Aris Kaksis, 2026, Riga Latvia http://aris.gusc.lv/Index.html University

Prigogine electrochemistry attractors for dissolution, protolysis, and reduction-oxidation of Mn compounds.

$MnO_2+4OH^-=MnO_4^-+2H_2O+3e^-$; Expression of absolute potential has standard $E°_{classic}$=0,595 V [1], water logarithm -0,0591/3*log(55,3^2)=-0,068663 and sum ΔE°=0,10166-0,37239:

$E°_{MnO2/MnO4-}$=$E°_{MnO2/MnO4-}$-0,0591/3•log($[H_2O]^2$)+ΔE°=0,595-0,0591/3*log(55,3^2)+0,10166-0,37239=**0,25561** V

$\Delta G_{eqMnO2/MnO4-}$=-E°$_{MnO2/MnO4-}$•F•3=-0,**25561***96485*3=**73,9876** kJ/mol,

$\Delta G_{eqMnO2/MnO4-}$=G_{MnO4-}+2G_{H2O}-(G_{MnO2}+4G_{OH-})=**476,95**+2*0-(**93,5224**+4*77,36)=**73,9876** kJ/mol,

G_{MnO2}=G_{MnO4-}+2G_{H2O}-($\Delta G_{eqMnO2/MnO4-}$+4G_{OH-})=**476,95**+2*0-(**73,9876**+4*77,36)=**93,5224** kJ/mol,

$MnO_2+6H_2O=MnO_4^-+4H_3O^++3e^-$; Expression of potential has standard $E°_{classic}$=1,679 V [1], water logarithm -0,0591/3*log(1/55,3^6)=+0,20599 and ΔE°=0,10166-0,37239:

$E°_{MnO2/MnO4}$=$E°_{MnO2/H+}$-0,0591/3•log(1/$[H_2O]^6$)+ΔE°=1,679-0,0591/3*log(1/55,3^6)+0,10166-0,37239=**1,61426** V

$\Delta G_{eqMnO2/H+}$=E°$_{MnO2/H+}$•F•3=**1,61426***96485*3=**467,2556** kJ/mol,

$\Delta G_{eqMnO2/H+}$=G_{MnO4-}+4G_{H3O+}-(G_{MnO2}+6G_{H2O})=**476,95**+4*22,44-(**99,4544**+6*0)=**467,2556** kJ/mol,

G_{MnO2}=G_{MnO4-}+4G_{H3O+}-($\Delta G_{eqMnO2/H+}$+6G_{H2O})=**476,95**+4*22,44-(**467,2556**+6*0)=**99,4544** kJ/mol,

Substanc	$\Delta H°_H$, kJ/mol	$\Delta S°_H$, J/mol/K	$\Delta G°_H$, kJ/mol	$G_{BioChemH2O}$=237,191-**151,549**=**85,642** kJ/mol.
H_2O	-285,85	69,9565	-237,191	CRC Handbook of Chemistry and Physics, [1]
H_2O	**-286,65**	**-453,188**	**-151,549**	Biochem.Thermodyn., Massachusetts Technology Inst.[8] pH=7,36
H_3O^+	$G_{AlbertyH3O}$=	**22,44**	**-257,46**	$\Delta G°_{H3O+\_absolute}$=$G_{H3O+}$-(0,5$G_{H2}^{gas}$+1,5*$G_{O2}^{gas}$)=**-257,46** kJ/mol;
H_3O^+	–285,809	-168,8	-217,2345	$\Delta G°_{H3O+}$=ΔH-T*ΔS=-285,809-298,15*-168,8/1000=-235,48 kJ/mol;
G_{e-} H_3O^+	formation	-235,48	**22,029**	G_{e-}=ΔG°-G_{H3O+}+(1,5*G_{H2}^{gas}+0,5*G_{O2}^{gas})=**22,029** kJ/mol; [1,8,26].
H_2^{gas}	Alberty	pH=7,36	**85,64**	Biochem.Thermodyn., Massachusetts Technology Inst.[8] pH=7,36
$H_{2(aq)}$	23,4	-130	99,13	$\Delta H°_{H3O+}$=-285,809 kJ/mol Mischenko 1972, Himia, Leningrad [26,1]
$H_{2(aq)}$	**-5,02**	**-363,92**	**103,24**	Biochem.Thermodyn., Massachusetts Technology Inst.[8] pH=7,36
H(Pt)$_{aq}$	-	-	**48,56**	ΔG_{eq}=**-847,7** kJ/mol ; ΔG_{Hess}=-1044,2 kJ/mol
MnO_4^-	-541,4	-191,2	-447,2	[1]
MnO_4^-	formation	-447,2	**391,572**	[1,8] G_{MnO4-}=$\Delta G°_{MnO4-}$+(G_{Mn}+2G_{O2}+G_{e-})=**391,572** kJ/mol;
MnO_4^-	E° $_{Mn2+/MnO4-}$	**1,483458**V	**714,133**	G_{MnO4-}=$\Delta G_{eqMn2+/MnO4-}$-8G_{H3O+}+(G_{Mn2+}+12G_{H2O})=**714,133** kJ/mol;
MnO_4^-	ΔE°$_{H/MnO4-}$=	**-1,754188**	**714,133**	G_{MnO4-}=G_{Mn2+}+7G_{H2O}-($\Delta G_{HessPt)H}$+3G_{H3O}+5$G_{H(Pt)}$)= **714,133** kJ/mol;
MnO_4^{2-}	-653,0	59,0	-500,7	[1]
MnO_4^{2-}	formation	-500,7	**359,294**	[1,8] G_{MnO42-}=$\Delta G°_{MnO42-}$+(G_{Mn}+2G_{O2}+2G_{e-})=**359,294** kJ/mol;
MnO_4^{2-}	=**0,25561**	**457,396**	**449,233**	G_{MnO42-}=$\Delta G_{eqMnO4-/MnO42-}$+$G_{MnO4-}$=**-27,717**+(**714,13**)=**449,23** kJ/mol;
MnO	-385,2	59,7	-362,9	ΔG°=ΔH–T*ΔS=-385,2-298,15*-0,0592=-367,5495 kJ/mol; [1]
MnO	formation	-362,9	**0**	G_{MnO}=$\Delta G°_{MnO}$+(G_{Mn}+G_{O2}^{gas})=-362,9+(**211,35**+0,5***303,1**)=**0** kJ/mol;
MnO_2	-520	53,1	-465,1	ΔG°=ΔH–T*ΔS=-520-298,15*-0,0531=-504,168 kJ/mol; [1]
MnO_2	formation	-465,1	**49,35**	G_{MnO2}=$\Delta G°_{MnO2}$+(G_{Mn}+G_{O2}^{gas})=465,1+(**211,35**+**303,1**)=**49,35** kJ/mol;
MnO_2	G_{MnO2}=**0**	kJ/mol [1,8]	G_{Mn}=**162**	G_{MnO2}=0=$\Delta G°_{MnO2}$+G_{Mn}+G_{O2}^{gas}=-465,1+G_{Mn}+**303** kJ/mol; [1,8]
MnO_2	E°$_{MnO2/OH}$	**0,25561 V**	**330,7054**	OH- G_{MnO2}=G_{MnO4-}+2G_{H2O}-($\Delta G_{eqMnO2/MnO4-}$+4G_{OH})=**330,7054** kJ/mol;
MnO_2	E°$_{MnO2/H}$	**1,61426**	**336,6374**	H+ G_{MnO2}=G_{MnO4-}+4G_{H3O+}-($\Delta G_{eqMnO2/H+}$+6G_{H2O})=**336,6374** kJ/mol;
MnOOH	E°$_{MnOOH/MnO2}$	**1,072265**V	**255,62**	G_{MnOOH}=$\Delta G_{eqMnOOH/MnO2}$+G_{H2O}-(G_{MnO2}+G_{H3O+})=**255,62** kJ/moll;
MnOOH	Formation	**1,072265**V	**256,042**	G_{MnOOH}=$\Delta G°_{MnOOH}$+(G_{Mn}+G_{O2}^{gas}+0,5G_{H2})=**256,042** kJ/mol;
Mn^{2+}	–220,8	-73,6	-228,1	ΔG°=ΔH–T*ΔS=-220,8-298,15*-0,073=-199,035 kJ/mol; [1]
Mn^{2+}	E°$_{Mn(H2O)6/Mn}$	**-1,146745**	**227,684**	G_{Mn2+}=$\Delta G_{Mn2+H2O/Mn}$+G_{Mn}+G_{H2O}=**-221,287**+**448,97**=**227,684** kJ/mol;
Mn^{2+}	E°$_{Mn2+/Mn}$	**-1,404233**	**177,996**	G_{Mn2+}=$\Delta G_{Mn2+H2O/Mn}$+(G_{Mn}+G_{H2O})=**-270,97474**+**448,97**=**178** kJ/mol;
Mn^{2+}	E°$_H$-E°$_{MnO4-}$	**-1,754188**	**177,989**	G_{Mn2+}=$\Delta G_{HessPt)H}$-7G_{H2O}+(G_{MnO4}+3G_{H3O}+5$G_{H(Pt)}$)=**177,989** kJ/mol;
G_{e}-Mn^{2+}	formation	-228,1	21,44	G_{Mn2+}=**448,97** ; 2G_{e-}=$\Delta G°_{Mn2+}$-G_{Mn2+}+(G_{Mn})=2***21,44** kJ/mol;
Mn_{H2O}^{2+}	**1,483458 V**	-228,1	**177,996**	$G_{[Mn(H2O)]2+}$=$\Delta G°_{Mn2}$-2G_{e-}+(G_{Mn}+G_{H2}+0,5G_{O2}/2)=**177,996** kJ/mol;
Mn_{H2O}^{2+}	formation	-228,1	**415,181**	$G_{[Mn(H2O)]2+}$=$\Delta G°_{Mn2+}$-2G_{e-}+(G_{Mn}+G_{H2}+0,5G_{O2}/2)=**415,181** kJ/mol;
Mn	G_{MnOOH}=	32,0 CRC	**211,4**	G_{Mn}=-$\Delta G°_{MnO2}$-G_{O2}^{gas}=362,9-0,5***303,1**=**211,35** kJ/mol. [1,8]
Mn G_{Mn2+}=**227,684**		**-1,146745**	**448,971**	G_{Mn}=G_{Mn2+}-($\Delta G_{eqMn2+/Mn}$+G_{H2O})=**227,684**+**221,287**=**448,971** kJ/mol,;
Mn G_{MnMn2+}=**177,996**		**-1,404233**	**448,971**	G_{Mn}=G_{Mn2+}-($\Delta G_{eqMn2+/Mn}$+G_{H2O})=**448,971** kJ/mol;
O_{2aqua}	**-11,7**	**-94,2**	**16,4**	Biochem.Thermodyn., Massachusetts Technology Inst.[8] pH=7,36

Formation $Mn+2O_2^{gas}+e^-=MnO_4^-$;

$\Delta G°_{MnO4-}$=G_{MnO4-}-(G_{Mn}+2G_{O2}+G_{e-})=**714,133**-(**211,35**+2***303,1**+**21,222**)=-447,2 kJ/mol;

$G_{MnO4-}=\Delta G°_{MnO4-}+(G_{Mn}+2G_{O2}+G_{e-})=-447,2+(\mathbf{211,35}+2*\mathbf{303,1}+\mathbf{21,222})=\mathbf{714,133}$ $^{kJ}/_{mol}$;

$G_{e-}=G_{MnO4-}-(G_{Mn}+2G_{O2}+\Delta G°_{MnO4-})=\mathbf{714,133}-(\mathbf{211,35}+2*\mathbf{303,1}-447,2)=\mathbf{21,222}$ $^{kJ}/_{mol}$;

$\Delta G°_{MnO4-}=G_{MnO4-}-(G_{Mn}+2G_{O2}+G_{e-})=\mathbf{476,957}-(\mathbf{211,35}+2*\mathbf{303,1}+\mathbf{21,222})=-447,2$ $^{kJ}/_{mol}$;

$G_{MnO4-}=\Delta G°_{MnO4-}+(G_{Mn}+2G_{O2}+G_{e-})=-447,2+(\mathbf{211,35}+2*\mathbf{303,1}+\mathbf{21,222})=\mathbf{476,957}$ $^{kJ}/_{mol}$;

$G_{e-}=G_{MnO4-}-(G_{Mn}+2G_{O2}+\Delta G°_{MnO4-})=\mathbf{476,957}-(\mathbf{211,35}+2*\mathbf{303,1}-447,2)=\mathbf{21,222}$ $^{kJ}/_{mol}$;

Formation $Mn+2\mathbf{O_2}^{gas}+2e^-=MnO_4^{2-}$**;**

$\Delta G°_{MnO42-}=G_{MnO42-}-(G_{Mn}+2G_{O2}+2G_{e-})=\mathbf{359,294}-(\mathbf{211,35}+2*\mathbf{303,1}+2*\mathbf{21,222})=-500,7$ $^{kJ}/_{mol}$;

$G_{MnO42-}=\Delta G°_{MnO42-}+(G_{Mn}+2G_{O2}+2G_{e-})=-500,7+(\mathbf{211,35}+2*\mathbf{303,1}+2*\mathbf{21,222})=\mathbf{359,294}$ $^{kJ}/_{mol}$;

$2G_{e-}=G_{MnO42-}-(G_{Mn}+2G_{O2}+\Delta G°_{MnO42-})=\mathbf{359,294}-(\mathbf{211,35}+2*\mathbf{303,1}-500,7)=2*\mathbf{21,222}=\mathbf{42,444}$ $^{kJ}/_{mol}$;

Formation $1,5\mathbf{H_2}^{gas}+0,5\mathbf{O_2}^{gas}=\mathbf{H_3O}^++e^-$; $\Delta G°_{H3O+}=\Delta H-T*\Delta S=-285,809-298,15*-168,8/1000=-235,48$ $^{kJ}/_{mol}$;

$\Delta \mathbf{G}°=G_{H3O+}+G_{e-}-(1,5*G_{H2}{}^{gas}+0,5*G_{O2}{}^{gas})=\mathbf{22,44}+G_{e-}-(1,5*\mathbf{85,6}+0,5*\mathbf{303,1})=-235,48$ $^{kJ}/_{mol}$;

$G_{e-}=\Delta \mathbf{G}°-G_{H3O+}+(1,5*G_{H2}{}^{gas}+0,5*G_{O2}{}^{gas})=-235,48-\mathbf{22,44}+(1,5*\mathbf{85,6}+0,5*\mathbf{303,1})=\mathbf{22,029}$ $^{kJ}/_{mol}$;

Formation $Mn+\mathbf{O_2}^{gas}=MnO_2$**;** $\Delta G°_{MnO2}=G_{MnO2}-(G_{Mn}+G_{O2}{}^{gas})=\mathbf{49,35}-(\mathbf{211,35}+\mathbf{303,1})=-465,1$ $^{kJ}/_{mol}$;

$G_{MnO2}=\Delta G°_{MnO2}+(G_{Mn}+G_{O2}{}^{gas})=-465,1+(\mathbf{211,35}+\mathbf{303,1})=\mathbf{49,35}$ $^{kJ}/_{mol}$;

$G_{Mn}=G_{MnO2}-(\Delta G°_{MnO2}+G_{O2}{}^{gas})=\mathbf{49,35}-(-465,1+\mathbf{303,1})=\mathbf{211,35}$ $^{kJ}/_{mol}$. [1,8]

Formation $Mn+0,5\mathbf{O_2}^{gas}=MnO$**;** $\Delta G°_{MnO}=G_{MnO}-(G_{Mn}+G_{O2}{}^{gas}/2)=\mathbf{0}-(\mathbf{211,35}+0,5*\mathbf{303,1})=-362,9$ $^{kJ}/_{mol}$;

$G_{MnO}=\Delta G°_{MnO}+(G_{Mn}+G_{O2}{}^{gas})=-362,9+(\mathbf{211,35}+0,5*\mathbf{303,1})=\mathbf{0}$ $^{kJ}/_{mol}$;

$G_{Mn}=G_{MnO}-(\Delta G°_{MnO}+G_{O2}{}^{gas})=-0-(-362,9+0,5*\mathbf{303,1})=\mathbf{211,35}$ $^{kJ}/_{mol}$;

$Mn^{2+}+12H_2O=MnO_4^-+8H_3O^++5e^-$; Expression of potential has standard $E°_{classic}=1,507$ V [1], water logarithm and $\Delta E°$: $E°_{Mn2+/MnO4-}=E_o-0,0591/5\bullet\log(1/[H_2O]^{12})=1,507-0,0591/5\bullet\log(1/55,3\hat{}12)+0,10166-0,37239=\mathbf{1,483458}$ V.

$\Delta \mathbf{G}_{\mathbf{eq}Mn2+/MnO4-}=E°_{Mn2+/MnO4-}\bullet F\bullet 5=\mathbf{1,483458}*96485*5=\mathbf{715,657}$ $^{kJ}/_{mol}$,

$\Delta \mathbf{G}_{\mathbf{eq}Mn2+/MnO4-}=G_{MnO4-}+8G_{H3O+}-(G_{Mn2+}+12G_{H2O})=\underline{\mathbf{476,95}}+8*22,44-(\mathbf{-59,187}+12*0)=\mathbf{715,657}$ $^{kJ}/_{mol}$,

$G_{MnO4-}=\Delta \mathbf{G}_{\mathbf{eq}Mn2+/MnO4-}-8G_{H3O+}+(G_{Mn2+}+12G_{H2O})=\mathbf{715,657}-8*22,44+(\mathbf{-59,187}+12*0)=\mathbf{476,95}$ $^{kJ}/_{mol}$,

$G_{Mn2+}=G_{MnO4-}+8G_{H3O+}-(\Delta \mathbf{G}_{\mathbf{eq}Mn2+/MnO4-}+12G_{H2O})=\underline{\mathbf{476,95}}+8*22,44-(\mathbf{715,657}+12*0)=\mathbf{-59,187}$ $^{kJ}/_{mol}$,

$\Delta \mathbf{G}_{\mathbf{eq}Mn2+/MnO4-}=G_{MnO4-}+8G_{H3O+}-(G_{Mn2+}+12G_{H2O})=\mathbf{714,133}+8*22,44-(\mathbf{177,989}+12*0)=\mathbf{715,657}$ $^{kJ}/_{mol}$,

$G_{MnO4-}=\Delta \mathbf{G}_{\mathbf{eq}Mn2+/MnO4-}-8G_{H3O+}+(G_{Mn2+}+12G_{H2O})=\mathbf{715,657}-8*22,44+(\mathbf{177,989}+12*0)=\mathbf{714,133}$ $^{kJ}/_{mol}$,

$G_{Mn2+}=G_{MnO4-}+8G_{H3O+}-(\Delta \mathbf{G}_{\mathbf{eq}Mn2+/MnO4-}+12G_{H2O})=\mathbf{714,133}+8*22,44-(\mathbf{715,657}+12*0)=\mathbf{177,989}$ $^{kJ}/_{mol}$,

Formation $Mn+6\mathbf{H_2}^{gas}+3\mathbf{O_2}^{gas}=[Mn(\mathbf{H_2O})_6]^{2+}+2\mathbf{e-}$;

One coordinative bond has $\mathbf{190,5255}$ $^{kJ}/_{mol}$=$\mathbf{H_2O}$=>□ΔMn^{2+};

but six coordinative bonds have sum of six times $6*\mathbf{190,5255}=\mathbf{1143,153}$ $^{kJ}/_{mol}$ $[Mn(\mathbf{H_2O})_6]^{2+}$;

$\Delta G°_{Mn26H2O/}=G_{Mn26H2O}+2G_{e-}-(G_{Mn}+6G_{H2}+3G_{O2})=G_{Mn2+6H2O}+2*\mathbf{21,222}-(\mathbf{448,971}+6*\mathbf{85,64}+3*\mathbf{303,1})=-228,1$ $^{kJ}/_{mol}$;

$G_{Mn26H2O}=\Delta G°_{Mn26H2O}+2G_{e-}-(G_{Mn}+6G_{H2}+3G_{O2})=-228,1-2*\mathbf{21,222}+(\mathbf{448,971}+6*\mathbf{85,64}+3*\mathbf{303,1})=\mathbf{1601,567}$ $^{kJ}/_{mol}$;

Formation $Mn=Mn^{2+}+2\mathbf{e-}$;

$\Delta G°_{Mn2}=G_{Mn2+}+2G_{\mathbf{e-}}-(G_{Mn})=\mathbf{177,989}+2*\mathbf{21,44}-(\mathbf{448,971})=-228,1$ $^{kJ}/_{mol}$;

$2G_{\mathbf{e-}}=\Delta G°_{Mn2+}-G_{Mn2+}+(G_{Mn})=-228,1-(\mathbf{177,989})+(\mathbf{448,971})=\mathbf{42,44}=2*\mathbf{21,44}$ $^{kJ}/_{mol}$;

Formation $Mn+0,5\mathbf{O_2}^{gas}+H_2{}^{gas}=[Mn(\mathbf{H_2O})]^{2+}+2e^-$;

$\Delta G°_{Mn2+}=G_{[Mn(\mathbf{H2O})]2+}+2G_{\mathbf{e-}}-(G_{Mn}+G_{H2}+0,5G_{O2}/2)=\mathbf{415,181}+2*\mathbf{21,44}-(\mathbf{448,971}+\mathbf{85,64}+\mathbf{303,1}/2)=-228,1$ $^{kJ}/_{mol}$;

$G_{[Mn(\mathbf{H2O})]2+}=\Delta G°_{Mn2+}-2G_{\mathbf{e-}}+(G_{Mn}+G_{H2}+0,5G_{O2}/2)=-228,1-2*\mathbf{21,44}+(\mathbf{448,971}+\mathbf{85,64}+\mathbf{303,1}/2)=\mathbf{415,181}$ $^{kJ}/_{mol}$;

$Mn+6H_2O=[Mn(\mathbf{H_2O})_6]^{2+}+2e^-$; Expression of potential has standard $E°_{classic}=-1,185$ V [1], water logarithm and $\Delta E°$: $E°_{Mn2+H2O/Mn}=E_o-0,0591/2\bullet\log(1/[\,H_2O]^6)=-1,185-0,0591/2\bullet\log(1/55,3\hat{}6)+0,10166-0,37239=\mathbf{-1,146745}$ **V.**

$\Delta \mathbf{G}_{Mn2+H2O/Mn}=E°_{Mn2+/Mn}\bullet F\bullet 2=\mathbf{-1,146745}*96485*2=\mathbf{-221,287}$ $^{kJ}/_{mol}$,

$\Delta \mathbf{G}_{Mn2+H2O/Mn}=G_{Mn2+}-(G_{Mn}+G_{H2O})=\mathbf{-9,937}-(\mathbf{211,35}+0)=\mathbf{-221,287}$ $^{kJ}/_{mol}$,

$G_{Mn2+}=\Delta \mathbf{G}_{Mn2+H2O/Mn}+(G_{Mn}+G_{H2O})=\mathbf{-221,287}+(\mathbf{211,35}+0)=\mathbf{-9,937}$ $^{kJ}/_{mol}$,

$G_{Mn}=G_{Mn2+}-(\Delta \mathbf{G}_{\mathbf{eq}Mn2+/Mn}+G_{H2O})=\mathbf{-9,937}-(\mathbf{-221,287}+0)=\mathbf{211,35}$ $^{kJ}/_{mol}$,

$\Delta \mathbf{G}_{Mn2+H2O/Mn}=E°_{Mn2+/Mn}\bullet F\bullet 2=\mathbf{-1,146745}*96485*2=\mathbf{-221,287}$ $^{kJ}/_{mol}$,

$\Delta \mathbf{G}_{Mn2+H2O/Mn}=G_{Mn2+}-(G_{Mn}+G_{H2O})=\mathbf{177,996}-(\mathbf{399,283}+0)=\mathbf{-221,287}$ $^{kJ}/_{mol}$,

$G_{Mn2+}=\Delta \mathbf{G}_{Mn2+H2O/Mn}+(G_{Mn}+G_{H2O})=\mathbf{-221,287}+(\mathbf{399,283}+0)=\mathbf{177,996}$ $^{kJ}/_{mol}$,

$G_{Mn}=G_{Mn2+}-(\Delta \mathbf{G}_{\mathbf{eq}Mn2+/Mn}+G_{H2O})=\mathbf{177,996}-(\mathbf{-221,287}+0)=\mathbf{399,283}$ $^{kJ}/_{mol}$,

$\Delta \mathbf{G}_{Mn2+H2O/Mn}=E°_{Mn2+/Mn}\bullet F\bullet 2=\mathbf{-1,146745}*96485*2=\mathbf{-221,287}$ $^{kJ}/_{mol}$,

$\Delta \mathbf{G}_{Mn2+H2O/Mn}=G_{Mn2+}-(G_{Mn}+G_{H2O})=\mathbf{227,684}-(\mathbf{448,971}+0)=\mathbf{-221,287}$ $^{kJ}/_{mol}$,

$G_{Mn2+}=\Delta \mathbf{G}_{Mn2+H2O/Mn}+(G_{Mn}+G_{H2O})=\mathbf{-221,287}+(\mathbf{448,971}+0)=\mathbf{227,684}$ $^{kJ}/_{mol}$,

$G_{Mn}=G_{Mn2+}-(\Delta \mathbf{G}_{\mathbf{eq}Mn2+/Mn}+G_{H2O})=\mathbf{227,684}-(\mathbf{-221,287}+0)=\mathbf{448,971}$ $^{kJ}/_{mol}$,

$Mn+H_2O=[Mn(\mathbf{H_2O})]^{2+}+2e^-$; Expression of potential has standard $E°_{classic}=-1,185$ V [1], water logarithm and $\Delta E°$: $E°_{Mn2+H2O/Mn}=E_o-0,0591/2\bullet\log(1/[H_2O]^6)=-1,185-0,0591/2*\log(1/55,3\text{^}1)+0,10166-0,37239=\mathbf{-1,4042325\ V}$.

$\mathbf{\Delta G}_{Mn2+H2O/Mn}=E^{\circ}_{Mn2+/Mn}\bullet F\bullet 2=\mathbf{-1,40423247}*96485*2=\mathbf{-270,97474}\ ^{kJ}/_{mol}$,

$\mathbf{\Delta G}_{Mn2+H2O/Mn}=G_{Mn2+}-(G_{Mn}+G_{H2O})=\mathbf{-59,6247-(211,35+0)=-270,97474}\ ^{kJ}/_{mol}$,

$G_{Mn2+}=\mathbf{\Delta G}_{Mn2+H2O/Mn}+(G_{Mn}+G_{H2O})=\mathbf{270,97474+(211,35+0)=-59,6247}\ ^{kJ}/_{mol}$,

$G_{Mn}=G_{Mn2+}-(\mathbf{\Delta G_{eq}}_{Mn2+/Mn}+G_{H2O})=\mathbf{-59,6247-(-270,97474+0)=211,79}\ ^{kJ}/_{mol}$,

$\mathbf{\Delta G}_{Mn2+H2O/Mn}=E^{\circ}_{Mn2+/Mn}\bullet F\bullet 2=\mathbf{-1,40423247}*96485*2=\mathbf{-270,97474}\ ^{kJ}/_{mol}$,

$\mathbf{\Delta G}_{Mn2+H2O/Mn}=G_{Mn2+}-(G_{Mn}+G_{H2O})=\mathbf{177,996-(448,971+0)=-270,97474}\ ^{kJ}/_{mol}$,

$G_{Mn2+}=\mathbf{\Delta G}_{Mn2+H2O/Mn}+(G_{Mn}+G_{H2O})=\mathbf{-270,97474+(448,971+0)=177,996}\ ^{kJ}/_{mol}$,

$G_{Mn}=G_{Mn2+}-(\mathbf{\Delta G_{eq}}_{Mn2+/Mn}+G_{H2O})=\mathbf{177,996-(-270,97474+0)=448,971}\ ^{kJ}/_{mol}$,

$MnO_4^{2-}=MnO_4^-\mathbf{+e^-}$; Expression of potential has standard $E°_{classic}=0,558$ V [1], water logarithm +0,20599 and $\Delta E°$:

$E°_{MnO4/MnO4-}=E°-0,0591/1\bullet\log([H_2O]^0)+0,10166-0,37239=0,558-0,000+0,10166-0,37239=\mathbf{0,28727}$ V;

$MnO_4^-\mathbf{+e^-}=MnO_4^{2-}$; inverse $\mathbf{\Delta G_{eqeq}}_{MnO4-MnO42-}=E^{\circ}_{\mathbf{eq}MnO4-MnO42-}\bullet F\bullet 1=\mathbf{-0,28727}*96485*1=\mathbf{-27,717}\ ^{kJ}/_{mol}$,

$\mathbf{\Delta G_{eq}}_{MnO4-/MnO42-}=G_{MnO42-}-G_{MnO4-}=\mathbf{449,233-(714,133)=-27,717}\ ^{kJ}/_{mol}$,

$G_{MnO42-}=\mathbf{\Delta G_{eq}}_{MnO4-/MnO42-}+G_{MnO4-}=\mathbf{-27,717+(714,133)=449,233}\ ^{kJ}/_{mol}$,

$MnO_2+4OH^-=MnO_4^-+2H_2O\mathbf{+3e^-}$; Expression of potential has standard $E°_{classic}=0,595$ V [1],

water logarithm -0,06866 V and $\Delta E°$: $E°_{MnO2//OH}=\mathbf{0,25561}$ V

$E°_{MnO2//OH}=E°_{classic}-0,0591/3\bullet\log([H_2O]^2)+0,10166-0,37239=$ $=$

$=0,595-0,0591/3\bullet\log(55,3\text{^}2)+0,10166-0,37239=\mathbf{0,25561}$ V

$\mathbf{\Delta G}_{MnO2//OH}=E°_{MnO2//OH}\bullet F\bullet 3=\mathbf{0,25561}*96485*3=\mathbf{73,9876}\ ^{kJ}/_{mol}$,

$\mathbf{\Delta G_{eq}}_{MnO2/MnO4-}=G_{MnO4-}+2G_{H2O}-(G_{MnO2}+4G_{OH-})=\mathbf{714,133}+2*0-(\mathbf{93,5224}+4*77,36)=\mathbf{73,9876}\ ^{kJ}/_{mol}$,

$G_{MnO2}=G_{MnO4-}+2G_{H2O}-(\mathbf{\Delta G_{eq}}_{MnO2/MnO4-}+4G_{OH-})=\mathbf{714,133}+2*0-(\mathbf{73,9876}+4*77,36)=\mathbf{330,7054}\ ^{kJ}/_{mol}$,

$MnO_2+6H_2O=MnO_4^-+4H_3O^+\mathbf{+3e^-}$; Expression of potential has standard $E°_{classic}=1,679$ V [1],

water logarithm $-0,0591/3*\log(1/55,3\text{^}6)=+0,20599$ and $\Delta E°=0,10166-0,37239$

$E°_{MnO2/H+}=E°_{MnO2/H+}-0,0591/3\bullet\log(1/[H_2O]^6)+\Delta E°=1,679-0,0591/3*\log(1/55,3\text{^}6)+0,10166-0,37239=\mathbf{1,61426}$ V

$\mathbf{\Delta G_{eq}}_{MnO2/H+}=E^{\circ}_{MnO2/H+}\bullet F\bullet 3=\mathbf{1,61426}*96485*3=\mathbf{467,2556}\ ^{kJ}/_{mol}$,

$\mathbf{\Delta G_{eq}}_{MnO2/H+}=G_{MnO4-}+4G_{H3O+}-(G_{MnO2}+6G_{H2O})=\mathbf{714,133}+4*22,44-(\mathbf{336,6374}+6*0)=\mathbf{467,2556}\ ^{kJ}/_{mol}$,

$G_{MnO2}=G_{MnO4-}+4G_{H3O+}-(\mathbf{\Delta G_{eq}}_{MnO2/H+}+6G_{H2O})=\mathbf{714,133}+4*22,44-(\mathbf{467,2556}+6*0)=\mathbf{336,6374}\ ^{kJ}/_{mol}$,

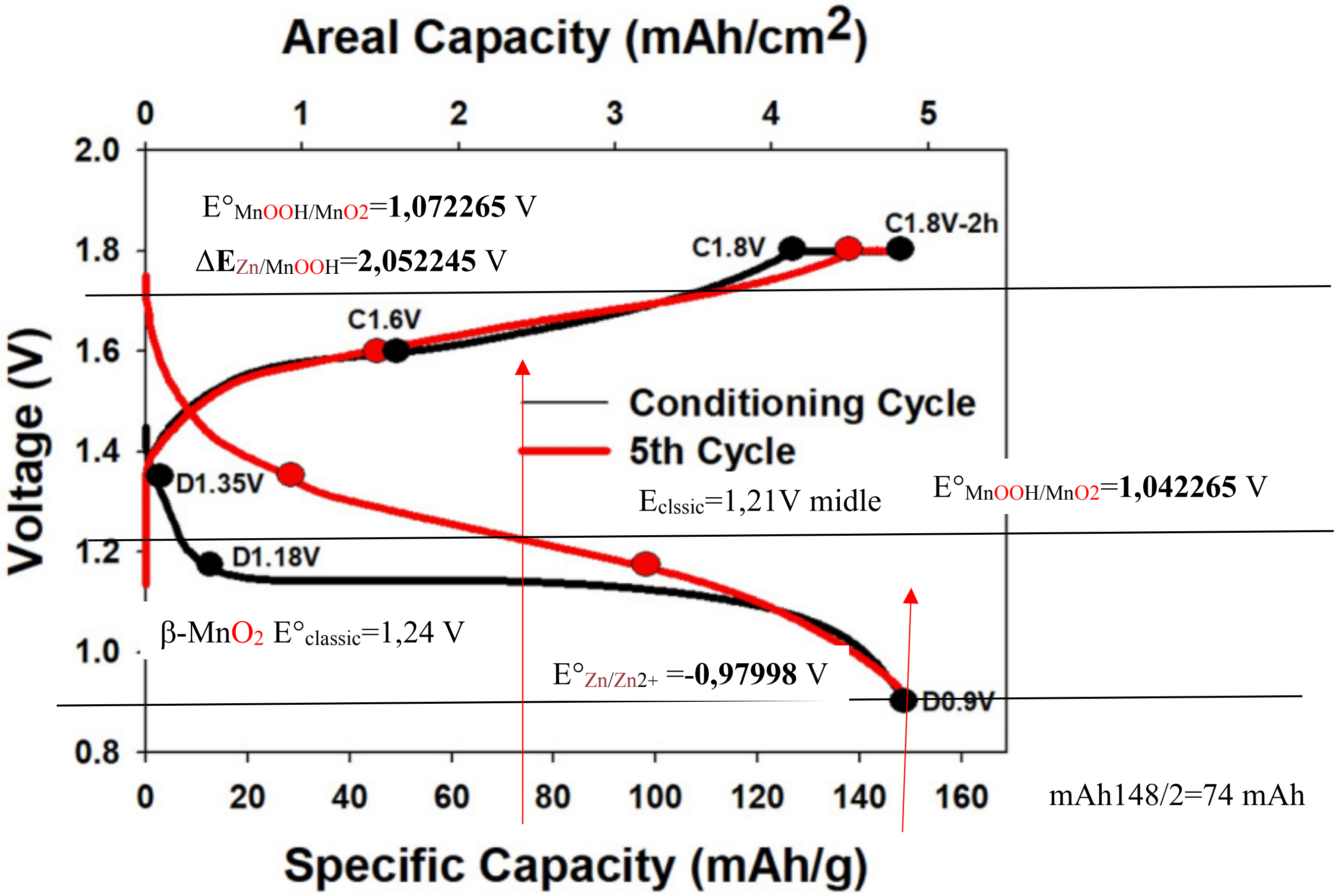


Figure 2. Discharge/charge voltage profiles for the first and fifth cycles of a Zn||EMD cell showing where electrodes were extracted for characterization. $\underline{MnO_2}+H_3O^+\mathbf{+e^-}=MnOOH+H_2O$; $Zn+H_2O=Zn^{2+}\mathbf{+2e^-}$;

Manganese(III) oxyhydroxide $MnOOH+H_2O=\beta\text{-}MnO_2+H_3O^{+}+e^{-}$; oxidation Nernst's half reaction Average standard potential has $E°_{classic}$=1,24 V [36], water logarithm and sum ΔE°:

$$E°_{MnOOH/MnO2}=E°-0{,}0591/1\bullet\log(1/[H_2O]^1)+0{,}10166-0{,}37239=1{,}24+0{,}103+0{,}10166-0{,}37239=\mathbf{1{,}072265}\text{ V};$$

$\beta\text{-}MnO_2+H_3O^{+}+e^{-}=MnOOH+H_2O$;inverse $\Delta G_{MnOOH/MnO2}=E°_{MnOOH/MnO2}\bullet F\bullet 1=\mathbf{-1{,}072265}*96485*1=\mathbf{-103{,}4575}$ kJ/mol,

$$\Delta\mathbf{G}_{eqMnOOH/MnO2}=G_{MnOOH}+G_{H2O}-(G_{MnO2}+G_{H3O+})=\mathbf{255{,}62}+0-(\mathbf{336{,}6374}+22{,}44)=\mathbf{-103{,}4575}\text{ kJ/mol},$$

$$G_{MnOOH}=\Delta\mathbf{G}_{eqMnOOH/MnO2}+G_{H2O}-(G_{MnO2}+G_{H3O+})=\mathbf{-103{,}4575}-0+(\mathbf{336{,}6374}+22{,}44)=\mathbf{255{,}62}\text{ kJ/mol},$$

Formation $\Delta G°_{MnOOH}=G_{MnOOH}-(G_{Mn}+G_{O2}^{gas}+0{,}5G_{H2})=\mathbf{255{,}62}-(\mathbf{448{,}971}+\mathbf{303{,}1}+0{,}5*\mathbf{85{,}64})=\mathbf{-538{,}849}$ kJ/mol.

$$G_{MnOOH}=\Delta G°_{MnOOH}+(G_{Mn}+G_{O2}^{gas}+0{,}5G_{H2})=\mathbf{-538{,}849}+(\mathbf{448{,}971}+\mathbf{303{,}1}+0{,}5*\mathbf{85{,}64})=\mathbf{256{,}042}\text{ kJ/mol}.$$

$$\mathbf{K}_{eqMnOOH/MnO2}=[MnOOH]*[H_2O]/[\underline{MnO_2}]/[H_3O^{+}]=([MnOOH]/[\underline{MnO_2}])*(55{,}3/10^{(-7{,}36)})=10^{18{,}125}=$$

$$=\mathbf{exp(-\Delta G_{eqMnOOH/MnO2}/R/T)}=\exp(\mathbf{103457{,}5}/8{,}3144/298{,}15)=10^{18{,}125};$$

In water medium and pH=7,36 ratio is $([MnOOH]/[\underline{MnO_2}])=10^{18{,}125}/(55{,}3/10^{(-7{,}36)})=1052627880$;

ε-MnO_2 E°=1,322 V; β-MnO_2 E°=1,238 to 1,242 V; average $E°_{classic}$=1,24 V; γ-MnO_2 E°=1,322 V; [36] standard Gibbs energies of formation are calculated to β-MnO_2 be -462,7 kJ/mol and ε-MnO_2 -427,3 kJ/mol, rand from CRC 2017 [1] $\Delta G°_{MnO2}$=-465,1 kJ/mol likeβ-MnO_2 be -462,7 kJ/mol respectively.

Formation shows more deep stability $\Delta G°_{MnOOH}$=**-535,5297** kJ/mol between manganesium oxides, where one mol manganesium invest free energy G_{Mn}=**448,971** kJ/mol, as in formation of β-MnO_2 just G_{Mn}=**162** kJ/mol.

Since β-MnO_2 is the thermodynamically most stable in phase of MnO_2, these formation energies indicate that the ε-MnO_2 is less stable by -35,4 kJ/mol, i. e., ε-MnO_2 => β-MnO_2 ΔG° transform: -35:4 kJ/mol ;

$Zn+H_2O=Zn^{2+}+\mathbf{2e^{-}}$, $2\beta\text{-}MnO_2+2H_3O^{+}+\mathbf{2e^{-}}=2MnOOH+2H_2O$; $Zn+2\beta\text{-}MnO_2+2H_3O^{+}=Zn^{2+}+2MnOOH+2H_2O$,

Absolute potential has $E°_{Classic}$=-0,7618 V [32], water logarithm -0,0515 and sum ΔE° summa

ΔE°: $E°_{Zn/Zn2+}=E°_{classic}-0{,}0591/2*\log(1/([H_2O]))+\Delta E°=-0{,}7618+0{,}051497+0{,}10166-0{,}371339=\mathbf{-0{,}97998}$ V.

$$\Delta\mathbf{G}_{eq\_Zn}=E°_{Zn}\bullet F\bullet 2=\mathbf{-0{,}97998}*96485*2=\mathbf{-189{,}10674}\text{ kJ/mol},$$

$$\Delta\mathbf{G}_{eqZn}=G_{Zn2+}-(G_{Zn}+G_{H2O})=\mathbf{215{,}55}-(\mathbf{404{,}657}+\mathbf{0})=\mathbf{-189{,}107}\text{ kJ/mol};$$

$$G_{Zn2+}=\Delta\mathbf{G}_{eqZn}+(G_{Zn}+G_{H2O})=\mathbf{-189{,}107}+(\mathbf{404{,}657}+\mathbf{0})=\mathbf{215{,}55}\text{ kJ/mol};$$

$$\Delta\mathbf{G}_{eq\,Zn/MnOOH}=(E°_{Zn/Zn2+}-E°_{MnOOH/MnO2})\bullet F\bullet 1\bullet 2=\mathbf{(-0{,}97998-1{,}0723)}*96485*2=\mathbf{-2{,}0523}*96485*2=\mathbf{-396{,}0217}\text{ kJ/mol}.$$

$$\mathbf{K}_{eq}\mathbf{=exp(-\Delta G_{eq\,H/MnO4}/R/T)}=\exp(\mathbf{396021{,}7}/8{,}3144/298{,}15)=\exp(159{,}7546)=10^{69{,}3805};$$

Sum of standard potentials $\Delta\mathbf{E}_{Zn/MnOOH}=(E°_{Zn/Zn2+}-E°_{MnOOH/MnO2})=(\mathbf{-0{,}97998-1{,}072265})=\mathbf{-2{,}052245}$ V;

$$MnO_4^{-}+8H_3O^{+}+5e^{-}=Mn^{2+}+12H_2O;\ \underline{5H(Pt)}+5H_2O=5H_3O^{+}+5e^{-};$$

$$MnO_4^{-}+3H_3O^{+}+\underline{5H(Pt)}=Mn^{2+}+7H_2O;$$

Balancing the Electrons $+ne^{-}=5e^{-}=-ne^{-}$ gives the Red-Ox reaction: $MnO_4^{-}+3H_3O^{+}+\underline{5H(Pt)}=Mn^{2+}+7H_2O$;

Absolute scale Biochemistry Thermodynamic, Massachusetts Technology Inst. [8] pH=7,36

$\Delta\mathbf{G}_{eqH/MnO4}=(E°_{H}-E°_{MnO4-})\bullet F\bullet 1\bullet 5=(-0{,}27073\mathbf{-1{,}483458})*96485*5=\mathbf{-1{,}754188}*96485*5=\mathbf{-846{,}2641459}$ kJ/mol

$\Delta G_{HessPt)H}=G_{Mn2+}+7G_{H2O}-(G_{MnO4}+3G_{H3O}+5G_{H(Pt)})=\mathbf{177{,}989}+7*0-(\mathbf{714{,}133}+3*\mathbf{22{,}44}+5*\mathbf{48{,}56})=\mathbf{-846{,}2642}$ kJ/mol;

$G_{MnO4-}=G_{Mn2+}+7G_{H2O}-(\Delta G_{HessPt)H}+3G_{H3O}+5G_{H(Pt)})=\mathbf{177{,}989}+7*0-(\mathbf{-846{,}2642}+3*\mathbf{22{,}44}+5*\mathbf{48{,}56})=\mathbf{714{,}133}$ kJ/mol;

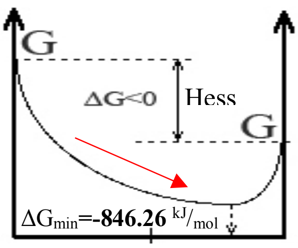
$G_{Mn2+}=\Delta G_{HessPt)H}-7G_{H2O}+(G_{MnO4}+3G_{H3O}+5G_{H(Pt)})=\mathbf{-846{,}2642}-7*0+(\mathbf{714{,}133}+3*\mathbf{22{,}44}+5*\mathbf{48{,}56})=\mathbf{177{,}989}$ kJ/mol;

$$E°_{H}-E°_{MnO4-}=\mathbf{-1{,}754188}\text{ V}$$

$\mathbf{K}_{eq}\mathbf{=exp(-\Delta G_{eq\,H/MnO4}/R/T)}=\exp(\mathbf{846264{,}1459}/8{,}3144/298{,}15)=\exp(341{,}382)=10^{148{,}26}$;

Exothermic and exoergonic MnO_4^{-} reduction by $\underline{5H(Pt)}$ Hess free energy change negative and equilibrium state minimum $\Delta\mathbf{G}_{min}=\Delta\mathbf{G}_{eqOxRed}$=**-846,26** kJ/mol reaching

equilibrium mixture $10^{148{,}5}=\mathbf{K}_{eq}=\dfrac{[H_2O]^7\cdot[Mn^{2+}]}{[(Pt)H]^5\cdot[MnO_4^{-}]\cdot[H_3O^{+}]^3}$;



5A+B+3C 50% D+8E

reactants $\underline{5H(Pt)}+MnO_4^{-}+3H_3O^{+}$

products $Mn^{2+}+7H_2O$

Prigogine attractor is free energy change minimum ΔG_{min}. Free energy change minimum reaching establishes equilibrium. Equilibrium state is attractor for all infinite non-equilibrium states.

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