} + 2e^- \rightarrow Zn$	$E° = -0.76$ V
$2H_2O + 2e^- \rightarrow H_2 + 2\ OH^-$	$E° = -0.83$ V

24. Which of the following statements is true for the following galvanic cell?

I. The copper electrode gains mass
II. The copper electrode is the cathode
III. The direction of electron flow in the wire is from the copper electrode to the zinc electrode



A) I only B) II only C) III only D) I and II E) I, II and III

25. Electrolysis of a $CuSO_4$ solution with two copper electrodes:
    I. Will produce copper at the cathode
    II. Will produce hydrogen gas at the anode
    III. Will occur if a battery has a potential of 1.5 V

    A) I only B) II only C) I and II D) I and III E) I, II and III

CCC 2013

19. If the standard reduction potentials of $Al^{3+}|Al$ and $Sn^{2+}|Sn$ electrodes are –1.676 V and –0.137 V respectively, and both metal cations in the electrochemical cell have concentrations of 1.0 mol L^{-1}, which of the following is true?

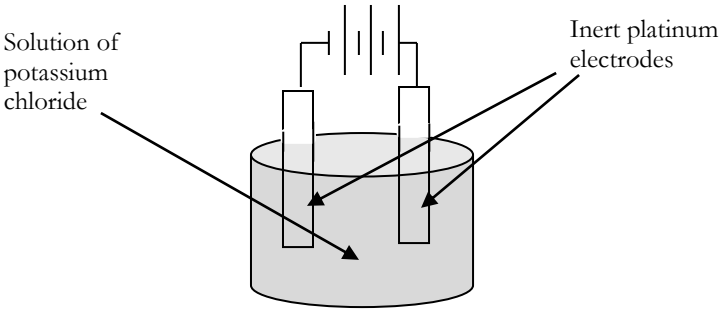
A. Al is oxidized at one electrode and Sn is oxidized at the other
B. Al is oxidized at one electrode and Sn is reduced at the other
C. Al is reduced at one electrode and Sn is oxidized at the other
D. Al is reduced at one electrode and Sn is reduced at the other
E. Al is oxidized and Sn is reduced at both electrodes

24. The cell depicted below is powered by three 1.5 V batteries and has platinum electrodes in an aqueous solution of potassium chloride. The following standard reduction potentials are provided as a reference.

$Cl_2 + 2e^- \rightarrow 2\ Cl^-$	$E^\circ = 1.36$ V
$O_2 + 4\ H^+ + 4e^- \rightarrow 2\ H_2O$	$E^\circ = 1.23$ V
$2\ H_2O + 2\ e^- \rightarrow H_2 + 2\ OH^-$	$E^\circ = -0.83$ V
$K^+ + e^- \rightarrow K$	$E^\circ = -2.92$ V

What is the product at the cathode?

A. O_2 B. l_2 C. D. $_2$ E. $_2O$



CCC 2012

20. Given the following standard electrode potentials

$Ag^+(aq) + e^- \rightarrow Ag(s)$ $\quad E° = +0.80$ V

$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ $\quad E° = +0.34$ V

Which of the following statements is/are TRUE for the standard electrochemical cell below?

$$Cu(s)\,|\,Cu^{2+}(aq)\;||\;Ag^+(aq)\,|\,Ag(s)$$

I the cathode reaction is $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$
II the cell potential is 1.14 V
III the silver electrode will increase in mass when the cell operates

A. I only B. II only **C. III only**

CCC 2011

6. The concentration of sulfite ions ($SO_3^{2-}(aq)$) in wastewater from the pulp and paper industry can be analyzed by titration with permanganate ion under acidic conditions. The titration makes use of a redox reaction which may be represented as:

$$\_\_\_SO_3^{2-}(aq) + \_\_\_MnO_4^-(aq) \rightarrow \_\_\_SO_4^{2-}(aq) + \_\_\_Mn^{2+}(aq)$$

This is an unbalanced partial equation, showing only the oxidized and reduced species with no stoichiometric coefficients. If the complete balanced equation is considered, how many moles of $KMnO_4$ react with each mole of sulfite ion?

A. 0.2 B. 0.4 C. 1 D. 2.5 E. 5

CCC 2010

17.In one type of breathalyser used to detect alcohol in a driver's breath, an orange solution of potassium dichromate (K2Cr2O7) in dilute sulfuric acid

reacts with alcohol (if present) to form green $Cr_2(SO_4)_3$, and the intensity of the green colour is measured. In this reaction, what is the change in the oxidation number of each chromium atom?

A. –-6 B. –3 C. 0 D. +3 E. +6

21. A possible battery system for electric cars is the zinc-chlorine battery, in which the overall reaction is:

$$Zn(s) + Cl_2(g) \rightarrow ZnCl_2(aq)$$

What is the overall voltage of each battery cell under standard conditions, given the following reduction potentials:

$$Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq); \quad E^\Theta = +1.358\ V$$
$$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s); \quad E^\Theta = -0.763\ V$$

A. 0.168 V B. 0.595 V C. 1.943 V D. 2.121 V E. 3.469 V

CCC 2009

20. In the aluminum-air battery, an aluminum anode is oxidized in alkaline solution:

$$Al(s) + 4OH^-(aq) \rightarrow Al(OH)_4^-(aq) + 3e^-$$

At the carbon-air cathode, oxygen is reduced by the half-reaction:

$$O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$$

for which the standard reduction potential $E^\Theta(O_2, OH^-) = +0.40$ V. The standard voltage of the cell $E^\Theta_{cell} = 2.71$ V. We may conclude that the standard reduction potential at the anode, $E^\Theta(Al^{3+}, Al)$, is:

A. +3.11 V B. +2.31 V C. 0.00 V D. –2.31 V E. –3.11 V

11. The reaction between manganese dioxide and hydrochloric acid may be written:

$$MnO_2(s) + 4H^+(aq) + 2Cl^-(aq) \rightarrow Mn^{2+}(aq) + 2H_2O(s) + Cl_2(g)$$

In this reaction

A. Chlorine is oxidized and manganese is reduced
B. Chlorine is reduced and manganese is oxidized
C. Chlorine is reduced and hydrogen is oxidized
D. Hydrogen is oxidized and manganese is reduced
E. Oxidation and reduction do not occur

4. Which one of the following series of compounds is written in order of increasing oxidation state of chlorine:

A. $NaClO_4 < NaClO_3 < NaClO_2 < NaClO$
B. $NaClO_4 < NaClO < NaClO_3 < NaClO_2$
C. $NaClO_3 < NaClO_2 < NaClO < NaClO_4$
D. $NaClO < NaClO_2 < NaClO_3 < NaClO_4$
E. $NaClO < NaClO_3 < NaClO_2 < NaClO_4$

CCC 2008

10. The iodate ion (IO_3^-) can oxidize Fe^{2+} to Fe^{3+} in acid solution. If IO_3^- is reduced to iodide (I^-) in this reaction, then the number of moles of Fe^{2+} that can be oxidized by 1 mole of IO_3^- is

A. 2 B. 3 C. 4 D. 5 E. 6

21. Given the following standard reduction potentials:

$$2\,H_2O(l) + 2e^- \rightarrow H_2(g) + 2\,OH^-(aq); \quad E^\ominus = -0.83\ V$$
$$O_2(g) + 2\,H_2O(l) + 4e^- \rightarrow 4\,OH^-(aq); \quad E^\ominus = +0.40\ V$$

What is the electromotive force of a fuel cell with the overall reaction:

$$2\,H_2(g) + O_2(g) \rightarrow 2\,H_2O(l)\ ?$$

A. –1.23 V B. –0.43 V C. +0.43 V D. +1.23 V E. +2.06 V

CCC 2007