

Protolytic solubility in water relates the absolute electrode potential to the zero of the absolute free energy scale $G_{H_2O} = G_{CO_2, gas} = 0$ kJ/mol and depends on absolute temperature. In solubility and protolysis reactions with water molecules, instead of classical molar concentrations, thermodynamics requires the use of mole fractions of water, soluble reactants and products.

The solubility and protolysis process consumes water molecules for aqua dissolve product formation.

Solubility of gases: oxygen $O_{2, gas} + H_2O = O_{2, aq}$; hydrogen $H_{2, gas} + H_2O = H_{2, aq}$; nitrogen $N_{2, gas} + H_2O = N_{2, aq}$; hydrogen sulfide $H_2S_{gas} + H_2O = H_2S_{aq}$; sulfur dioxide $SO_{2, gas} + H_2O = H_2SO_{3, aq}$;
Electrodes of metals: hydrogen $H(Pt) + H_2O = H_3O^+ + e^-$; iron $Fe_{(s)} + H_2O = Fe^{2+} + 2e^-$; zinc $Zn + H_2O = Zn^{2+} + 2e^-$; copper amalgam $Cu(Hg) + H_2O = Cu^{2+} + (Hg) + 2e^-$; silver $Ag_{(s)} + H_2O = Ag^+ + e^-$; chromium $Cr + H_2O = Cr^{3+} + 3e^-$;
For solid solubility: silver chloride $AgCl_{(s)} + 2H_2O = Ag^+ + Cl^-$; calomel $Hg_2Cl_{2(s)} + 3H_2O = Hg_2^{2+} + 2Cl^-$; mercury(II) oxide $Hg + H_2O + 2OH^- = HgO + 2H_2O + 2e^-$, mercury(I) sulfate $Hg_2SO_{4(s)} + 2H_2O = Hg_2^{2+} + SO_4^{2-}$;
For protolysis: peroxide $H_2O_2 + H_2O = H_3O^+ + HOO^-$ pK_a=11,75; water $2H_2O = H_3O^+ + OH^-$ pK_w=14.

The solubility of gaseous oxygen $O_{2, gas} + H_2O = O_{2, aq}$ in oxidation half-reaction compensates one water molecule $6H_2O = O_{2, gas} + H_2O + 4H_3O^+ + 4e^-$ from six to five $5H_2O = O_{2, aq} + 4H_3O^+ + 4e^-$. Its decreases the calculate free energy content of metal hydrogen from $G_{H(Pt)} = 51.05$ kJ/mol to $G_{H(Pt)} = 48.56$ kJ/mol. The absolute standard potential scale reference increases from $E^{\circ}_H = -0.29654$ V to $E^{\circ}_H = -0.27073$ V less negative. The absolute potential scale shift down of thermodynamic 0,10166 V to absolute -0.37239 V so coupled sum is $\Delta E^{\circ} = +0.10166 - 0.37239$. Standard potential shift down to $E^{\circ}_{O_2} = 1.0868$ V for oxygen and for glucose to $E^{\circ}_{C_6H_{12}O_6} = -0.13858$ V.

The operations sequence of the absolute standard potential determination: $E^{\circ}_{O_2} = 1.0868$ Volts for two water oxygen oxidation in Nernst's half-reaction $5H_2O = O_{2, aq} + 4H_3O^+ + 4e^-$.

From Nernst classical value $E^{\circ}_{classic O_2} = 1.2288$ V subtract $E^{\circ}_{H_2O} = -0.0591/4 * \log(1/55.3^{15}) = 0.1287$ the counting logarithm of five water molecules. The concentration of water in one liter is 55.3 M if solution concentrations sum is less as 0.1 M. Then add the coupled sum $\Delta E^{\circ} = +0.10166 - 0.37239$. The absolute standard potential is summing from three components: classic $E^{\circ}_{classic}$ + water logarithm account + ΔE° the coupled sum:

$$E^{\circ}_{O_2} = E^{\circ}_{classic O_2} - 0.0591/4 * \log(1/55.3^{15}) + \Delta E^{\circ} = 1.2288 + 0.1287 + 0.10166 - 0.37239 = 1.0868 \text{ Volts.}$$

The Nernst half-reaction $5H_2O = O_{2, aq} + 4H_3O^+ + 4e^-$ is expressed with absolute potential in mathematic equation:

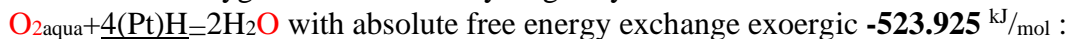
$$E_{O_2} = E^{\circ}_{O_2} + 0.0591/4 * \log \frac{[O_2]_{aqua} \cdot [H_3O^+]^4}{[H_2O]^5} = 1.0868 + 0.0591/4 * \log \frac{[O_2]_{aqua} \cdot [H_3O^+]^4}{55,3^{15}} \text{ Volts.}$$

The inverse standard potential for the reduction of oxygen $O_{2, aq} + 4H_3O^+ + 4e^- = 5H_2O$ has minus sign $-E^{\circ}_{O_2}$.

The oxygen reducing reaction is exoergic $\Delta G_{eq O_2} = E^{\circ}_{O_2} \cdot F \cdot n = 1.0868 * 96485 * 4 / 1000 = -419.44$ kJ/mol; $\Delta G_{eq O_2} = 5G_{H_2O} - (G_{O_{2, aq}} + 4G_{H_3O^+}) = 5 * 0 - (329.68 + 4 * 22.44) = -419.44$ kJ/mol; and coincides with the absolute potential scale. Oxygen energy $G_{O_{2, gas}} = 303.1$ kJ/mol grows $G_{O_{2, aq}} = G_{O_{2, gas}} + G_{O_{2, sp}} = 303.1 + 26.58 = 329.68$ kJ/mol at solubility.

Nernst's hydrogen oxidation $4(Pt)H + 4H_2O = 4H_3O^+ + 4e^-$ standard absolute potential is $E^{\circ}_H = -0.27073$ Volts.

In sum reduction reaction of oxygen with metallic hydrogen synthesizes two water molecules:



$$\Delta G_{eq} = (E^{\circ}_H - E^{\circ}_{O_2}) \cdot F \cdot 1 \cdot 4 = (-0.27073 - 1.0868) * 96485 * 4 = -1.3575 * 96485 * 4 / 1000 = 2 * 261.96 = -523.925 \text{ kJ/mol.}$$

Exchange $\Delta G_{eq 2H_2O} = 2G_{H_2O} - 4G_{(Pt)H} - G_{O_{2, aqua}} = 2 * 0 - (4 * G_{(Pt)H} + 329.68) = -523.925$ kJ/mol gives metal hydrogen free energy content $G_{H(Pt)} = (2G_{H_2O} - \Delta G_{eq 2H_2O} - G_{O_{2, aqua}}) / 4 = (2 * 0 + 523.925 - 329.68) / 4 = 194.245 / 4 = 48.56$ kJ/mol.

The determination of the hydrogen electrode reference point $E^{\circ}_H = -0.27073$ V on the absolute potential and absolute free energy scales in the Nernst half reaction is based on the property of inverse symmetry: The potential and free energy change of the inverse reaction belong to the same number with opposite sign on both absolute scales.

Absolute and **inverse** free energy and potential scaling requires accounting for water and hydroxonium based on Alberty's data for hydrogen gas and the absolute free energy value of the solution. [8]

In the reaction, $H(Pt) + H_2O = H_3O^+ + e^-$, the standard absolute potential is $E^{\circ}_H = -0.27073$ V.

The standard oxidation of hydrogen using absolute standard potential produced absolute free energy change is exoergic: $\Delta G_{eq} = E^{\circ}_H \cdot F \cdot 1 \cdot 1 = -0.27073 * 96485 * 1 = -26.12$ kJ/mol and is identical to the change in the absolute free energy calculated by Hess's law on a scale related to the zero free energy content of water $G_{H_2O} = 0$ kJ/mol:

$$\Delta G_{Hess, eq} = G_{H_3O^+} + G_{e^-} - (G_{H(Pt)} + G_{H_2O}) = 22.44 + 0 - (48.56 + 0) = -26.12 \text{ kJ/mol.}$$

The **absolute** standard potential $E^{\circ}_H = -0.27073$ in Volts coincides with Alberty absolute free energy. [8,15]

I type electrode hydrogen metal **H(Pt)** interface / to its cations **H₃O⁺** solution application

Attractor pH=7.36 staying at equilibrium have true pOH=6.64 value as pK_w=14=pH+pOH=7.36 +6.64. Water amount in titer is [H₂O]=963/18=53.5 M for [H₂SO₄]=[H₃O⁺]=1 M solution with 1.061 g/mL density in Nernst equations for **hydrogen electrode** has classic standard potential E_{o_classic}=0 V reference zero:

H(Pt)=H⁺+e⁻; E_{classic}=E_{o_classic}+0.0591•logK^o_{classicH(Pt)}=0+0.0591•log[H⁺]=0+0.0591•log(1 M)=0 Volts. [11] Thermodynamic account Hydroxonium ions demand the water: **H(Pt)+H₂O<=>H₃O⁺+e⁻** and E^o_H=0.10166 V. The ratio [H₃O⁺]/([H₂O]-[H₃O⁺])=1 M/52.5 M=X_{H₃O⁺}/X_{H₂O} is mol fraction instead molarity [H⁺]=1 M at classic potential expression. The water account gave thermodynamic standard E^o_H=0.10166 V on potential scale.

Nernst's expression with classic zero measurement demands thermodynamic standard potential E^o_H=0.10166 V :

$$E = E^{\circ}_H + \ln(10) \cdot R \cdot T / F \cdot 1 \cdot \log(X_{H_3O^+} / X_{H_2O}) = E_o + E^{\circ}_H + 0.0591 \cdot \log(1/52.5) = 0.10166 - 0.10166 = 0 \text{ V.}$$

As ratio **1=K_{H(Pt)}=X_{H₃O⁺}/X_{H₂O}** is one than E^o_H=0.10166 V is thermodynamic standard potential:

$$E = E^{\circ}_H + \frac{\ln(10) \cdot R \cdot T}{F \cdot 1} \cdot \log \frac{X_{H_3O^+}}{X_{H_2O}} = 0.10166 + 0.0591 \cdot \log(1) = 0.10166 \text{ V. Metal oxidation free energy change}$$

minimum is different endoergic ΔG_{eq}=E^o_H•F•1=0.10166*96485*1=9.81 kJ/mol instead Alberty is exoergic.

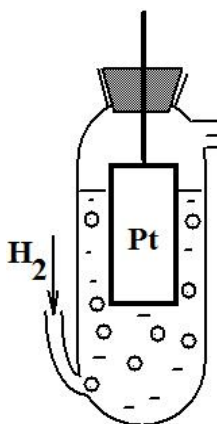
Alberty Hess value is in did exoergic: ΔG_{Hess_eq}=G_{H₃O⁺}+G_{e⁻}-(G_{H(Pt)} +G_{H₂O})=22.44+0-(48.56+0)=-26.12 kJ/mol .

Free energy changes are determined on water and carbon dioxide gas as zero G_{H₂O}=G_{CO₂gas}=G_{e⁻}=0 kJ/mol reference scale. Absolute scale hydrogen standard potential is E^o_H=ΔG_{eq}/F1=-26.12/96485/1=-0.27073 Volts. Equilibrium free energy change minimum is exoergic ΔG_{eq}=E^o_H•F•1=-0.27073*96485*1=-26.12 kJ/mol coincident with Alberty data. Absolute potential scale decreases about ΔE=-0.27073-0.10166=-0,37239 Volts relative to classic zero scale. Nernst's equilibrium constant is grater as one for metal oxidation to hydroxonium ion favored **K_{H(Pt)_Red}=[H₃O⁺]*[e⁻]/[H₂O]/[H(Pt)]=EXP(-ΔG_{Alberty}/R/T)=EXP(26120/8,3144/298,15)=37675,6.**

I type electrode Metal interface **H(Pt)** / on its cation **H₃O⁺** solution application.

High rate protolysis attractors [H₃O⁺]=10^{-7.36} M , pH=7.36 and water mass [H₂O]=996/18=55.3 M account in liter shows metal hydrogen strong reducing potential E_{pH=7.36}=-0.27073+0.0591*log(10^{-7.36}/55.3)=-0.8087 V and free energy change at homeostasis exoergic ΔG_{eqpH_7.36}=E^o_H•F•1=-0.8087*96485*1/1000=-78,03 kJ/mol .

Nernst's half reaction metal has reduction potential and energy change E^o_H=-0.27073 V and ΔG_{eq}=-26.12 kJ/mol.



Platinum sheet immersed in hydroxonium ions [H⁺]=[H₃O⁺]=[H₂SO₄]=1 M sulfuric acid solutions **H(Pt)<=>H⁺+e⁻**: E=E^o+0.0591•log[H⁺]=0.0+0.0591•log(1 M)=0 V is classic.

Ratio [H₃O⁺]/[H₂O]=1/52.5=X_{H₃O⁺}/X_{H₂O} instead zero 0 classic give thermodynamic standard potential: E^o_H=0.10166 V and from Alberty data on absolute scale

the absolute standard potential is E^o_H=-0.27073 Volts.

$$\text{absolute } E^{\circ}_H = -0.27073 \text{ V}$$

$$\text{classic zero } E^{\circ}_H = 0 \text{ V}$$

$$0.10166 \text{ V } E, \text{V}$$

$$E_{(Pt)H/H^+} = E^{\circ}_H + 0.0591 \cdot \log\left(\frac{X_{H_3O^+}}{X_{H_2O}}\right) \quad E_{H_classic} = E^{\circ}_H + 0.0591 \cdot \log([H_3O^+]) \quad \text{thermodynamic } E^{\circ}_H$$

Absolute standard potential E^o_H=-0.27073 V based on Alberty data G_{H₂gas}=85.64 kJ/mol and G_{H₂aq}=103.24 kJ/mol for hydrogen, which was detected on water and carbon dioxide gas

G_{H₂O}=G_{CO₂gas}=G_{e⁻}=0 kJ/mol as zero scale reference. Reducing agent metal hydrogen at

pH=7.36, [H₃O⁺]=10^{-7.36} M with potential E_{pH=7.36}=-0.27073+0.0591*log(10^{-7.36}/55.3)=-0.8087 V is strong reductant. Free energy content in one mol metal hydrogen is: G_{H(Pt)}=48.56 kJ/mol .

Substance	ΔH ^o _H , kJ/mol	ΔS ^o _H , J/mol/K	ΔG ^o _H , kJ/mol	ΔG ^o _{H₂O} =G _{H₂O} -(G _{H₂aq} +G _{O₂aq} /2)=-0-(103,24+88,04/2)=-147,26 kJ/mol;
H ₂ O	-285.85	69.9565	-237.191	G _{H₂O} =ΔG _{H₂O} Alberty-(ΔG ^o _{H₂O})=-151.549-(-237.191)=85.6 kJ/mol [8]
H ₂ O	-286.65	-453.188	-151.549	ΔG _H =ΔH _H -T*ΔS _H =-286.65-298.15*-0.453188=-151.5 kJ/mol;
H ₃ O ⁺	-285.81	-3.854	-213.2746	ΔG ^o _{H₃O⁺} , kJ/mol Mischenko 1972, Himia, Leningrad [26]
H ₂ gas	Alberty	pH=7,36	85.64	Biochem.Thermodyn. Massachusetts Technology Inst. [8]
H(Pt)(aq)	E ^o _H =	-0,27073	48,56	ΔG _{Hess_eq} =G _{H₃O⁺} -(G _{H(Pt)} +G _{H₂O})=22.44-(48.56+0)=-26.12 kJ/mol.
H ₂ (aq)	-5.02	-363.92	103.24	2006, Massachusetts Technology Inst. Alberty pH=7,36 [8]
O ₂ aqua	-11.70	-94.2	16.4	2006, Massachusetts Technology Inst. Alberty pH=7,36 [8]

The solubility of gaseous hydrogen $\text{H}_{2\text{gas}}+\text{H}_2\text{O}=\text{H}_{2\text{aq}}$ compensates for $\text{H}_{2\text{gas}}+2\text{H}_2\text{O}=\text{H}_{2\text{aq}}+\text{H}_2\text{O}=2\text{H}_3\text{O}^++2\text{e}^-$ one water molecule in Nernst oxidation of hydrogen to hydroxonium and is arbitrary because the change in absolute free energy is negative $\Delta G_{\text{Hess}_\text{H}_3\text{O}^+}=2G_{\text{H}_3\text{O}^+}+2G_{\text{e}^-}-(G_{\text{H}_{2\text{aq}}}+G_{\text{H}_2\text{O}})=2*22.44+2*0-(103.24+0)=-58.36 \text{ kJ/mol}$. A graphite electrode oxidizes a solution of $\text{H}_{2\text{aq}}$ to hydroxonium at the absolute standard potential:

$$E^\circ_{\text{H}_{2\text{aq}}}=-58.36*1000/96485/2=-0.3024 \text{ V.}$$

The sum of the Nernst and inverse half reactions $\text{H}_{2\text{aq}}+\text{H}_2\text{O}=2\text{H}_3\text{O}^++2\text{e}^-$; $2\text{H}_3\text{O}^++2\text{e}^-=2\text{H(Pt)}+2\text{H}_2\text{O}$ shows the solubility of hydrogen in the platinum crystal lattice $\text{H}_{2\text{aq}}=2\text{H(Pt)}+\text{H}_2\text{O}$;

The oxidation potential of hydrogen solution $\text{H}_{2\text{aq}}+\text{H}_2\text{O}=2\text{H}_3\text{O}^++2\text{e}^-$ $E^\circ_{\text{H}_{2\text{aq}}}=-0.302 \text{ V}$ plus the inverse potential $E^\circ_{\text{H(Pt)}}=+0.27073 \text{ V}$ in the electrochemical solubility of the metal $2\text{H}_3\text{O}^++2\text{e}^-=\text{H(Pt)}+2\text{H}_2\text{O}$ shows the solubility of hydrogen mole fraction $[\text{H}_{2\text{aq}}]/[\text{H}_2\text{O}]$ in platinum exoergic, arbitrary at value of equilibrium constant $K_{\text{spH(Pt)}}$ greater as one:

$$\Delta G_{\text{spH(Pt)}}=\Delta E^\circ_{\text{spH(Pt)}}\cdot F\cdot 2=(E^\circ_{\text{H}_{2\text{aq}}}-E^\circ_{\text{H(Pt)}})\cdot F\cdot 2=(-0.302+0.27073)*96485*2=-0.03128*96485*2=-6.03 \text{ kJ/mol}$$
 and constant $K_{\text{spH(Pt)}}=[\text{H(Pt)}]^2\cdot[\text{H}_2\text{O}]/[\text{H}_{2\text{aq}}]=\text{EXP}(-\Delta G_{\text{spH(Pt)}}/R/T)=\text{EXP}(6036,1/8,3144/298,15)=11,415$.

The solubility in platinum $\text{H}_{2\text{aq}}=2\text{H(Pt)}+\text{H}_2\text{O}$ shows the electrochemical solubility product of hydrogen in the metal exoergic $\Delta G_{\text{sp}_\text{H(Pt)}}=2G_{\text{H(Pt)}}+G_{\text{H}_2\text{O}}-(G_{\text{H}_{2\text{aq}}})=2*48.56+0-(103.24)=-6.12 \text{ kJ/mol}$ and constant greater as >1 :

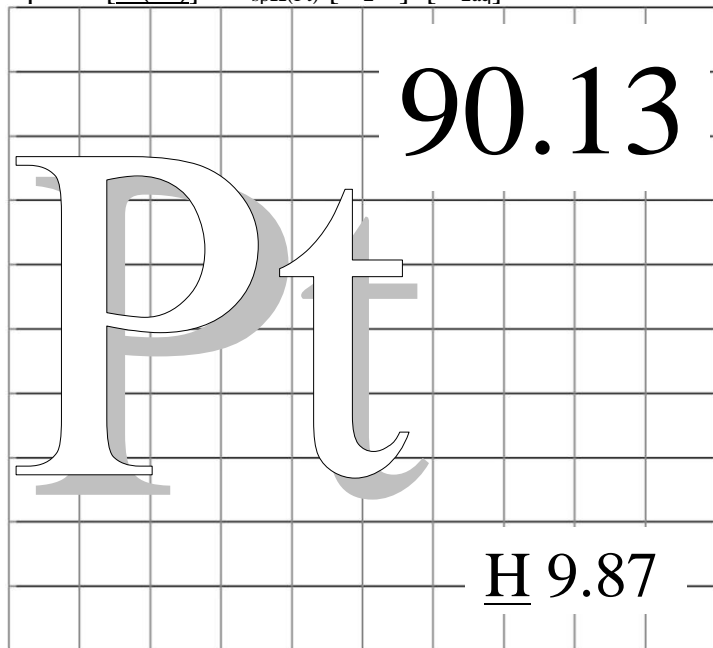
$$K_{\text{sp}_\text{H(Pt)}}=[\text{H(Pt)}]^2\cdot[\text{H}_2\text{O}]/[\text{H}_{2\text{aq}}]=\text{EXP}(-\Delta G_{\text{sp}_\text{H(Pt)}}/R/T)=\text{EXP}(6120/8.3144/298.15)=11.808$$
 .

Solubility $\text{H}_{2\text{gas}}+\text{H}_2\text{O}=\text{H}_{2\text{aq}}$ constant $\Delta G_{\text{H}_{2\text{spAlberty}}}=G_{\text{H}_{2\text{aq}}}-G_{\text{H}_{2\text{gas}}}-G_{\text{H}_2\text{O}}=103,24-85,64-0=17,6 \text{ kJ/mol}$ is weak:

$$K_{\text{H}_{2\text{sp}}}=[\text{H}_{2\text{aq}}]/[\text{H}_2\text{O}]/X_{\text{H}_{2\text{gas}}}=\text{EXP}(-\Delta G_{\text{H}_{2\text{sp}}}/R/T)=\text{EXP}(-17600/8,3144/298,15)=0,0008253.$$

It calculates the solubility $[\text{H}_{2\text{aq}}]=K_{\text{H}_{2\text{sp}}}\cdot[\text{H}_2\text{O}]\cdot X_{\text{H}_{2\text{gas}}}=0,0008253*55,3*1=0,04564 \text{ M}$, if the mole fraction of pure gas is one $X_{\text{H}_{2\text{gas}}}=1$.

From the ratio $[\text{H(Pt)}]^2/[\text{H}_{2\text{aq}}]=K_{\text{sp}_\text{H(Pt)}}/[\text{H}_2\text{O}]=11.808/55.3=0.213526$ obtains mol fraction of H(Pt) metal square: $[\text{H(Pt)}]^2=K_{\text{spH(Pt)}}/[\text{H}_2\text{O}]\cdot[\text{H}_{2\text{aq}}]=11.808/55.3*0.04564=0.009745$.



Saturated solubility in platinum lattice $[\text{H(Pt)}]=\text{SQRT}(0.009745)=0.0987$ in mol fraction units is hydrogen atom surface fraction 9.87% shared with platinum atoms fraction 90.13% on total 100% platinum lattice surface. $\text{H}_{2\text{aqAlberty}}=2\text{H(Pt)}+\text{H}_2\text{O}$ Solubility mol fractions concentrations are unit less as constant too $K_{\text{sp}_\text{H(Pt)}}=11.808$.

H(Pt) solubility in water $2\text{H(Pt)}+\text{H}_2\text{O}=\text{H}_{2\text{aqAlberty}}$ constant is less as one $K_{\text{spH(Pt)_H}_{2\text{aq}}}=1/11.808=0.08469$ and $\Delta G_{\text{Alberty}}=G_{\text{H}_{2\text{aq}}}-2G_{\text{H(Pt)}}-G_{\text{H}_2\text{O}}=6.12 \text{ kJ/mol}$ positive, unfavored, non-spontaneous. It keeps metal lattice saturated with hydrogen 9.87%, because is positive 6.12 kJ/mol and constant less as one 0.08469 so is unfavored for hydrogen dissolution

$$K_{\text{spH(Pt)_H}_{2\text{aq}}}=[\text{H}_{2\text{aq}}]/[\text{H(Pt)}]^2/[\text{H}_2\text{O}]=\text{EXP}(-\Delta G_{\text{sp}_\text{H(Pt)}}/R/T)=\text{EXP}(-6120/8.3144/298.15)=0.08469.$$

Metal iron I-type electrode in $[\text{Fe}^{2+}]=0.1 \text{ M}$ solution, density 1.03 g/mL , $0.1 \text{ Molarity mass FeSO}_4=15.191 \text{ g}$. $\text{Fe(s)}+\text{H}_2\text{O}=\text{Fe}^{2+}+2\text{e}^-$. The absolute standard potential is composed of the classic $E^\circ_{\text{classic}}=-0.4402 \text{ V}$ standard potential [17], the logarithm of water accounting $-0.0591/2*\log(1/(55.3))=0.0515$ and the coupled sum $\Delta E^\circ=+0.10166-0.37239$ in the expression:

$$E^\circ_{\text{Fe/Fe}^{2+}}=E^\circ_{\text{classic}}-0.0591/2*\log(1/([\text{H}_2\text{O}]))+\Delta E^\circ=-0.4402+0.0515+0.10166-0.37239=-0.65943 \text{ V.}$$

$$E_{\text{Fe}}=E^\circ_{\text{Fe/Fe}^{2+}}+0.0591/2*\log([\text{Fe}^{2+}]/[\text{Fe}]/([\text{H}_2\text{O}]))=-0.65943+0.0591/2*\log(0.1/1/(55.3))=-0.74048 \text{ V;}$$

$$\Delta G_{\text{eq}_\text{Fe}}=E^\circ_{\text{Fe}}\cdot F\cdot 2=-0.65943*96485*2=-127.25 \text{ kJ/mol,}$$

$$\Delta G_{\text{eq}_\text{Fe}}=G_{\text{Fe}^{2+}}-(G_{\text{Fe}}+G_{\text{H}_2\text{O}})=-82.14-(45.1+0)=-127.25 \text{ kJ/mol ;}$$

$G_{\text{Fe}}=G_{\text{Fe}^{2+}}-(\Delta G_{\text{eq}_\text{Fe}}+G_{\text{H}_2\text{O}})=-82.14-(-127.25+0)=45.1 \text{ kJ/mol}$; Difference -0.74048 V in the 4th digit $4 -0.74059 \text{ V}$.

$E_{\text{Fe}}=E^\circ_{\text{Fe/Fe}^{2+}}+0.0591/2*\log([\text{Fe}^{2+}]/[\text{Fe}]/([\text{H}_2\text{O}]-6[\text{Fe}^{2+}]))=-0.658382+0.0591/2*\log(0.1/1/(56.38-0.6))=-0.7395 \text{ V;}$
 $[\text{H}_2\text{O}]=55.3 \text{ M}=(996\text{g/L})/(18\text{g/mol})$; $m_{\text{H}_2\text{O}}=m_{\text{L}}-m_{\text{FeSO}_4}=1030-15.191=1014.8 \text{ g}$; $[\text{H}_2\text{O}]=1014.8 \text{ g}/18 \text{ g/mol}=56.38 \text{ M}$.

Coordinate metal ion aqua complexes are hexagonal like the hexa aqua iron(II) ion $[\text{Fe}^{2+}(\text{H}_2\text{O})_6]$ and like tetragonal as the tetra aqua copper(II) ion $[\text{Cu}^{2+}(\text{H}_2\text{O})_4]$.

Substance	ΔH°_H kJ/mol	ΔS°_H J/mol/K	ΔG°_H , kJ/mol
Fe	$E^\circ_{Fe} =$	-0.6594 V	45.11
Fe ²⁺	-87.45	-17.8	-82.14
Fe ²⁺	-89.1	-137.7	-78.9
Fe ³⁺	-44.79	-110	-11.99
Fe ³⁺	-48.5	-315.9	-4.7
Cu	$E^\circ_{Cu} =$	0.1243 V	70.02
Cu ²⁺	64.8	-98	94.0187
Zn	$E^\circ_{Zn} =$	-0.98098 V	68.65
Zn ²⁺	-153.39	-109.8	-120.653

$G_{Fe} = G_{Fe^{2+}} - (\Delta G_{eq_Fe} + G_{H_2O}) = -82.14 - (-127.25 + 0) = 45.11$ kJ/mol;
 [8] Biochem. Thermodyn. Massachusetts Technology Inst. pH=7,36
 CRC 2010 [1]
 $G_{Cu} = G_{Cu^{2+}} - (\Delta G_{eq_Cu} + G_{H_2O}) = 94.0187 - (24.0 + 0) = 70.02$ kJ/mol ;
 [1] $\Delta G_{Cu^{2+}} = \Delta H_H - T \cdot \Delta S_H = 64.8 - 298.15 \cdot -0.098 = 94.0187$ kJ/mol;
 $G_{Zn} = G_{Zn^{2+}} - (\Delta G_{eq_Zn} + G_{H_2O}) = -120.653 - (-189.3 + 0) = 68.65$ kJ/mol;
 [1] $\Delta G_{Zn^{2+}} = \Delta H_H - T \cdot \Delta S_H = -153.39 - 298.15 \cdot -0.1098 = -120.65$ kJ/mol;

Metal copper I-type electrode in $[Cu^{2+}] = 1$ M solution, density 1.19 g/mL and Molar mass $M_{CuSO_4} = 159.602$ g/mol;
 $Cu(Hg) + H_2O = Cu^{2+} + (Hg) + 2e^-$; The absolute standard potential is composed of the classic $E^\circ_{classic} = 0.3435$ V
 standard potential [18], the logarithm of water accounting $-0.0591/2 \cdot \log(1/(55.3)) = 0.0515$ and the coupled sum
 $\Delta E^\circ = +0.10166 - 0.37239$ in the expression:

$E^\circ_{Cu/Cu^{2+}} = E^\circ_{Classic} - 0.0591/2 \cdot \log(1/([H_2O])) + \Delta E^\circ_{Cu} = 0.3435 + 0.0515 + 0.10166 - 0.371339 = 0.1243$ V.
 $E_{Cu} = E^\circ_{Cu} + 0.0591/2 \cdot \log([Cu^{2+}]/[Cu]/([H_2O])) = 0.1243 + 0.0591/2 \cdot \log(1/1/(55.3)) = 0.0728$ V;
 Distinguish on number 0.0728 V in the second digit 0.0733 V.
 $m_{H_2O} = (m_L - m_{CuSO_4})/18 = 1190 - 159.602 = 1030.4/18 = 57.24 - 4 = 53.24$ mol;

$E_{Cu} = E^\circ_{Cu} + 0.0591/2 \cdot \log([Cu^{2+}]/[Cu]/([H_2O] - 4[Cu^{2+}])) = 0.1243 + 0.0591/2 \cdot \log(1 \text{ M}/1/(57.24 - 4)) = 0.0733$ V;
 $\Delta G_{eq_Cu} = E^\circ_{Cu} \cdot F \cdot 2 = 0.1243 \cdot 96485 \cdot 2 = 24.0$ kJ/mol, $\Delta G_{eq_Cu} = G_{Cu^{2+}} - (G_{Cu} + G_{H_2O}) = 94.0187 - (G_{Cu} + 0) = 24.0$ kJ/mol ;
 $G_{Cu} = G_{Cu^{2+}} - (\Delta G_{eq_Cu} + G_{H_2O}) = 94.0187 - (24.0 + 0) = 70.02$ kJ/mol;

Metal copper I-type electrode in $[Zn^{2+}] = C_{ZnSO_4} = 2$ M solution, density 1.31 g/mL, Molar mass $ZnSO_4 = 161.44$ g/mol, and mass of two moles $m_{ZnSO_4} = 2 \cdot 161.44 = 322.88$ g; $Zn + H_2O = Zn^{2+} + 2e^-$, standard potential $E^\circ_{Zn/Zn^{2+}} = -0.98098$ V.
 The absolute standard potential is composed of the classic $E^\circ_{classic} = -0.7628$ V standard potential [18], the logarithm of water accounting $-0.0591/2 \cdot \log(1/(55.3)) = 0.0515$ and the absolute potential coupled sum
 $\Delta E^\circ = +0.10166 - 0.37239$ in the expression:

$E^\circ_{Zn/Zn^{2+}} = E^\circ_{classic} - 0.0591/2 \cdot \log(1/([H_2O])) + \Delta E^\circ_{Zn} = -0.7628 + 0.0515 + 0.10166 - 0.371339 = -0.98098$ V.
 $E_{Zn} = E^\circ_{Zn/Zn^{2+}} + 0.0591/2 \cdot \log([Zn^{2+}]/[Zn]/([H_2O])) = -0.980981 + 0.0591/2 \cdot \log(2/1/(55.3)) = -1.0215$ V
 Distinguish on number -1.0215 V in the fourth digit -1.02358 V 2M;
 Solubility 57.7 g/100g in hundred grams of water; $w\% = 57.7/157.7 \cdot 100 = 36.6\%$;

$m_{H_2O} = m_L - m_{ZnSO_4} = 1310 - 161.44 \cdot 2 = 987.12$ g; $m_{ZnSO_4} = 2 \cdot 161.44 = 322.88$ g; $[H_2O] = 987.12/18 \text{ g/mol} = 54.84$ M.

$E_{Zn} = E^\circ_{Zn/Zn^{2+}} + 0.0591/2 \cdot \log \frac{[Zn^{2+}]}{[Zn] \cdot ([H_2O] - 4[Zn^{2+}])} = -0.980981 + 0.0591/2 \cdot \log(2/1/(54.84 - 4 \cdot 2)) = -1.02358$ V;
 $\Delta G_{eq_Zn} = E^\circ_{Zn} \cdot F \cdot 2 = -0.980981 \cdot 96485 \cdot 2 = -189.3$ kJ/mol, $\Delta G_{eq_Zn} = G_{Zn^{2+}} - (G_{Zn} + G_{H_2O}) = -120.65 - (G_{Zn} + 0) = -189.3$ kJ/mol ;
 $G_{Zn} = G_{Zn^{2+}} - (\Delta G_{eq_Zn} + G_{H_2O}) = -120.653 - (-189.3 + 0) = 68.65$ kJ/mol;

Metal chromium I-type electrode in $[Cr^{3+}] = 1$ M solution, M density 1.172 g/mL, molar $Cr_2(SO_4)_3 = 392.16$ g/mol mass, mass $m_{H_2O} = m_L - m_{Cr_2(SO_4)_2} = 1172 - 392.16 = 779.84$ g/L, amount $[H_2O] = 779.84/18 \text{ g/mol} = 43.3244$ M.
 $Cr + H_2O = Cr^{3+} + 3e^-$, absolute standard potential $E^\circ_{Cr/Cr^{3+}} = -0.9793$ V. The absolute standard potential is composed of the classic $E^\circ_{classic} = -0.744$ V standard potential [18], the logarithm $-0.0591/3 \cdot \log(1/(55.3)) = 0.03433$ of water accounting and the absolute potential coupled sum $\Delta E^\circ = +0.10166 - 0.37239$:

$E^\circ_{Cr/Cr^{3+}} = E^\circ_{Classic} - 0.0591/3 \cdot \log(1/([H_2O])) + \Delta E^\circ_{Cr} = -0.744 + 0.03433 + 0.10166 - 0.371339 = -0.9793$ V.
 $E_{Cr} = E^\circ_{Cr} + 0.0591/3 \cdot \log([Cr^{3+}]/[Cr]/([H_2O])) = -0.9793 + 0.0591/3 \cdot \log(1/1/55.3) = -1.0136$ V;
 Distinguish on number -1.0136 V 1M; in the third digit -1.00208 V 2.32 M;

$E_{Cr} = E^\circ_{Cr} + 0.0591/3 \cdot \log \frac{[Cr^{3+}]}{[Cr] \cdot ([H_2O] - 6[Cr^{3+}])} = -0.9793 + 0.0591/3 \cdot \log(2,343/1/(39,59 - 6 \cdot 1)) = -1,00208$ V;

Solubility 64 g/100g in hundred grams of water; $w\% = 64/164 \cdot 100 = 39.2\%$;

$39.2/100 \text{ g} = X/1172/\text{g/L}$; $39.2/100 \cdot 1172 = 459.4 = X/\text{g/L}$; $C_{Cr_2(SO_4)_2} = 459.4/392.16 = 2.343$ M $Cr_2(SO_4)_3$;

$m_{H_2O} = m_L - m_{Cr_2(SO_4)_2} = 1172 - 459.4 = 712.6$ g; $m_{Cr_2(SO_4)_2} = 457.07$ g; $[H_2O] = 712.6/18 \text{ g/mol} = 39.59$ M.

Note: Oxidative stress cause **non-enzymatic** oxidation in multiple radical chain and reactions of parallel product formations to contaminate and destroy the organism! Destructive hazard for life!

Oxygen gas solubility $O_{2gas}+H_2O=O_{2aq}$ compensate one water molecule $6H_2O=O_{2gas}+H_2O+4H_3O^++4e^-$ on Nernst's half reaction $5H_2O=O_{2aq}+4H_3O^++4e^-$, forming absolute standard potential $E^{\circ}_{5HOH}=1.0868$ V.

$$E^{\circ}_{5HOH}=E^{\circ}_{classic}-0.0591/4*\lg(1/[H_2O]^5)+\Delta E^{\circ}=1.2288+0.1287+0.10166-0.37239=1.0868$$
 V.

Oxygen solution $O_{2aq}+4H_3O^++4e^-=5H_2O$ is strong oxidant with inverse standard potential $-E^{\circ}_{5HOH}=-1.0868$ V.

The oxygen attracts four free electrons with four protons from hydroxonium ions, forming two water molecules the reduced products. Solubility free energy content increases **26.58** kJ/mol from **303.1** kJ/mol to **330** kJ/mol:

Substance	$\Delta H^{\circ}_{H_2}$, kJ/mol	$\Delta S^{\circ}_{H_2}$, J/mol/K	$\Delta G^{\circ}_{H_2}$, kJ/mol
H₂O	-285.85	69.9565	-237.191
H₂O	-286.65	-453.188	-151.549
H₃O⁺	-285.81	-3.854	-213.2746
H₂gas	<u>Alberty</u>	pH=7,36	85.64
H₂(aq)	23.4	-130	99.13
H(Pt)(aq)	$E^{\circ}_H-E^{\circ}_{O_2}$	-1.3575	48.56
H₂(aq)	-5.02	-363.92	103.24
O₂aqua	-11.70	-94.2	16.4
O₂aqua	-11.715	110.876	16.4

$$G_{O_{2aq}}=G_{O_{2gas}}+G_{O_{2sp}}=303.1+26.58=329.68=330$$
 kJ/mol.

$$G_{O_{2gas}}=2(G_{H_2O}-(G_{H_2gas}-\Delta G^{\circ}_{H_2O}))=2*(0-(85.64-237,19))=303.1$$
 kJ/mol

pH=7.36 Massachusetts Technology Inst. Alberty [8]

Mischenko 1972, Himia, Leningrad [26]

Biochem. Thermodyn. Massachusetts Technology Inst. [8]

CRC 2010 [1]

$$G_{H(Pt)}=(2G_{H_2O}-\Delta G_{eq2H_2O}-G_{O_{2aqua}})/4=48.56$$
 kJ/mol;

pH=7,36 [8] Biochem. Thermodyn. Massachusetts Technology Inst.

pH=7,36 [8] Massachusetts Technology Inst. Alberty [8]

CRC [1]

$$G_{O_{2gas}}=303$$
 kJ/mol, $G_{O_{2aq}}=329.68$ kJ/mol;

Oxygen solubility free energy change is exothermic and endoergic $O_{2gas}+H_2O=O_{2aq}$, which mol fraction for gas

$[O_{2air}]=1$ and in water has $[O_{2aq}]/[H_2O]=1.22*10^{-(3)}$ M/55.3 M=2.206*10⁻⁵ unit less concentration. $K_{speq}=[O_{2aq}]/[O_{2gas}]/[H_2O]=2.206*10^{-5}/1=2.206*10^{-5}$ constant is less as

one. $\Delta G_{Hess}=\Delta G^{\circ}_{O_{2aqua}}-\Delta G^{\circ}_{H_2O}-\Delta G^{\circ}_{O_{2gas}}=16.4-(0-237.191)=253.6$ kJ/mol Hess energy change for pure reagents is positive. So positive on absolute scale expressions

$\Delta G_{Alberty O_{2aq}}=G_{O_{2aq}}-(G_{H_2O}+G_{O_{2gas}})=330-(0+303.1)=26.58$ kJ/mol and at equilibrium

minimum $\Delta G_{speq}=-R\cdot T\cdot \ln(K_{speq})=-8.3144*298.15*\ln(2.206*10^{-5})=26.58$ kJ/mol. $[O_2]$

solubility Hess free energy change is positive $\Delta G_{Hess}=253.6$ kJ/mol, but minimized at

equilibrium mixture $K_{speq}=[O_{2aq}]/[O_{2gas}]/[H_2O]=2.206*10^{-5}$. Equilibrium state is

attractor for all non-equilibrium states. At minimum establishes equilibrium. 53rd page

Osmolar $C_{osm}=0$ M and ionic force $I=0$ M in water from air 20.95% oxygen solubility is

$$[O_{2aq}]=K_{speq}\cdot [O_{2air}]\cdot [H_2O]=2.206*10^{-5}\cdot 0.2095\cdot 55.3=0.00025546$$
 M.

Pure 1atm mol fraction $[O_{2gas}]=1$. Osmolar $C_{osm}=0.305$ M, ionic force $I=0.25$ M, air 20.95% oxygen dissolve $[O_{2aq}]=9.768\cdot 10^{-5}$ M. Therefore $K_{O_{2sp}Air}=[O_{2aq}]/[O_{2air}]=9.768\cdot 10^{-5}/0.2095=4.663\cdot 10^{-4}$ M is solubility on air.

Arterial $[O_{2aq}]=6\cdot 10^{-5}$ M and venous $[O_{2aq}]=0.426\cdot 10^{-5}$ M isooxia is maintained by osmosis oxygen molecules, which cross membranes through aquaporins channels against osmolar concentration gradient $C_{osm}=0.305$ M.

Inverse: $O_{2aqua}+4H_3O^++4e^-=6H_2O$; $-E^{\circ}_{O_2}=-1.0868$ V; Nernst's: $4(Pt)H+4H_2O=4H_3O^++4e^-$; $E^{\circ}_H=-0.27073$ V;

$O_{2aqua}+4(Pt)H-2H_2O$ electrodes standard potential sum give standard free energy change:

$$\Delta G_{eq}=(E^{\circ}_H-E^{\circ}_{O_2})\cdot F\cdot 1\cdot 4=(-0.27073-1.0868)\cdot 96485\cdot 4=-1.3575\cdot 96485\cdot 4/1000=2\cdot 261.96=-523.925$$
 kJ/mol;

Knowing equilibrium value $\Delta G_{eq2H_2O}=2G_{H_2O}-4G_{(Pt)H}-G_{O_{2aqua}}=2\cdot 0-(4\cdot G_{(Pt)H}+329.68)=-523.925$ kJ/mol, hydrogen metal free energy is $G_{H(Pt)}=(2G_{H_2O}-\Delta G_{eq2H_2O}-G_{O_{2aqua}})/4=(2\cdot 0+523.925-329.68)/4=194.251/4=48.56$ kJ/mol.

Free energy $G_{H_3O^++OH^-}=G_{H_3O^+}+G_{OH^-}=22.44+77.36=99.8$ kJ/mol of water protolysis $H_2O+H_2O\rightleftharpoons H_3O^++OH^-$

Biochemistry oxygen O_{2aqua} decreases free energy content $G_{O_{2aqua}}=329.68$ kJ/mol to $G_{O_2Biochemistry}=88.22$ kJ/mol.

Arterial concentration $[O_{2aqua}]=6\cdot 10^{-5}$ M, pH=7.36 concentrations $[H_3O^+]=10^{-7.36}$ M potential is decreasing

$$E_{O_2}=E^{\circ}_{O_2}+0.0591/4\cdot \lg([O_{2aqua}]\cdot [H_3O^+]^4/[H_2O]^5)=1.0868+0.0591/4\cdot \lg(6\cdot 10^{-(5)}\cdot 10^{-(7.36\cdot 4)}/55.3^{(5)})=0.46174$$
 V

by $\Delta E_{arterial}=(E_{O_2}-E^{\circ}_{O_2})=-1.0868+0.46174=-0.62506$ Volts and

free energy content by $\Delta G_{arterial}=\Delta E_{H_2O}\cdot F\cdot n=0.62506\cdot 96485\cdot 4/1000=-241.24$ kJ/mol.

The free energy content of O_{2gas} AIR+ $H_2O=O_{2Blood}$ with solubility contribution increases by:

$$K_{speq}=\frac{[O_{2aqua}]}{[O_{2gas}]\cdot [H_2O]}=2.205\cdot 10^{-5}; G_{O_{2speq}}=-R\cdot T\cdot \ln(K_{speq})=-8.3144\cdot 298.15\cdot \ln(2.205\cdot 10^{-5})=26.58$$
 kJ/mol.

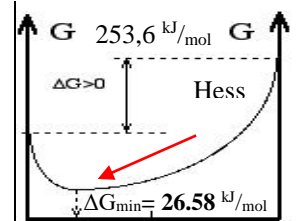
Protolysis decreases free energy to $G_{O_2Biochem_arterial}=G_{O_{2aq}}+G_{O_{2sp}}+\Delta G_{arterial}=303.1+26.58-241.456=88.22$ kJ/mol

and oxygen becomes fire safe biochemical oxidant, forming arterial concentration $[O_{2aqua}]=6\cdot 10^{-5}$ M as safe Bioenergetic sustaining normal isooxia. [3];

1) Water 55.346 M decreases potential from **1.0868** V about **-0.1288** V=**0.9580-1.0868**= ΔE_{H_2O} .

$$E_{O_2}=E^{\circ}_{O_2}+0.0591/4\cdot \lg(1/[H_2O]^5)=1.0868+0.01478\cdot \lg(1/55.346^{(5)})=0.95805$$
 V ;

2) Acid H_3O^+ increases 10 times the potential and free energy content increases about $\Delta E_{H_3O^+}=0.05912$ V



A + B 50% C + D
Reactants
 $O_{2gas}+H_2O_{Blood}$
product $O_{2aq-Blood}$.

$\Delta E_{H_3O} = 0.01478 \cdot \lg([H^+]^4) = 0.05912$ V and $\Delta G_{max} = \Delta E_{H_3O} \cdot F \cdot n = 0.05912 \cdot 96485 \cdot 4 / 1000 = 22.817$ kJ/mol;

3) Air 20.95% replaced with 100% oxygen $[O_{2aqua}]$ concentration 5 times increase potential about

$$\Delta E_{O_{2100\%}} = 0.01478 \cdot \lg(100\% [O_{2aqua}]) = 0.01478 \cdot \lg(5) = +0.0103$$
 V . Free energy content for

oxygen increases about $\Delta G_{max} = \Delta E_{H_3O} \cdot F \cdot n = 0.01033 \cdot 96485 \cdot 4 / 1000 = 3.987$ kJ/mol . [6th page](#).

NASA Apollo Moon project closes 1972 because of oxidative stress and technical hazards risk.

Glucose and inverse oxygen absolute and standard potentials sum $\Delta E^\circ = (E^\circ_{C_6H_{12}O_6} - E^\circ_{O_2})$:

$$\Delta E^\circ = (E^\circ_{C_6H_{12}O_6} - E^\circ_{O_2}) = \Delta G_{Lehninger} / F \cdot n = -2840000 / 96485 / 24 = -1.2264$$
 V give the absolute free energy change

$$\Delta G_{Lehninger} = \Delta E^\circ \cdot F \cdot n = (E^\circ_{C_6H_{12}O_6} - E^\circ_{O_2}) \cdot F \cdot n = (-1.2264) \cdot 96485 \cdot 24 = -2840$$
 kJ/mol for the oxidation reaction

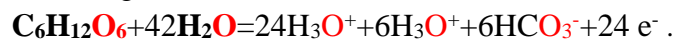


The sum of the absolute standard potentials $(E^\circ_{C_6H_{12}O_6} - E^\circ_{O_2}) = (E_{C_6H_{12}O_6} - 1,086865) = -1,22644$ V of glucose and oxygen allows us to determine the absolute standard potential for glucose

$E^\circ_{C_6H_{12}O_6} = \Delta E + E^\circ_{O_2} = -1,22644 + 1,086865 = -0,139575$ V, which is calculated from the value of the inverse Nernst's half reaction absolute standard potential of oxygen reduction $-E^\circ_{O_2} = -1.0868$ V .

Glucose oxidation, the absolute standard potential is negative because the strong of 24-electron donor, what reduce the six oxygen molecules in Nernst's reaction $O_{2aqua} + 4H_3O^+ + 4e^- = 5H_2O$ with an inverse absolute standard potential $-E^\circ = -1.0868$ V. Classic glucose standard potential $E^\circ_{classic} = -0.04915$ V, 42 water account logarithm $-0,0591/24 \cdot \lg(1/55,3^{42}) = 0.18024$ and $\Delta E^\circ = +0,10166 - 0,37239$ the coupled sum expressed potential is

$$E^\circ_{C_6H_{12}O_6} = E^\circ_{classic} - 0,0591/24 \cdot \lg(1/55,3^{42}) + \Delta E^\circ = -0,04915 + 0,18024 + 0,10166 - 0,37239 = -0,13964$$
 V .



Arterial oxygen $[O_{2arterial}] = 6 \cdot 10^{(-5)}$ M; hydroxonium $[H_3O^+]^{30} = 10^{(-7,36 \cdot 30)}$ M and $[C_6H_{12}O_6] = 0,005$ M glucose concentrations in blood produce very negative arterial potential:

$$E_{C_6H_{12}O_6arterial} = E^\circ_{C_6H_{12}O_6} + 0,0591/24 \cdot \lg([HCO_3^-]^6 \cdot [H_3O^+]^{30} / [H_2O]^{42} / [C_6H_{12}O_6]) =$$

$$= -0,13958 + 0,0591/24 \cdot \lg(0,0154 \cdot 10^{(-7,36 \cdot 30)} / 0,005 / 55,346^{42}) = -0,86237$$
 V

and inverse Nernst's half reaction absolute arterial potential of oxygen is

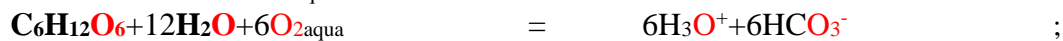
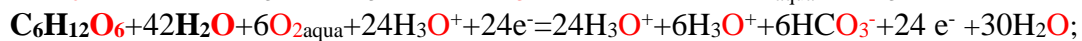
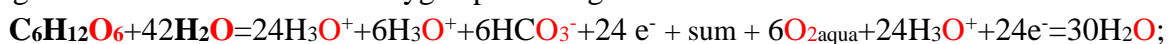
$$E_{O_{2arterial}} = E^\circ_{O_2} + 0,0591/4 \cdot \lg([H_2O]^5 / [O_{2aqua}] / [H_3O^+]^4) = -1,086865 + 0,0591/4 \cdot \lg(55,346^{42} / 6 / 10^{(-5)} / 10^{(-7,36 \cdot 4)}) = -0,46074$$
 V .

Homeostasis potential sum is more negative $\Delta E_{arterial} = E_{C_6H_{12}O_6arterial} + E_{O_{2arterial}} = -0,86237 - 0,46074 = -1,3231$ Volts.

Free energy change $\Delta G_{arterial}$ is more negative as standard value $\Delta G_{Lehninger}$:

$$\Delta G_{arterial} = \Delta E \cdot F \cdot n = (E_{C_6H_{12}O_6arterial} - E_{O_{2arterial}}) \cdot F \cdot n = (-0,86237 - 0,46074) \cdot 96485 \cdot 24 = -3063,846$$
 kJ/mol.

One mol glucose oxidize six mols of oxygen producing six mols bicarbonate $6H_3O^+ + 6HCO_3^-$:



$$G_{H_3O^+} + G_{HCO_3^-} = G_{H_3O^+} + G_{HCO_3^-} = 22,44 + 56,08 = 78,52$$
 kJ/mol,

[Glc](#) 6th page Formation from elements $C + 6H_{2gas} + 3O_{2gas} = C_6H_{12}O_6$ free energy change calculates from

Alberty data at pH=7.36 $\Delta G^\circ_{Alberty} = G_{C_6H_{12}O_6} - (6G_{Cgraph} + 6G_{H_2gas} + 3G_{O_2gas}) = -402,05$ kJ/mol ;

2006, Massachusetts Technology Inst. Alberty [8] pH=7,36.

CRC 2010

pH=7.36 [Glc](#) $\Delta G^\circ_{Alberty} + (6G_{Cgraph} + 6G_{H_2gas} + 3G_{O_2gas}) = G_{C_6H_{12}O_6} = 1568$ kJ/mol;

Calculation of free energy in glucose oxidation $C_6H_{12}O_6 + 6O_{2aqua} + 12H_2O = 6H_3O^+ + 6HCO_3^-$ in three ways:

1) Alberty data at pH=7.36 pH=7,36 $\Delta G^\circ_{Alberty} = G_{C_6H_{12}O_6} - (6G_{Cgraph} + 6G_{H_2gas} + 3G_{O_2gas}) = -402,05$ kJ/mol standard free energy content in the mol is:

$$G_{C_6H_{12}O_6} = \Delta G^\circ_{Alberty} + (6G_{Cgraph} + 6G_{H_2gas} + 3G_{O_2gas}) = -402,05 + (6 \cdot 91,26 + 6 \cdot 85,6 + 3 \cdot 303) = 1568$$
 kJ/mol ,

2) Lehninger's $\Delta G_{C_6H_{12}O_6} = 6G_{H_3O^+} + 6G_{HCO_3^-} - (G_{StandardC_6H_{12}O_6} + 6G_{O_{2aqua}} + 12G_{H_2O_{Biochem}}) = -2840$ kJ/mol

standard content in the mol of glucose $G_{StandardC_6H_{12}O_6} = 6 \cdot (22,44 + 56,08) - (-2840 + 6 \cdot 330 + 12 \cdot 0) = 1331$ kJ/mol and

3) free energy content $\Delta G_{arterial_C_6H_{12}O_6} = 6G_{H_3O^+} + 6G_{HCO_3^-} - (G_{arterial_C_6H_{12}O_6} + 6G_{O_{2aqua}} + 12G_{H_2O}) = -3064$ kJ/mol

per mol of glucose at homeostasis $G_{arterial_C_6H_{12}O_6} = 6 \cdot (22,44 + 56,08) - (-3064 + 6 \cdot 88,22 + 12 \cdot 85,64) = 1978$ kJ/mol.

[8,6]

Generated $6HCO_3^- + 6H_3O^+$ ions drive reactants $6O_{2aqua}$ and $6H_2O$ through membranes aquaporins channels by osmosis against the concentration gradients but transporting ions $6HCO_3^- + 6H_3O^+$ opposite down the gradients through bicarbonate and proton channels consuming produced free energy $\Delta G_{arterial} = -3064$ kJ/mol.

Absolute potential and free energy values include accounting for hydroxonium H_3O^+ and water H_2O .

Oxygen in the inverse half-reaction with free energy $G_{\text{O}_2\text{aqua}}=330 \text{ kJ/mol}$ is reduced to $\text{O}_2\text{aqua}+4\text{H}_3\text{O}^++4\text{e}^-=5\text{H}_2\text{O}$ with inverse potential $-E_{\text{O}_2}=-1.0868 \text{ V}$ by oxidizing four metal hydrogen atoms with free energy content per mole $G_{\text{H(Pt)}}=48.56 \text{ kJ/mol}$ in the Nernst half-reaction $4(\text{Pt})\text{H}+4\text{H}_2\text{O}=4\text{H}_3\text{O}^++4\text{e}^-$ and with standard absolute potential $E_{\text{H}}^{\circ}=-0.27073 \text{ V}$. Standard free energy change in aqua reaction $\text{O}_2\text{aq}+4(\text{Pt})\text{H}=2\text{H}_2\text{O}$ from elements is

$$\Delta G_{\text{Hess}2\text{H}_2\text{O}}=2G_{\text{H}_2\text{O}}-4G_{\text{H(Pt)}}-G_{\text{O}_2\text{aqua}}=2*0-(4*48.56+330)=-524.24=2*-262 \text{ kJ/mol.}$$

Standard potentials sum $\Delta G_{\text{eq}}=(E_{\text{H}}^{\circ}-E_{\text{O}_2}^{\circ})\cdot F\cdot 4=(-0.27073-1.0868)*96485*4=-1.3575*96485*4=-523.925=2*-262 \text{ kJ/mol}$ let independently from Hess law calculate formation from elements in water oxygen O_2aqua and metal hydrogen (Pt)H free absolute energy change $\Delta G_{\text{eq(Pt)H}_2\text{O}}=-262 \text{ kJ/mol}$, which is coincident with absolute free energy $G_{\text{H(Pt)}}=48.56 \text{ kJ/mol}$ determination for free aqua elements O_2aqua , (Pt)H. Hydrogen standard free energy in water solution $G_{\text{H}_2\text{aqua}}=103.24 \text{ kJ/mol}$ is at $\text{pH}=7.36$. [8] $\text{O}_2\text{aqua}+2\text{H}_2\text{aqua}=2\text{H}_2\text{O}$; The standard free energy change in Hess's law for the formation of aqua elements is

$$\Delta G_{\text{HessCRCaqua}}=2\Delta G^{\circ}\text{H}_2\text{O}-2\Delta G^{\circ}\text{H}_2\text{aqua}-\Delta G^{\circ}\text{O}_2\text{aqua}=2*-237.191-(2*99.13/2+16.4)=-589.91=2*-295 \text{ kJ/mol.} [1]$$

In Hess's law, changes are calculated from CRC data when pure reactants convert into pure products and the maximum possible change is greater than the standard $\Delta G_{\text{HessCRCaqua}}=-295 \text{ kJ/mol} > \Delta G_{\text{eq(Pt)H}_2\text{H}_2\text{O}}=-262 \text{ kJ/mol}$. Formation from aqua elements $\Delta G^{\circ}\text{H}_2\text{O}=-151.55 \text{ kJ/mol}$ Alberty [8] and homeostasis $\Delta G^{\circ}\text{H}_2\text{O}=-147.26 \text{ kJ/mol}$.

Substance	$\Delta H^{\circ}_{\text{H}_2}$, kJ/mol	$\Delta S^{\circ}_{\text{H}_2}$, J/mol/K	$\Delta G^{\circ}_{\text{H}_2}$, kJ/mol	$\Delta G^{\circ}\text{H}_2\text{O}=G_{\text{H}_2\text{O}}-(G_{\text{H}_2\text{aq}}+G_{\text{O}_2\text{aq}}/2)=0-(103.24+88.22/2)=-147.35 \text{ kJ/mol}$
H_2O	-285.85	69.9565	-237.191	$G_{\text{H}_2\text{O}}=\Delta G_{\text{H}_2\text{O}}\text{Alberty}-(\Delta G^{\circ}\text{H}_2\text{O})=-151.549-(-237.191)=85.6 \text{ kJ/mol} [8]$
H_2O	-286.65	-453.188	-151.549	$\Delta G_{\text{H}}=\Delta H_{\text{H}}-T*\Delta S_{\text{H}}=-286.65-298.15*-0.453188=-151.5 \text{ kJ/mol};$
H_3O^+	-285.81	-3.854	-213.2746	$\Delta G^{\circ}\text{H}_3\text{O}^+$, kJ/mol Mischenko 1972, Himia, Leningrad [26]
$\text{H}_2(\text{aq})$	23.4	-130	99.13	CRC [1]
$\text{H}_2(\text{aq})$	-5.02	-363.92	103.24	$\text{pH}=7,36 [8]$ Massachusetts Technology Inst. Alberty
$E^{\circ}(\text{Pt})\text{H}$	-0.27073	-1.0868	48.56	$G_{\text{H(Pt)}}=(2G_{\text{H}_2\text{O}}-\Delta G_{\text{eq}2\text{H}_2\text{O}}-G_{\text{O}_2\text{aqua}})/4=48.56 \text{ kJ/mol}$
O_2aqua	-11.70	-94.2	16.4	$\text{pH}=7.36 [8]$ Biochem. Thermodyn Massachusetts Technology Inst.
O_2aqua	-11.715	110.876	16.4	CRC [1] The equilibrium constant is favorably greater than one:

$$K_{\text{eq}2\text{H}_2\text{O}}=K_{\text{OxRed}}=\exp(-\Delta G_{\text{OxRed}}/R/T)=\exp(261960.6/8.3144/298.15)=\exp(105.675)=7.832*10^{45}.$$

Exothermic and exoergic O_2aqua reduction with metallic hydrogen $4(\text{Pt})\text{H}$ and H_2O_2 dismutation Hess free energy change negative $\Delta G_{\text{HessAquaH}_2\text{O}}=-295 \text{ kJ/mol}$, but reaching equilibrium state $\Delta G_{\text{eq}2\text{H}_2\text{O}}=-262 \text{ kJ/mol}$ at minimum has constant greater over one $K_{\text{eq}2\text{H}_2\text{O}}=7.832*10^{45}$. The equilibrium state is attractor for irreversible states. Free energy change minimum reaching establish equilibrium state. Oxidation and reduction of peroxide have absolute standard $E^{\circ}\text{H}_2\text{O}_2\text{Ox}=0.4753 \text{ V}$

Ox $\text{H}_2\text{O}_2+\text{H}_2\text{O}=\text{O}_2\text{aqua}+2\text{H}_3\text{O}^++2\text{e}^-$ and inverse standard $-E^{\circ}\text{H}_2\text{O}_2\text{Red}=-1.7113 \text{ V}$

Red $\text{H}_2\text{O}_2+2\text{H}_3\text{O}^++2\text{e}^-=4\text{H}_2\text{O}$ potentials. Two peroxide molecules protolytic dismutation is exoergic, exothermic $2\text{H}_2\text{O}_2\text{aq}+2\text{H}_2\text{O}=>\text{O}_2\text{aqua}+3\text{H}_2\text{O}$ standard sum $(E^{\circ}\text{H}_2\text{O}_2\text{Ox}-E^{\circ}\text{H}_2\text{O}_2\text{Red})=(0.4753-1.7113)=-1.236 \text{ V}$ $\Delta G_{\text{eqStandard}_\text{H}_2\text{O}_2}=-238.51 \text{ kJ/mol}$.

Oxygen solubility compensate water Reactants $4(\text{Pt})\text{H}+ \text{O}_2\text{aqua}$ and products $2\text{H}_2\text{O}$ 4A+B 50% 2D; molecule $\text{O}_2\text{gas}+2\text{H}_2\text{O}=\text{O}_2\text{aqua}$ Reactants $2\text{H}_2\text{O}_2\text{aq}$ and products $\text{O}_2\text{aqua}+\text{H}_2\text{O}$ 2A 50% B+C

Classic peroxide oxidation standard potential $E^{\circ}\text{classicH}_2\text{O}_2\text{Ox}=0.6945 \text{ V}$ [19], plus water account logarithm $-0.0591/2*\lg(1/[\text{H}_2\text{O}]^1)=0.0515$ and the coupled sum $\Delta E^{\circ}=+0.10166-0.37239$ expressed absolute potential is $E^{\circ}\text{H}_2\text{O}_2\text{Ox}=E^{\circ}\text{classicH}_2\text{O}_2\text{Ox}-0.0591/2*\lg(1/[\text{H}_2\text{O}]^2)+\Delta E^{\circ}=0.6945+0.0515+0.10166-0.37239=0.4753 \text{ V}$. Classic peroxide reduction standard potential $E^{\circ}\text{classicH}_2\text{O}_2\text{Red}=1.776 \text{ V}$ [17], plus 4 water account logarithm $-0.0591/2*\lg(1/[\text{H}_2\text{O}]^4)=0.206$ and the coupled sum $\Delta E^{\circ}=+0.10166-0.37239$ expressed absolute potential is $E^{\circ}\text{H}_2\text{O}_2\text{Red}=E^{\circ}\text{classicH}_2\text{O}_2\text{Red}-0.0591/2*\lg(1/[\text{H}_2\text{O}]^4)+\Delta E^{\circ}=1.776+0.206+0.10166-0.37239=1.7113 \text{ V}$;

Peroxide oxidation and inverse reduction standard potentials sum calculates standard free energy change :

$$\Delta G_{\text{eqStandard}_\text{H}_2\text{O}_2}=(E^{\circ}\text{H}_2\text{O}_2\text{Ox}-E^{\circ}\text{H}_2\text{O}_2\text{Red})\cdot F\cdot n=(-1.7113+0.4753)*96485*2=(-1.236)*96485*2=-238.51 \text{ kJ/mol.}$$

$$\Delta G_{\text{eqAlberty}}=G_{\text{O}_2\text{aqua}}+G_{\text{H}_2\text{O}}-2G_{\text{AlbertyH}_2\text{O}_2}=330+0-2*284.255=-238.51 \text{ kJ/mol.} [8]$$

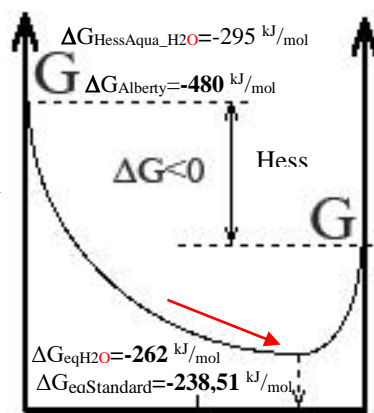
$$G_{\text{AlbertyH}_2\text{O}_2}=(G_{\text{O}_2\text{Biochem}}+G_{\text{H}_2\text{O}}-\Delta G_{\text{eqBioChem}})/2=(330+0+238.51)/2=284.255 \text{ kJ/mol.}$$

Absolute potential scale coinciding with [Alberty](#) absolute free energy scale.

$$K_{\text{eqStandard}_\text{H}_2\text{O}_2}=\frac{[\text{O}_2]_{\text{aqua}}\cdot[\text{H}_2\text{O}]}{[\text{H}_2\text{O}_2]_{\text{aqua}}^2}=K_{\text{H}_2\text{O}_2}=\exp(-\Delta G_{\text{eq}}/R/T)=\exp(238511/8.3144/298.15)=6.11*10^{41}.....$$

$[\text{H}_2\text{O}_2]=1\text{M}$; Biochemistry concentrations $[\text{O}_2\text{aqua}]=6*10^{-5} \text{ M}$, $[\text{H}_3\text{O}^+]=10^{-7.36} \text{ M}$, $[\text{H}_2\text{O}]=55.3 \text{ M}$.

$E_{\text{Red}}=E^{\circ}\text{H}_2\text{O}_2+0.0591/2*\lg([\text{O}_2\text{aqua}]*[\text{H}_3\text{O}^+]^2/[\text{H}_2\text{O}_2]/[\text{H}_2\text{O}])=0.4753+0.0591/2*\lg(6*10^{(-5)}*10^{(-7.36*2)}/1/55.3)=-0.13593 \text{ V}$



$-E_{Ox} = -E^{\circ}_{H_2O_2/Ox} + 0.0591/2 \cdot \log([H_2O_2] \cdot [H_3O^+]^2 / [H_2O]^4) = -1.7113 + 0.0591/2 \cdot \lg(1 \cdot 10^{(-7.36 \cdot 2)} / 55.3^4) = -2.3523 \text{ V}$
 Sum Nernst's + inverse reaction homeostasis absolute free energy electrochemical change has energy content
 $[H_2O_2] = 1 \text{ M}$; $\Delta G_{eqBioChem} = (E^{\circ}_{Red} - E^{\circ}_{Ox}) \cdot F \cdot n = (-2.3523 - 0.13593) \cdot 96485 \cdot 2 = (-2.48823) \cdot 96485 \cdot 2 = -480.15 \text{ kJ/mol}$;
 $\Delta G_{Alberty} = G_{O_2Biochem_arterial} + G_{H_2O} - 2 \cdot G_{H_2O_2} = 88.22 + 85.64 - 2 \cdot 284.255 = -394.65 \text{ kJ/mol}$;
 Biochemistry concentrations $[H_2O_2] = 10^{(-10)} \text{ M}$, $[O_{2aqua}] = 6 \cdot 10^{-5} \text{ M}$, $[H_3O^+] = 10^{-7.36} \text{ M}$, $[H_2O] = 55.3 \text{ M}$
 $E_{Red} = E^{\circ}_{H_2O_2} + 0.0591/2 \cdot \lg([O_{2aqua}] \cdot [H_3O^+]^2 / [H_2O_2] / [H_2O]) = 0.4753 + 0.0591/2 \cdot \lg(6 \cdot 10^{(-5)} \cdot 10^{(-7.36 \cdot 2)} / 10^{-10} / 55.3) = 0.15957 \text{ V}$
 $-E_{Ox} = -E^{\circ}_{H_2O_2/Ox} + 0.0591/2 \cdot \log([H_2O_2] \cdot [H_3O^+]^2 / [H_2O]^4) = -1.7113 + 0.0591/2 \cdot \lg(10^{(-10)} \cdot 10^{(-7.36 \cdot 2)} / 55.3^4) = -2.64777 \text{ V}$
 $\Delta G_{eqBioChem} = (E^{\circ}_{Red} - E^{\circ}_{Ox}) \cdot F \cdot n = (0.15957 - 2.64777) \cdot 96485 \cdot 2 = (-2.4882) \cdot 96485 \cdot 2 = -480.15 \text{ kJ/mol}$
 $\Delta G_{Alberty} = G_{O_2Biochem} + G_{H_2O} - 2 \cdot G_{H_2O_2} = 88.22 + 85.64 - 2 \cdot 284.255 = -394.65 \text{ kJ/mol}$. Absolute potential scale coinciding with [Alberty](#) absolute free energy scale at all $10^{(-10)} \text{ M} < [H_2O_2] < 1 \text{ M}$ concentrations.

High rate protolysis peroxide anions collisions in peroxisomes produce 100% efficiency of essential $\omega=6$, $\omega=3$ fatty acids C20:4, oxygen, water and heat: $2H_2O_{2aq} + 2H_2O = O_{2aqua} + 3H_2O + Q$.

Collision $H^+ + HOO^- \rightarrow \cdot OOH + H^+$ in water activation energy is high $E_a = 79000 \text{ J/mol}$ with slow rate of reaction. In collision $HOO^- \rightarrow Fe^{3+}$ with iron(III) ion peroxide has small activation energy $E_a = 29 \text{ J/mol}$. It increases reaction rate thirty million times faster. Peroxide formation from aqua elements $O_{2aqua} + H_{2aqua} = H_2O_2$ exoergic, negative

$$\Delta G_{formH_2O_2} = G_{H_2O_2} - G_{H_2aqua} - G_{O_{2aqua}} = 284,255 - (103,24 + 330) = -148,985 \text{ kJ/mol}.$$

Alberty data formation give $G_{H_2O_2} = \Delta G_{formH_2O_2} + (G_{H_2aqua} + G_{O_{2aqua}}) = -148,985 + (103,24 + 330) = 284,255 \text{ kJ/mol}$. [8]

Substance	$\Delta H^{\circ}_H, \text{kJ/mol}$	$\Delta S^{\circ}_H, \text{J/mol/K}$	$\Delta G^{\circ}_H, \text{kJ/mol}$
H_2O_{2aq}	-191.99	-481.688	-48.39
H_2O_{2aq}	-191.17	143.9	-134.03
H_2O_{2aq}	Formation	-48.39	340.25
H_2O_{2aq}	Formation	-134.03	254.61
H_2O_{2aq}	Formation	-148,985	284,255
H_2O_{2aq}	$\Delta E^{\circ}_{H_2O_2/RedOx}$	-1.236	284.255
HOO^-	$pK_a = 11.75$	77.016	338.831
H_2O_{2l}	-237.129	69.91	-237.129

$G_{H_2O_2} = 284.255 \text{ kJ/mol}$; $G_{HOO^-} = 338.831 \text{ kJ/mol}$;
Biochem. Thermodynamic 2006 Massachusetts Technology Inst.[8]
 University Alberta 1997. [19]
 $G_{H_2O_{2aq}} = \Delta G_{H_2O_2Alberty} + (G_{O_2gas} + G_{H_2gas}) = 340.25 \text{ kJ/mol}$;
 $G_{H_2O_{2aq}} = \Delta G_{H_2O_2Alberty} + (G_{O_2gas} + G_{H_2gas}) = 254.61 \text{ kJ/mol}$;
 $G_{H_2O_{2aq}} = \Delta G_{H_2O_2form} + (G_{O_2gas} + G_{H_2gas}) = 284.255 \text{ kJ/mol}$;
 $G_{AlbertyH_2O_2} = (G_{O_2Biochem} + G_{H_2O} - \Delta G_{eqBioChem}) / 2 = 284.255 \text{ kJ/mol}$;
 $G_{HOO^-} = -G_{H_3O^+} + \Delta G_{aH_2O_2} + (G_{H_2O_2} + G_{H_2O}) = 338.831 \text{ kJ/mol}$;
 CRC [1]

Peroxide protolysis $H_2O_2 + H_2O = H_3O^+ + HOO^-$ $pK_a = 11.75$ give the free energy change at equilibrium state $\Delta G_{aH_2O_2} = -R \cdot T \cdot \ln(K_a / [H_2O]) = -8.3144 \cdot 298.15 \cdot \ln(10^{(-11.75)} / 55.3) = 77.016 \text{ kJ/mol}$ and by Hess law endoergic too $\Delta G_{aH_2O_2} = G_{H_3O^+} + G_{HOO^-} - (G_{H_2O_2} + G_{H_2O}) = 22.44 + G_{HOO^-} - (284.255 + 0) = 77.016 \text{ kJ/mol}$. Expressed anion free energy content is $G_{HOO^-} = -G_{H_3O^+} + \Delta G_{aH_2O_2} + (G_{H_2O_2} + G_{H_2O}) = -22.44 + 77.016 + (284.255 + 0) = 338.831 \text{ kJ/mol}$. Peroxide anion $HOO^- + H_2O = O_{2aqua} + H_3O^+ + 2e^-$ half reaction standard potential $E^{\circ}_{HOO^-} = \Delta G_{HOO^-} / F = 13609 / 96485 = 0.07952 \text{ V}$ is obtained in free energy change $\Delta G_{HOO^-} = G_{O_{2aqua}} + G_{H_3O^+} - (G_{HOO^-} + G_{H_2O}) = 330 + 22.44 - (338.831 + 0) = 13.609 \text{ kJ/mol}$. Classic standard potential is $E^{\circ}_{classic} = 0.28975 \text{ V}$.

Classic standard potential of oxidation $E^{\circ}_{classic} = 0.28975 \text{ V}$, plus $-0.0591/2 \cdot \log(1/[H_2O]) = 0.0515$ water logarithm accounting and the coupled sum $\Delta E^{\circ} = +0.10166 - 0.37239$ expressed absolute standard potential is $E^{\circ}_{HOO^-/Ox} = E^{\circ} - 0.0591/2 \cdot \lg(1/[H_2O]) + 0.10166 - 0.37239 = 0.28975 - 0.0515 + 0.10166 - 0.37239 = 0.07052 \text{ V}$;

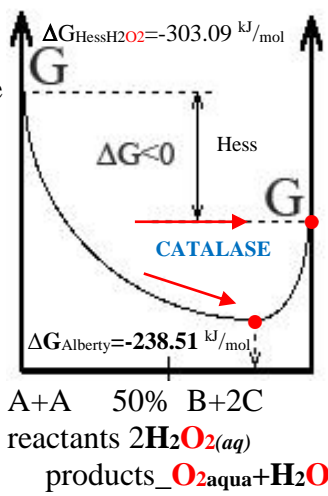
Exothermic and exoergic $H_2O_2(aq)$ dismutation Hess $\Delta G_{HessH_2O_2} = -303.09 \text{ kJ/mol}$ free energy change is negative, but minimized $\Delta G_{eqAlberty} = -238.51 \text{ kJ/mol}$ reaching standard equilibrium mixture favored constant $K_{eq} = 1.11 \cdot 10^{40}$. Le Chatelier principle is Prigogine attractor as free energy change minimum ΔG_{min} reaching. High rate protolysis attractors $pH = 7.36$, oxygen 20.95% in air stay at equilibrium, while homeostasis irreversibly continues, as not equilibrium states are. Prigogine attractors are Nobel Prize in Chemistry 1977th. CATALASE erase peroxide molecules H_2O_2 reaching 100% efficiency for $\omega=6$, $\omega=3$ fatty acids C20:4 elongation synthesis in peroxisomes. CATALASE reactivity is indispensable irreversible homeostasis Brownian molecular engine for evolution and survival. Peroxide [Formation](#) from elements $O_{2gas} + H_{2gas} = H_2O_{2aq}$; are two sources $\Delta G^{\circ}_{UnivAlberta} = -134.03 \text{ kJ/mol}$, [19] $\Delta G^{\circ}_{Alberty} = -48.39 \text{ kJ/mol}$. [8] From Alberty data obtained

$$\Delta G_{HessH_2O_2} = G_{H_2O_2} - G_{H_2gas} - G_{O_{2gas}} = 284.255 - (85.64 + 303) = -104.385 \text{ kJ/mol}$$
 values for

$G_{H_2O_2} - G_{H_2gas} - G_{O_{2gas}}$ are located between $\Delta G^{\circ}_{UnivAlberta} = -134.03 \text{ kJ/mol}$ and $\Delta G^{\circ}_{Alberty} = -48.39 \text{ kJ/mol}$ much close as CRC data $\Delta G^{\circ}_{CRC} = -237.129 \text{ kJ/mol}$. [1] Data on the absolute free energy scale $G_{AlbertyH_2O_2} = 284.255 \text{ kJ/mol}$ lie between the molar content $G_{H_2O_{2aq}} = 254.61 \text{ kJ/mol}$, [19] and $G_{H_2O_{2aq}} = 340.25 \text{ kJ/mol}$ [8]:

$$G_{H_2O_{2aq}} = \Delta G_{H_2O_2CRC} + (G_{O_{2gas}} + G_{H_2gas}) = -134.03 + (303 + 85.64 + 0) = 254.61 \text{ kJ/mol}$$
; [19]

$$G_{H_2O_{2aq}} = \Delta G_{H_2O_2Alberty} + (G_{O_{2gas}} + G_{H_2gas}) = -48.39 + (303 + 85.64 + 0) = 340.25 \text{ kJ/mol}$$
; [8] 41st, 54th [page](#) [1,8,20]



Sulfur / H₂S_{aq} red-ox systems. H₃O⁺ and [H₂O]=55.3 M accounting on absolute free energy and potential scale.

Substance	ΔH ^o _H /kJ/mol	ΔS ^o _H /J/mol/K	ΔG ^o _H /kJ/mol
H ₂ S _{gas}	formation	-81.96	7.1636
H ₂ S _{gas}	Solubility	promote	38.1196
H ₂ S _{gas}	-20.6	205.81	-81.96
H ₂ S _{aq}	-38.6	126	-76.167
H ₂ S _{aq}	-22.9596	-256.064	53.3896
H ₂ S _{aq}	S+2(Pt)H=	H ₂ S _{aq}	84.343
HS ⁻	-16.3	67	-36.276
HS ⁻	E ^o _{↓/HS2=}	-0.8517 V	90.5336
HS ⁻	pK _{a1} =7.05	favored	81.138
HS ⁻	pK _{a2} =19	-	92.65
S _{rhombic}	formation	-81.96	3.5436
S _{rhombic}	E ^o _{↓/H2Saq=}	-0.025735 V	3.5436
S ²⁻	E ^o _{↓/S2=}	-0.79853V	157.63

G_{H2gas}=**85.6** kJ/mol; G_{H2Saq}=**53.3896** kJ/mol; G_{Srhombic}=**3.5436** kJ/mol;
 favored G_{H2Sgas}=ΔG_{Hess_H2Sgas}+(G_{Srhombic}+G_{H2})=**7.1636** kJ/mol.
 G_{H2Sgas}=G_{H2Saq}-(ΔG_{eq}+G_{H2O})=**53.3896**-(**15.27**+0)=**38.1196** kJ/mol
 CRC ΔG_{H2Sgas}=ΔH_H-T*ΔS_H=-20.6-298.15*0.20581=-81.96 kJ/mol;
 CRC ΔG_{H2Saq}=ΔH_H-T*ΔS_H=-38.6-298.15*0.126=-76.167 kJ/mol;
 2006. Massachusetts Technology Inst. pH=7.36 Alberty [8]
 G_{H2Saq}=ΔG_{HessH2S}+(2G_{H(Pt)}+G_{Srhombic})=**84.343** kJ/mol;
 CRC [1] ΔG_{HS-}=ΔH_H-T*ΔS_H=-16.3-298.15*0.067=-36.276 kJ/mol;
 G_{HS-aq}=G_{Srhombic}+2G_{H2O}-(ΔG_{eqHS-aq}+G_{OH})=**90.5336** kJ/mol;
 favored G_{HS-}=ΔG_{eq}-G_{H3O}+(G_{H2S}+G_{H2O})=**81.138** kJ/mol;
 G_{HS-}=G_{S2}+G_{H3O}-(ΔG_{eq}+G_{H2O})=**92.65** kJ/mol;
 G_{Srhombic}=G_{H2Sgas}-(ΔG_{Hess_H2Sgas}+G_{H2})=**3.5436** kJ/mol;
 favored G_{Srhombic}=ΔG_{eqH2Saq}-2G_{H3O}+(G_{H2Saq}+2G_{H2O})=**3.5436** kJ/mol;
 G_{S2-aq}=G_{Srhombic}+G_{H2O}-(ΔG_{eqS2-aq})=**157.63** kJ/mol;

Formation from elements S_{rhombic}+H₂gas=H₂S_{gas} G_{H2gas}=**85.6** kJ/mol; shows energy content G_{H2Sgas}=**7.1636** kJ/mol;
 Energy content is G_{H2Sgas}=ΔG^o_{H2Sgas}+(G_{Srhombic}+G_{H2})=-81.98+(**3.5436**+**85.6**)=**7.1636** kJ/mol. [1,8]

Energy content is G_{Srhombic}=G_{H2Sgas}-(ΔG^o_{H2Sgas}+G_{H2})=**7.1636**-(-81.98+**85.6**)=**3.5436** kJ/mol. [1,8]

Solubility H₂S_{gas}+H₂O=H₂S_{aq} 3.98 g/L 20° C [30] M_{H2S}=34.08 g/mol product K_{sp}=[H₂S_{aq}]=3.98/34.08=0.11678 M
 at equilibrium constant is K_{eq}=K_{sp}/[H₂O]=0.116784/55.3=0.0021118 with free energy change endoergic positive

$$\Delta G_{eq} = -R \cdot T \cdot \ln(K_{eq}) = -8.3144 \cdot 298.15 \cdot \ln(0.0021118) = G_{H2Saq} - (G_{H2Sgas} + G_{H2O}) = \mathbf{15.27} \text{ kJ/mol.}$$

The free energy per mole of hydrogen sulfide is G_{H2Sgas}=G_{H2Saq}-(ΔG_{eq}+G_{H2O})=**53.3896**-(**15.27**+0)=**38.1196** kJ/mol.

S²⁻=S_{rhombic}+H₂O+2e⁻; Standard potential E^o_{classic}=-0.4763 V [1], plus water account logarithm
 -0.0591/2*lg([H₂O]¹)=-0.0515 and the coupled sum ΔE^o=+0.10166-0.37239 expressed absolute potential is
 E^o_{↓/S2=}=E^o_{classic}-0.0591/2*lg([H₂O]¹)+ΔE^o=-0.4763-0.0515+0.10166-0.37239=**-0.79853V**;

$$\Delta G_{eqS2-} = E^o_{S2-} \cdot F \cdot n = \mathbf{-0.79853} \cdot 96485 \cdot 2 = \mathbf{-154.09} \text{ kJ/mol. } G_{Srhombic} = \mathbf{3.5436} \text{ kJ/mol;}$$

$$\Delta G_{eqS2-aq} = G_{Srhombic} + G_{H2O} - (G_{S2-aq}) = \mathbf{3.5436} + 0 - (\mathbf{157.63}) = \mathbf{-154.09} \text{ kJ/mol;}$$

$$G_{S2-aq} = G_{Srhombic} + G_{H2O} - (\Delta G_{eqS2-aq}) = \mathbf{3.5436} + 0 - (\mathbf{-154.09}) = \mathbf{157.63} \text{ kJ/mol;}$$

HS⁻+OH⁻=S_{rhombic}+2H₂O+2e⁻; Standard potential E^o_{classic}=-0.478 V [1], plus water account logarithm
 -0.0591/2*lg([H₂O]²)=-0.103 and the coupled sum ΔE^o=+0.10166-0.37239 expressed absolute potential is
 E^o_{↓/HS-}=E^o_{classic}-0.0591/2*lg([H₂O]²)+ΔE^o=-0.478-0.103+0.10166-0.37239=**-0.8517 V**;

$$\Delta G_{eqHS-} = E_{HS-} \cdot F \cdot n = \mathbf{-0.8517} \cdot 96485 \cdot 2 = \mathbf{-164.35} \text{ kJ/mol.}$$

$$\Delta G_{eqHS-aq} = G_{Srhombic} + 2G_{H2O} - (G_{HS-aq} + G_{OH}) = \mathbf{3.5436} + 2 \cdot 0 - (\mathbf{90.5336} + \mathbf{77.36}) = \mathbf{-164.35} \text{ kJ/mol;}$$

$$G_{HS-aq} = G_{Srhombic} + 2G_{H2O} - (\Delta G_{eqHS-aq} + G_{OH}) = \mathbf{3.5436} + 2 \cdot 0 - (\mathbf{-164.35} + \mathbf{77.36}) = \mathbf{90.5336} \text{ kJ/mol;}$$

H₂S_{aq}+2H₂O=S_{rhombic}+2H₃O⁺+2e⁻; Standard potential E^o_{classic}=0.142 V [1], plus water account logarithm
 -0.0591/2*lg(1/[H₂O]²)=0.103 and the coupled sum ΔE^o=+0.10166-0.37239 expressed absolute potential is
 E^o_{↓/H2S}=E^o_{classic}-0.0591/2*lg(1/[H₂O]²)+ΔE^o=0.142+0.103+0.10166-0.37239=**-0.025735 V**;

$$\Delta G_{eqH2S} = E^o_{H2S} \cdot F \cdot n = \mathbf{-0.025735} \cdot 96485 \cdot 2 = \mathbf{-4.966} \text{ kJ/mol.}$$

$$\Delta G_{eqH2Saq} = G_{Srhombic} + 2G_{H3O+} - (G_{H2Saq} + 2G_{H2O}) = \mathbf{3.5436} + 2 \cdot \mathbf{22.44} - (\mathbf{53.3896} + 2 \cdot 0) = \mathbf{-4.966} \text{ kJ/mol;}$$

$$G_{Srhombic} = \Delta G_{eqH2Saq} - 2G_{H3O+} + (G_{H2Saq} + 2G_{H2O}) = \mathbf{-4.966} - 2 \cdot \mathbf{22.44} + (\mathbf{53.3896} + 2 \cdot 0) = \mathbf{3.5436} \text{ kJ/mol;}$$

pK_a=7.0 Wikipedia; [1] pK_{a1}=7.05; pK_{a2}=19

$$pK_{a1} = 7.05 \text{ H}_2\text{S} + \text{H}_2\text{O} = \text{HS}^- + \text{H}_3\text{O}^+; K_{eq1} = K_{a1}/[\text{H}_2\text{O}] = 10^{-(7.05)}/55.3 = 0.000000001612;$$

$$\Delta G_{eq} = -R \cdot T \cdot \ln(K_{eq}) = -8.3144 \cdot 298.15 \cdot \ln(0.000000001612) = G_{HS-} + G_{H3O+} - (G_{H2S} + G_{H2O}) = \mathbf{50.188} \text{ kJ/mol;}$$

$$\Delta G_{eq} = G_{HS-} + G_{H3O+} - (G_{H2S} + G_{H2O}) = \mathbf{81.138} + \mathbf{22.44} - (\mathbf{53.3896} + 0) = \mathbf{50.188} \text{ kJ/mol;}$$

$$G_{HS-} = \Delta G_{eq} - G_{H3O+} + (G_{H2S} + G_{H2O}) = \mathbf{50.188} - \mathbf{22.44} + (\mathbf{53.3896} + 0) = \mathbf{81.138} \text{ kJ/mol;}$$

$$pK_{a2} = 19 \text{ HS}^- + \text{H}_2\text{O} = \text{S}^{2-} + \text{H}_3\text{O}^+; K_{eq1} = K_{a1}/[\text{H}_2\text{O}] = 10^{-(19)}/55.3 = 10^{-(20.74)};$$

$$\Delta G_{eq} = -R \cdot T \cdot \ln(K_{eq}) = -8.3144 \cdot 298.15 \cdot \ln(10^{-(20.74)}) = G_{S2-} + G_{H3O+} - (G_{HS-} + G_{H2O}) = \mathbf{118.38} \text{ kJ/mol;}$$

$$\Delta G_{eq} = G_{S2-} + G_{H3O+} - (G_{HS-} + G_{H2O}) = \mathbf{188.59} + \mathbf{22.44} - (\mathbf{81.138} + 0) = \mathbf{118.38} \text{ kJ/mol;}$$

$$G_{HS-} = G_{S2-} + G_{H3O+} - (\Delta G_{eq} + G_{H2O}) = \mathbf{188.59} + \mathbf{22.44} - (\mathbf{118.38} + 0) = \mathbf{92.65} \text{ kJ/mol;}$$

Sulfur reduction inverse potential: S_{rhombic}+2H₃O⁺+2e⁻=H₂S_{aq}+2H₂O; -E^o_s=**-0.025735 V**;

$$2(\text{Pt})\text{H} + 2\text{H}_2\text{O} = 2\text{H}_3\text{O}^+ + 2\text{e}^-; E^o_{\text{H}} = \mathbf{-0.27073} \text{ V; } S_{\text{rhombic}} + 2(\text{Pt})\text{H} = \text{H}_2\text{S}_{\text{aq}};$$

$$\Delta G_{eq} = (E^o_{\text{H}} - E^o_{\text{s}}) \cdot F \cdot 1 \cdot 2 = (\mathbf{-0.27073} + \mathbf{0.025735}) \cdot 96485 \cdot 2 = \mathbf{-0.244995} \cdot 96485 \cdot 2 = \mathbf{-47.277} \text{ kJ/mol;}$$

$$G_{H2Saq} = \Delta G_{HessH2S} + (2G_{H(Pt)} + G_{Srhombic}) = \mathbf{-47.277} + (2 \cdot \mathbf{48.56} + \mathbf{34.5}) = \mathbf{84.343} \text{ kJ/mol. } \text{2nd page.}$$

Alberty [8] and CRC [1] data: $G_{H_2gas}=85.6$ kJ/mol, $G_{H_2saq}=53.3896$ kJ/mol [8] and $\Delta G^\circ_{H_2O}=-237.191$ kJ/mol, $\Delta G^\circ_{H_2Sgas}=-81.98$ kJ/mol [1] allow calculating the absolute values of the free energy content of substances $G_{Srombic}=3.5436$ kJ/mol; $G_{O_2gas}=303$ kJ/mol, etc. relative to water and carbon dioxide gas on a zero reference scale $G_{H_2O}=G_{CO_2gas}=G_e=0$ kJ/mol. Formation from elements sulfuric acid and sulfates: $S_{rombic}+2O_{2gas}+H_{2gas}=H_2SO_{4aq}$; $\Delta G^\circ_{H_2SO_4Form}=G_{H_2SO_4}-(G_{Srombic}+2G_{O_2}+G_{H_2gas})=-690.0$ kJ/mol; [1] Content per mol

of H_2SO_4 is $G_{H_2SO_4}=\Delta G^\circ_{H_2SO_4Form}+(G_{Srombic}+2G_{O_2}+G_{H_2gas})=-690.0+(3.5436+2*303+85.6)=5.1436$ kJ/mol. $S_{rombic}+2O_{2gas}+H_{2gas}/2=HSO_4^-$; $\Delta G^\circ_{HSO_4Form}=G_{HSO_4}-(G_{Srombic}+2G_{O_2}+0.5G_{H_2gas})=-755.9$ kJ/mol. Content per mol of HSO_4^- is $G_{HSO_4}=\Delta G^\circ_{HSO_4Form}+(G_{Srombic}+2G_{O_2}+0.5G_{H_2gas})=-755.9+(3.5436+2*303+85.6/2)=-103.56$ kJ/mol. $S_{rombic}+2O_{2gas}=SO_4^{2-}$; $\Delta G^\circ_{SO_4Form}=G_{SO_4}-(G_{Srombic}+2G_{O_2})=-747.75$ kJ/mol. Content per mol of SO_4^{2-} is $G_{SO_4}=\Delta G^\circ_{SO_4Form}+(G_{Srombic}+2G_{O_2})=-747.75+(3.5436+2*303)=-138.2$ kJ/mol.

The protolysis equilibrium $H_2SO_4+H_2O=HSO_4^-+H_3O^+$ in mol fractions is calculated by dividing the acid $K_{eq1}=K_{a1}/[H_2O]=10^{(-2.8)}/55.3=11.41$ constant K_{a1} (p $K_{a1}=-2.8$) by water $[H_2O]=55.3$ M. The change in free energy is $\Delta G_{eqH_2SO_4}=-R\cdot T\cdot\ln(K_{eq})=-8.3144*298.15*\ln(11.41)=G_{HSO_4}+G_{H_3O}-(G_{H_2SO_4}+G_{H_2O})=-6.035$ kJ/mol and from the Hess's law expression $\Delta G_{eqH_2SO_4}=G_{HSO_4}+G_{H_3O}-(G_{H_2SO_4}+G_{H_2O})=G_{HSO_4}+22.44-(-84.04-151.549)=-6.035$ kJ/mol the free energy content per mol of HSO_4^- anion is obtained

$$G_{HSO_4}=\Delta G_{eqH_2SO_4}-G_{H_3O}+(G_{H_2SO_4}+G_{H_2O})=-6.035-22.44+(5.1436+0)=-23.33$$
 kJ/mol.

Protolysis equilibrium $HSO_4^-+H_2O=SO_4^{2-}+H_3O^+$ p $K_{a2}=1.99$ $K_{eq2}=K_{a2}/[H_2O]=10^{(-1.99)}/55.3=0.0001850$ free energy is $\Delta G_{eqHSO_4}=-R\cdot T\cdot\ln(K_{eq2})=-8.3144*298.15*\ln(0.0001850)=G_{SO_4^{2-}}+G_{H_3O}-(G_{HSO_4}+G_{H_2O})=21.307$ kJ/mol. Hess expression $\Delta G_{eqHSO_4}=G_{SO_4^{2-}}+G_{H_3O}-(G_{HSO_4}+G_{H_2O})=G_{SO_4^{2-}}+22.44-(-23.33+0)=21.307$ kJ/mol free energy of SO_4^{2-} anion mol is $G_{SO_4^{2-}}=\Delta G_{eqHSO_4}-G_{H_3O}+(G_{HSO_4}+G_{H_2O})=21.307-22.44+(-23.33+0)=-24.46$ kJ/mol.

Formation from free elements $S_{rombic}+1.5O_{2gas}+H_{2gas}=H_2SO_{3aq}$ and solubility $SO_2^{gas}+H_2O=H_2SO_{3aq}$. $\Delta G^\circ_{H_2SO_3Form}=G_{H_2SO_3}-(G_{Srombic}+1.5\Delta G_{O_2}+G_{H_2gas})=-56.94-(3.5436+1.5*303+85.6)=-600.58$ kJ/mol;

$$G_{H_2SO_3}=\Delta G^\circ_{H_2SO_3Form}+(G_{Srombic}+1.5\Delta G_{O_2}+G_{H_2gas}/2)=-486.5+(3.5436+1.5*303+85.6/2)=-74.84$$
 kJ/mol;

$$G_{SO_3}=\Delta G^\circ_{SO_3Form}+G_{Srombic}+1.5\Delta G_{O_2}=-490.38-85.64+1.5*303=-121.52$$
 kJ/mol;

Equilibrium constants in mol fractions $K_{eq}=K_a/[H_2O]$ calculate dividing the acid constant by water $[H_2O]$.

$$H_2SO_3+H_2O=HSO_3^-+H_3O^+; pK_{a1}=1.85; K_{eq1}=K_{a1}/[H_2O]=10^{(-1.85)}/55.3=0.0002554;$$

$$\Delta G_{eqH_2SO_3}=-R\cdot T\cdot\ln(K_{eq1})=-8.3144*298.15*\ln(0.0002554)=G_{HSO_3^-}+G_{H_3O}-(G_{H_2SO_3}+G_{H_2O})=20.5075$$
 kJ/mol;

$$G_{HSO_3^-}=\Delta G_{eqH_2SO_3}-G_{H_3O}+(G_{H_2SO_3}+G_{H_2O})=20.5075-22.44+(-56.93796+0)=-58.87$$
 kJ/mol;

$$HSO_3^-+H_2O=SO_3^{2-}+H_3O^+; pK_{a2}=7.21; K_{eq2}=K_{a2}/[H_2O]=10^{(-7.21)}/55.3=0.00000001115;$$

$$\Delta G_{eqHSO_3}=-R\cdot T\cdot\ln(K_{eq2})=-8.3144*298.15*\ln(0.00000001115)=G_{SO_3^{2-}}+G_{H_3O}-(G_{HSO_3^-}+G_{H_2O})=51.1$$
 kJ/mol;

$$G_{SO_3^{2-}}=G_{SO_3^{2-}}+G_{H_3O}-(\Delta G_{eqHSO_3}+G_{H_2O})=-121.52+22.44-(51.1+0)=-150.2$$
 kJ/mol;

$H_2SO_3+4H_2O=HSO_4^-+3H_3O^++2e^-$ Standard potential $E^\circ_{classic}=0.172$ V [1], plus water account logarithm $-0.0591/2*\lg(1/[H_2O]^4)=0.206$ and the coupled sum $\Delta E^\circ=+0.10166-0.37239$ expressed absolute potential is

$$E^\circ_{H_2SO_3}=E^\circ_{classic}-0.0591/2*\lg(1/[H_2O]^4)+\Delta E^\circ=0.172+0.206+0.10166-0.37239=0.10726$$
 V;

$$pH<2 E_{H_2SO_3}=E^\circ_{H_2SO_3}+\frac{0.0591}{2}\cdot\log\frac{[HSO_4^-][H_3O^+]^4}{[H_2SO_3][H_2O]^5}=0.10726$$
 V + $\frac{0.0591}{2}\cdot\log\frac{[HSO_4^-][H_3O^+]^4}{[H_2SO_3][H_2O]^5}$

$$\Delta G_{eqH_2SO_3}=E^\circ_{H_2SO_3}\cdot F\cdot 2=0.10726*96485*2=20.69796$$
 kJ/mol;

$$\Delta G_{eqHSO_3}=G_{HSO_4^-}+3G_{H_3O}-(G_{H_2SO_3}+4G_{H_2O})=-103.56+3*22.44-(-56.93796+4*0)=20.69796$$
 kJ/mol;

$$G_{H_2SO_3}=G_{HSO_4^-}+3G_{H_3O}-(\Delta G_{eqH_2SO_3}+4G_{H_2O})=-103.56+3*22.44-(20.69796+4*0)=-56.94$$
 kJ/mol;

$$G_{HSO_4^-}=\Delta G_{eqH_2SO_3}-3G_{H_3O}+(G_{H_2SO_3}+4G_{H_2O})=20.69796-3*22.44+(-56.93796+4*0)=-103.56$$
 kJ/mol;

Solubility constants in mol fractions $K_{eq}=K_{sp}/[H_2O]$ calculate dividing saturate product with water $[H_2O]$. $SO_2^{gas}+H_2O=H_2SO_{3aq}$; $K_{sp}=[H_2SO_3]/[SO_2^{gas}]/[H_2O]=1.46724/1/51.64=0.028413$, as saturated state dissolute 94 g/L SO_2 M=64.066 g/mol $[SO_2]=94/64.066=1.46724$ M sulfurous acid $M_{H_2SO_3}=82.075$ g/mol with density 1.05 g/mL $m_{solution}=1050$ g/L and mas of acid $m_{H_2SO_3}=[SO_2]*M_{H_2SO_3}=1.46724$ M*82.075 g/mol=120.4327 g/L.

Water concentration is $m_{H_2O}=1050-120.4327=929.5673$ g; $n_{H_2O}=929.5673/18=51.64$ M. Free energy change is:

$$\Delta G_{spH_2SO_3}=-R\cdot T\cdot\ln(K_{sp})=-8.3144*298.15*\ln(0.028413)=G_{H_2SO_3}-(G_{SO_2}+G_{H_2O})=8.82727$$
 kJ/mol;

$$\Delta G_{eqH_2SO_3}=G_{H_2SO_3}-(G_{SO_2}+G_{H_2O})=-56.93796-(-81.735+0)=8.82727$$
 kJ/mol;

$$G_{SO_2}=G_{H_2SO_3}-(\Delta G_{eqH_2SO_3}+G_{H_2O})=-72.9075-(8.82727+0)=-81.73477$$
 kJ/mol; pH<2 [1]

$$G_{SO_2}=G_{H_2SO_3}-(\Delta G_{eqH_2SO_3}+G_{H_2O})=-56.93796-(8.82727+0)=-65.76523$$
 kJ/mol; 2=<pH<7 [17]

$$\Delta G_{eqH_2SO_3}=G_{H_2SO_3}-(G_{SO_2}+G_{H_2O})=-56.93796-(-65.76523+0)=8.82727$$
 kJ/mol;

Formation from free elements $S_{\text{rombic}} + O_{2,\text{gas}} = SO_2$; $\Delta G^{\circ}_{SO_2\text{Form}} = G_{SO_2} - (-85.64 + 303) = -370.82 \text{ kJ/mol}$;

$$G_{SO_2} = \Delta G^{\circ}_{SO_2\text{Form}} + (G_{S_{\text{rombic}}} + G_{O_2}) = -370.82 + (-85.64 + 303) = -153.46 \text{ kJ/mol}$$

$HSO_3^- + 4H_2O = SO_4^{2-} + 3H_3O^+ + 2e^-$ Standard potential $E^{\circ}_{\text{classic}} = 0.172 \text{ V}$ [17], plus water account logarithm $-0.0591/2 * \lg(1/[H_2O]^4) = 0.206$ and the coupled sum $\Delta E^{\circ} = +0.10166 - 0.37239$ expressed absolute potential is

$$E^{\circ}_{SO_4} = E^{\circ}_{\text{classic}} - 0.0591/2 * \lg(1/[H_2O]^4) + \Delta E^{\circ} = 0.172 + 0.206 + 0.10166 - 0.37239 = \mathbf{0.10726 \text{ V}}$$

$$2 = \langle \text{pH} \rangle < 7 \quad E_{HSO_3} = E^{\circ}_{HSO_3} + 0.0591/2 * \log \frac{[SO_4^{2-}] \cdot [H_3O^+]^3}{[HSO_3^-] \cdot [H_2O]^4} = \mathbf{0.10726 \text{ V}} + 0.0591/2 * \log \frac{[SO_4^{2-}] \cdot [H_3O^+]^3}{[HSO_3^-] \cdot [H_2O]^4}$$

$$\Delta G_{\text{eq}SO_4} = E^{\circ}_{HSO_4} \cdot F \cdot 2 = \mathbf{0.10726} * 96485 * 2 = \mathbf{20.69796 \text{ kJ/mol}}$$

$$\Delta G_{\text{eq}SO_4} = G_{SO_4} + 3G_{H_3O} - (G_{HSO_3} + 4G_{H_2O}) = \mathbf{-24.46} + 3 * 22.44 - (\mathbf{22.16} + 4 * 0) = \mathbf{20.7 \text{ kJ/mol}}$$

$$G_{HSO_3} = G_{SO_4} + 3G_{H_3O} - (\Delta G_{\text{eq}SO_4} + 4G_{H_2O}) = \mathbf{-24.46} + 3 * 22.44 - (\mathbf{20.69796} + 4 * 0) = \mathbf{22.16 \text{ kJ/mol}}$$

$$G_{SO_4} = \Delta G_{\text{eq}SO_4} - 3G_{H_3O} + (G_{HSO_3} + 4G_{H_2O}) = \mathbf{20.69796} - 3 * 22.44 + (\mathbf{22.16} + 4 * 0) = \mathbf{-24.46 \text{ kJ/mol}}$$

Substance	$\Delta H^{\circ}_H, \text{kJ/mol}$	$\Delta S^{\circ}_H, \text{J/mol/K}$	$\Delta G^{\circ}_H, \text{kJ/mol}$	
H ₂ SO ₄	-814.0	156.9	-690.0	CRC [1];
H ₂ SO ₄	avored	formation	5.1436	$G_{H_2SO_4} = \Delta G^{\circ}_{H_2SO_4} + G_{S_{\text{rombic}}} + 2\Delta G_{O_2} + G_{H_2,\text{gas}} + G_{H_2O} = \mathbf{5.1436 \text{ kJ/mol}}$
HSO ₄ ⁻	-887.3	131.8	-755.9	CRC [1]
HSO ₄ ⁻	-	pK _{a1} =-2.8	-23.33	$G_{HSO_4} = \Delta G_{\text{eq}H_2SO_4} - G_{H_3O} + (G_{H_2SO_4} + G_{H_2O}) = \mathbf{-23.33 \text{ kJ/mol}}$
HSO ₄ ⁻	pH<2	formation	-103.56	$G_{HSO_4} = \Delta G^{\circ}_{HSO_4} + G_{S_{\text{rombic}}} + 2\Delta G_{O_2} + G_{H_2,\text{gas}}/2 = \mathbf{-103.56 \text{ kJ/mol}}$
SO ₄ ²⁻	-907.62	-536.2	-747.75	BioTherm2006 pH=7.36 [8] $\Delta G_{SO_4} = \Delta H - T * \Delta S = \mathbf{-747.75 \text{ kJ/mol}}$
SO ₄ ²⁻	-	formation	-138.2	$G_{SO_4} = \Delta G^{\circ}_{SO_4\text{Form}} + G_{S_{\text{rombic}}} + 2\Delta G_{O_2} = \mathbf{-747.75 - 85.64 + 2 * 303 = -138.2 \text{ kJ/mol}}$
SO ₄ ²⁻	2=<pH<7	pK _{a2} =1.99	-24.46	$G_{SO_4} = \Delta G_{\text{eq}HSO_4} - G_{H_3O} + (G_{HSO_4} + G_{H_2O}) = \mathbf{-24.46 \text{ kJ/mol}}$
SO ₄ ²⁻	E ^o _{HSO₃} =	0.10726	-24.46	$G_{SO_4} = \Delta G_{\text{eq}SO_4} - 3G_{H_3O} + (G_{HSO_3} + 4G_{H_2O}) = \mathbf{-24.46 \text{ kJ/mol}}$; 2=<pH<7
SO ₄ ²⁻	E ^o _{SO₃} =	-1.2522	-213.4	$G_{SO_4} = \Delta G_{\text{eq}SO_3} - OH - G_{H_2O} + (G_{SO_3} + 2G_{OH}) = \mathbf{-213.4 \text{ kJ/mol}}$
SO ₄ ²⁻	-909.3	20.1	-744.5	CRC [1]
SO ₂ ^{gas}	-296.81	248.223	-370.82	$\Delta G_H = \Delta H_H - T * \Delta S_H = -296.81 - 298.15 * 0.248223 = -370.82 \text{ kJ/mol}$
SO ₂ ^{gas}		formation	-153.46	$G_{SO_2} = \Delta G^{\circ}_{SO_2\text{Form}} + (G_{S_{\text{rombic}}} + G_{O_2}) = \mathbf{-153.46 \text{ kJ/mol}}$
SO ₂ ^{gas}	$\Delta G_{K_{sp}} = 8.827$	pH<2	-81.735	$\Delta G_{SO_2} = G_{H_2SO_3} - (\Delta G_{spH_2SO_3} + G_{H_2O}) = \mathbf{-72.9075 - (8.82727 + 0) = -81.73477 \text{ kJ/mol}}$
SO ₂ ^{gas}	$\Delta G_{K_{sp}} = 8.827$	2<pH<7	-65.765	$G_{SO_2} = G_{H_2SO_3} - (\Delta G_{spH_2SO_3} + G_{H_2O}) = \mathbf{-65.76523 \text{ kJ/mol}}$
H ₂ SO ₃	Alberty [8]	pH=7.36	-600.58	$\Delta G^{\circ}_{H_2SO_3\text{Form}} = G_{H_2SO_3} - (G_{S_{\text{rombic}}} + 1.5\Delta G_{O_2} + G_{H_2,\text{gas}}) = \mathbf{-600.58 \text{ kJ/mol}}$
H ₂ SO ₃		formation	-72.9075	$G_{H_2SO_3} = \Delta G^{\circ}_{H_2SO_3\text{Form}} + (G_{S_{\text{rombic}}} + 1.5\Delta G_{O_2} + G_{H_2,\text{gas}}) = \mathbf{-72.9075 \text{ kJ/mol}}$
H ₂ SO ₃	E ^o _{H₂SO₃} =	0.10726	-56.93796	$G_{H_2SO_3} = G_{HSO_4} + 3G_{H_3O} - (\Delta G_{\text{eq}HSO_3} + 4G_{H_2O}) = \mathbf{-56.938 \text{ kJ/mol}}$; pH<2
HSO ₃ ⁻	E ^o _{HSO₃} =	0.10726	22.16	$G_{HSO_3} = G_{SO_4} + 3G_{H_3O} - (\Delta G_{\text{eq}SO_4} + 4G_{H_2O}) = \mathbf{22.16 \text{ kJ/mol}}$
HSO ₃ ⁻		formation	-74.84	$G_{HSO_3} = \Delta G^{\circ}_{HSO_3} + G_{S_{\text{rombic}}} + 1.5\Delta G_{O_2} + G_{H_2,\text{gas}}/2 = \mathbf{-74.84 \text{ kJ/mol}}$
HSO ₃ ⁻		pK _{a1} =1.85	-58.87	$G_{HSO_3} = \Delta G_{\text{eq}H_2SO_3} - G_{H_3O} + (G_{H_2SO_3} + G_{H_2O}) = \mathbf{-58.87 \text{ kJ/mol}}$
HSO ₃ ⁻	-635.5	-29	-486.5	CRC [1]
SO ₃ ²⁻	-632.19	-475.628	-490.38	BioTherm2006 pH=7.36 [8]
SO ₃ ²⁻	-	formation	-121.52	$G_{SO_3} = \Delta G_{\text{Form}} = \Delta G^{\circ}_{SO_3} + G_{S_{\text{rombic}}} + 1.5\Delta G_{O_2} = \mathbf{-121.52 \text{ kJ/mol}}$
SO ₃ ²⁻		pK _{a2} =7.21	-30.21	$G_{SO_3} = \Delta G_{\text{eq}HSO_3} + G_{H_3O} - (G_{HSO_3} + G_{H_2O}) = \mathbf{-30.21 \text{ kJ/mol}}$
SO ₃ ²⁻	E ^o _{SO₃-OH} =	-1.2522	62.457	$G_{SO_3} = G_{SO_4} - G_{H_2O} - (\Delta G_{\text{eq}SO_3} - OH + 2G_{OH}) = \mathbf{62.457 \text{ kJ/mol}}$; pH>7

$$G_{H_2SO_3} = \Delta G^{\circ}_{H_2SO_3\text{Form}} + (G_{S_{\text{rombic}}} + 1.5\Delta G_{O_2} + G_{H_2,\text{gas}}) = \mathbf{-72.9075 \text{ kJ/mol}}$$

$SO_3^{2-} + 2OH^- = SO_4^{2-} + H_2O + 2e^-$; pH>7; - Standard potential $E^{\circ}_{\text{classic}} = -0.93 \text{ V}$ [17], plus water account logarithm $-0.0591/2 * \lg([H_2O]) = 0.0515$ and the coupled sum $\Delta E^{\circ} = +0.10166 - 0.37239$ expressed absolute potential is

$$E^{\circ}_{SO_3-OH} = E^{\circ}_{\text{classic}} - 0.0591/2 * \lg([H_2O]) + \Delta E^{\circ} = -0.93 + 0.0515 + 0.10166 - 0.37239 = \mathbf{-1.2522 \text{ V}}$$

$$E_{SO_3-OH} = E^{\circ}_{SO_3-OH} + \frac{0.0591}{2} \cdot \log \frac{[SO_4^{2-}] \cdot [H_2O]}{[SO_3^{2-}] \cdot [OH]^2} = \mathbf{-1.2522 \text{ V}} + \frac{0.0591}{2} \cdot \log \frac{[SO_4^{2-}] \cdot [H_2O]}{[SO_3^{2-}] \cdot [OH]^2}$$

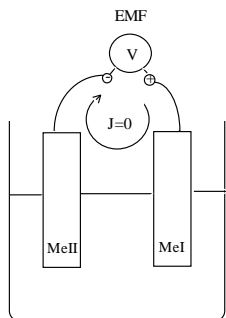
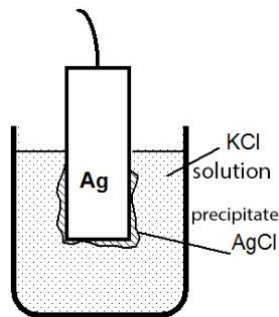
$$\Delta G_{\text{eq}SO_4-OH} = E^{\circ}_{SO_3-OH} \cdot F \cdot 2 = \mathbf{-1.2522} * 96485 * 2 = \mathbf{-241.637 \text{ kJ/mol}}$$

$$\Delta G_{\text{eq}SO_3-OH} = G_{SO_4} - G_{H_2O} - (G_{SO_3} + 2G_{OH}) = \mathbf{24.46} + 0 - (\mathbf{62.457} + 2 * 77.36) = \mathbf{-241.637 \text{ kJ/mol}}$$

$$G_{SO_3} = G_{SO_4} - G_{H_2O} - (\Delta G_{\text{eq}SO_3-OH} + 2G_{OH}) = \mathbf{-24.46} + 0 - (\mathbf{-241.637} + 2 * 77.36) = \mathbf{62.457 \text{ kJ/mol}}$$

$$G_{SO_4} = \Delta G_{\text{eq}SO_3-OH} - G_{H_2O} + (G_{SO_3} + 2G_{OH}) = \mathbf{-241.637} - 0 + (\mathbf{62.457} + 2 * 77.36) = \mathbf{-24.46 \text{ kJ/mol}}$$

Metal insoluble salt solution of salt anions II-type electrode.



K^+Cl^- solution, counter-ions Cl^- of $AgCl$ insoluble salt. Nernst's half reactions for electrode of silver metal Ag . Electric potential in volt measurement by couple of electrodes Electric Motion Force EMF in Volts. Between the indicator electrodes MeI and the reference electrode $MeII$ connected in a closed electrical circuit, the potential of the MeI indicator electrode EI is calculated as the sum: $EI=EMS+EII$. The standard reference electrode EII serves as a constant potential and chloride concentration.

The silver I-type electrode: $Ag(s)+H_2O=Ag^++e^-$ absolute potential is expression standard potential $E^\circ_{Classic}=0.7994$ V [18], water logarithm $-0.0591/1*\lg(1/55.3^{\wedge}1)=-0.103$ and sum $\Delta E^\circ=0.10166-0.37239$: $E_{Ag/Ag^+}=E^\circ_{classic}-0.0591/1*\lg(1/[H_2O]^1)+\Delta E^\circ=0.7994+0.103+0.10166-0.37239=0.6317$ V;

$$\Delta G_{eq_Ag}=E^\circ_{Ag}\cdot F\cdot 2=0.6317*96485*1=60.95 \text{ kJ/mol. } \Delta G_{eq_As}=G_{Ag^+}-(G_{Ag}+G_{H_2O})=77.1-(G_{Ag}+0)=60.95 \text{ kJ/mol ;}$$

$$G_{Ag}=G_{Ag^+}-(\Delta G_{eq_Ag}+G_{H_2O})=77.1-(60.95+0)=16.15 \text{ kJ/mol; [1]}$$

$$G_{Ag}=G_{Ag^+}-(\Delta G_{eq_Ag}+G_{H_2O})=103.8-(60.95+0)=42.85 \text{ kJ/mol; [8]}$$

$$G_{Ag^+}=\Delta G_{eq_As}+(G_{Ag}+G_{H_2O})=60.95+(42.855+0)=103.8 \text{ kJ/mol ; [8]}$$

Formation $2Ag^++Cl_2=2AgCl(s)$; $2\Delta G_{eq_AgCl}=2G_{AgCl}-(2G_{Ag}+G_{Cl_2})=2G_{AgCl}-(2*42.85+394.2)=-155.71$ kJ/mol ; [1]

$$G_{AgCl}=(2\Delta G_{eq_AgCl}+(2G_{Ag}+G_{Cl_2}))/2=(2*(-155.71+(2*42.85+394.2)))/2=84.24 \text{ kJ/mol ;}$$

Solubility equilibrium in mol fractions $AgCl(s)+2H_2O=Ag^++Cl^-$; $AgCl(s)+2H_2O-Cl^-=Ag^+$ absolute constant :

$$K_{AbsoluteAgCl}=K_{spAgCl}/[H_2O]^2=[Ag^+][Cl^-]/[AgCl(s)]=1.77*10^{(-10)}/55.3^2=5.79*10^{-14} ;$$

$$\Delta G_{AbsoluteAgCl}=-R\cdot T\cdot \ln(K_{AbsoluteAgCl})=-8.3144*298.15*\ln(5.788*10^{(-14)})=75.559 \text{ kJ/mol;}$$

$$\Delta G_{spAgCl}=G_{Ag^+}+G_{Cl^-}-(G_{AgCl}+2G_{H_2O})=103.8+101.97-(130.211+2*0)=75.559 \text{ kJ/mol ;}$$

$$G_{AgCl}=G_{Ag^+}+G_{Cl^-}-(\Delta G_{spAgCl}+2G_{H_2O})=103.8+101.97-(75.559+2*0)=130.211 \text{ kJ/mol ;}$$

compensate water molecule $Ag(s)+H_2O=Ag^++e^-$; $Ag(s)+H_2O+Cl^-=AgCl(s)+2H_2O+e^-$ on summary reaction

$Ag(s)+Cl^-=AgCl(s)+H_2O+e^-$ Expression of absolute potential has standard $E^\circ_{Classic}=0.2223$ V [18],

water and ΔE° : $E_{Ag/AgCl}=E^\circ_{classic}-0.0591/1*\lg([H_2O]^1)+\Delta E^\circ=0.2223-0.103+0.10166-0.37239=-0.1514$ V;

$$\Delta G_{eq_Ag}=E^\circ_{Ag}\cdot F\cdot 1=-0.1514*96485*1=-14.61 \text{ kJ/mol,}$$

$$\Delta G_{eq_Ag}=G_{AgCl}+G_{H_2O}-(G_{Ag}+G_{Cl^-})=-155.71+0-(42.855-183.955)=-14.61 \text{ kJ/mol ;}$$

$$G_{Ag}=G_{AgCl}+G_{H_2O}-(\Delta G_{eq_Ag}+G_{Cl^-})=-155.71+0-(-14.61-183.955)=42.855 \text{ kJ/mol ;}$$

Solubility NH_3 gas and Ag compensate each one water molecule in Nernst's half reaction products

NH_3 gas + $H_2O = NH_3$ aq; $Ag + H_2O = Ag^+ + e^-$; $Ag + H_2O + 2NH_3$ aq = $Ag(NH_3)_2^+ + 2H_2O + e^-$; Absolute potential has standard $E^\circ_{Classic}=0.373$ V [17], water $-0.0591/1*\lg([H_2O]^1)=-0.103$ logarithm and sum $\Delta E^\circ=0.10166-0.37239$:

$$E^\circ_{Ag/Ag(NH_3)_2^+}=E^\circ_{classic}-0.0591/1*\lg([H_2O]^1)+\Delta E^\circ=0.373-0.103+0.10166-0.37239=-0.000725$$
 V;

$$\Delta G_{Ag/Ag(NH_3)_2^+}=E^\circ_{Ag/Ag(NH_3)_2^+}\cdot F\cdot 1=-0.000725*96485*1=-0.06995 \text{ kJ/mol;}$$

$$G_{Ag(NH_3)_2^+}=\Delta G_{Ag/Ag(NH_3)_2^+}-G_{H_2O}+(G_{Ag}+2G_{NH_3aq})=-0.06995-0+(42.855-2*91.1)=-139.415 \text{ kJ/mol;}$$

$2Ag+2OH^-=Ag_2O(s)+H_2O+2e^-$; Expression of absolute potential has standard $E^\circ_{Classic}=0.345$ V [17],

water and ΔE° : $E^\circ_{2Ag/Ag_2O}=E^\circ_{classic}-0.0591/2*\lg([H_2O]^1)+\Delta E^\circ=0.345-0.0515+0.10166-0.37239=0.02277$ V

$$\Delta G_{Ag/Ag_2O}=E^\circ_{Ag/Ag_2O}\cdot F\cdot 2=0.02277*96485*2=4.394 \text{ kJ/mol;}$$

$$\Delta G_{Ag/Ag_2O}=G_{Ag_2O}+G_{H_2O}-(2G_{Ag}+2G_{OH^-})=G_{Ag_2O}+0-(2*42.855-2*77.36)=4.394 \text{ kJ/mol ;}$$

$$G_{Ag_2O}=\Delta G_{Ag/Ag_2O}-G_{H_2O}+(2G_{Ag}+2G_{OH^-})=4.394-0+(2*42.855-2*77.36)=-64.616 \text{ kJ/mol ;}$$

$$E^\circ_{Ag/Ag(NH_3)_2^+}=0.000725 \text{ V} + \frac{[Ag(NH_3)_2^+]}{[Ag] \cdot ([NH_3] \cdot 2 \cdot [Ag(NH_3)_2^+])^2} E^\circ_{2Ag/Ag_2O}=0.02277 \text{ V} + \frac{[Ag_2O][H_2O]}{[Ag]^2 \cdot [OH^-]^2}$$

Viela	ΔH°_H kJ/mol	ΔS° J/mol/K	ΔG°_H kJ/mol	
Ag	E°_{Ag/Ag^+}	-0.6317 V	16.15	ion $G_{Ag^+}=103.8$ kJ/mol over $G_{Ag}=42.855$ kJ/mol element 60.945; [8]
Ag	E°_{Ag/Ag^+}	-0.6317 V	42.85	CRC [1] $G_{Ag}=G_{Ag^+}-(\Delta G_{eq_Ag}+G_{H_2O})=77.1-(60.95+0)=16.15$ kJ/mol;
Ag	$E^\circ_{Ag/AgCl}$	-0.1514 V	42.855	$G_{Ag}=G_{Ag^+}-(\Delta G_{eq_Ag}+G_{H_2O})=103.8-(60.95+0)=42.85$ kJ/mol; [8]
Ag+	105.6	72.7	77.1	$G_{Ag}=G_{AgCl}+G_{H_2O}-(\Delta G_{eq_Ag}+G_{Cl^-})=-155.71+0-(-14.61-183.955)=42.855$ kJ/mol;
Ag+	E°_{Ag}	0.6317 V	103.8	CRC; [1] ion $G_{Ag^+}=77,1$ kJ/mol over element zero $\Delta G^\circ_{Ag}=0$ kJ/mol;
AgCl(s)	-127.01	96.25	-155.71	$G_{Ag^+}=\Delta G_{eq_As}+(G_{Ag}+G_{H_2O})=60.95+(42.855+0)=103.8$ kJ/mol ;
AgCl(s)	formation	-	84.24	$\Delta G_{AgCl}=\Delta H_H-T\cdot \Delta S_H=-127.01-298.15*0.09625=-155.71$ kJ/mol; [1]
AgCl(s)	K_{spAgCl}	$5,788*10^{-14}$	130.2	$G_{AgCl}=(2\Delta G_{eq_AgCl}+(2G_{Ag}+G_{Cl_2}))/2=84.24$ kJ/mol;
Cl-	$K_{spHg_2Cl_2}$	$10^{(-23,1)}$	101.97	$G_{AgCl}=G_{Ag^+}+G_{Cl^-}-(\Delta G_{spAgCl}+2G_{H_2O})=130.2$ kJ/mol;
Ag(NH ₃) ₂ ⁺	$E^\circ_{Ag(NH_3)_2^+}$	-0.000725	-139.415	$G_{Cl^-}=(-G_{Hg_2^{2+}}+\Delta G_{eqHg_2Cl_2}+(G_{Hg_2Cl_2}+3G_{H_2O}))/2=101.97$ kJ/mol;
AgCl	ΔG_{spAgCl}	K_{spAgCl}	-155.714	$G_{Ag(NH_3)_2^+}=\Delta G_{Ag/Ag(NH_3)_2^+}-G_{H_2O}+(G_{Ag}+2G_{NH_3aq})=-139.415$ kJ/mol;
Ag ₂ O(s)	-31.1	121.3	-11.2	$G_{AgCl}=G_{Ag^+}+G_{Cl^-}-(\Delta G_{spAgCl}+2G_{H_2O})=-155.714$ kJ/mol;
				CRC; [1]

$\text{Ag}_2\text{O}(\text{s})$	$E^\circ_{\text{Ag}/\text{Ag}_2\text{O}}=$	0.02277V	-64.616
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$$G_{\text{Ag}_2\text{O}} = \Delta G_{\text{Ag}/\text{Ag}_2\text{O}} - G_{\text{H}_2\text{O}} + (2G_{\text{Ag}} + 2G_{\text{OH}}) = -64.616 \text{ kJ/mol};$$

Nernst's potential studies $\text{Hg}/\text{Hg}_2^{2+}/\text{Hg}_2^{2+}$, Hg_2Cl_2 , $\text{Hg}_2\text{SO}_4(\text{s})$, HgO accounting hydroxonium H_3O^+ , water H_2O .

Substance	$\Delta H^\circ_{\text{H}}$, kJ/mol	$\Delta S^\circ_{\text{H}}$, J/mol/K	$\Delta G^\circ_{\text{H}}$, kJ/mol
Hg	HgO ; H ₂ O ₂	75.9	35.885
Hg	$E^\circ_{\text{HgCl}_2=}$	-0.1059 V	35.8
Hg ₂ ²⁺	-166.87	66.74	-146.97
Hg ₂ ²⁺	$E^\circ_{\text{Hg}/\text{Hg}_2^{2+}=}$	0.6888 V	204.52
Hg ²⁺	-170.21	-36.19	-
Hg ₂ SO ₄ (s)	-743.1	200.7	-625.8
Hg ₂ SO ₄ (s)	$K_{\text{AbsoluteHg}_2\text{SO}_4=}$	$10^{(-9.673)}$	-598.44
SO ₄ ²⁻	-907.62	-536.2	-747.75
SO ₄ ²⁻	$E^\circ_{\text{Hg}_2\text{SO}_4=}$	0.2918 V	-726.54
SO ₄ ²⁻	-909.3	20.1	-744.5
Cl ₂	formation	Hg ₂ Cl ₂ (s)	394,2
Hg ₂ Cl ₂ (s)	-265.37	191.6	-210.7
Hg ₂ Cl ₂ (s)	$E^\circ_{\text{HgCl}_2=}$	-0.1059 V	255.1
HgCl ₂ (s)	-224.3	146	-178.6
Cl ⁻	-167.08	56.6	-183.955
Cl ⁻	$K_{\text{AbsoluteHg}_2\text{Cl}_2=}$	$10^{(-23.1)}$	-112.825
HgO(s)	-99.79	70.25	-60.3675
HgO(s)	-90.8	70.3	-58.5
HgO(s)	-	formation	142.3
HgO(s)	$E^\circ_{\text{HgO}=}$	0.22423 V	147.15

$$(E^\circ_{\text{H}_2\text{O}_{\text{aqRed}}}-E^\circ_{\text{HgO}})*F*n=(0.5278+0.22318)=0.7510\text{V}$$

$$G_{\text{Hg}}=G_{\text{eqRedOx}_2\text{H}_2\text{O}_2}-G_{\text{O}_2\text{aqua}}+(G_{\text{HgO}}+G_{\text{H}_2\text{O}_2})=35.885 \text{ kJ/mol};$$

$$G_{\text{Hg}}=(G_{\text{Hg}_2\text{Cl}_2}+G_{\text{H}_2\text{O}}-(2G_{\text{Cl}}+\Delta G_{\text{eq}_\text{Hg}_2\text{Cl}_2}))/2=35.8 \text{ kJ/mol};$$

$$\Delta G_{\text{Hg}_2^{2+}}=\Delta H_{\text{H}}-T*\Delta S_{\text{H}}=-166.87-298.15*0.06674=-146.97 \text{ kJ/mol};$$

$$G_{\text{Hg}_2^{2+}}=\Delta G_{\text{eq}_\text{Hg}}+(2G_{\text{Hg}}+G_{\text{H}_2\text{O}})=132.92+(2*35.702+0)=204.32 \text{ kJ/mol};$$

CRC [1]

CRC [1]

$$G_{\text{Hg}_2\text{SO}_4}=G_{\text{Hg}_2^{2+}}+G_{\text{SO}_4^{2-}}-(\Delta G_{\text{eq}_\text{Hg}_2\text{SO}_4}+2G_{\text{H}_2\text{O}})=-598.44 \text{ kJ/mol};$$

Biochem. Thermodynamic 2006 Massachusetts Technology Inst. [8]

$$G_{\text{SO}_4}=G_{\text{Hg}_2\text{SO}_4}-(2G_{\text{Hg}}+\Delta G_{\text{eq}_\text{Hg}_2\text{SO}_4})=-726.54 \text{ kJ/mol}$$

CRC [1]

$$G_{\text{Cl}_2}=G_{\text{Hg}_2\text{Cl}_2(\text{s})}-(2G_{\text{Hg}}+\Delta G^\circ_{\text{Hg}_2\text{Cl}_2\text{Form}})=394,2 \text{ kJ/mol};$$

$$\text{CRC [1]} \Delta G^\circ_{\text{Hg}_2\text{Cl}_2\text{Form}}=G_{\text{Hg}_2\text{Cl}_2(\text{s})}-(2G_{\text{Hg}}+G_{\text{Cl}_2})=-210,7 \text{ kJ/mol};$$

$$G_{\text{Hg}_2\text{Cl}_2}=\Delta G_{\text{eq}_\text{Hg}_2\text{Cl}_2}-2G_{\text{H}_2\text{O}}+(2G_{\text{Cl}}+2G_{\text{Hg}})=255.1 \text{ kJ/mol};$$

CRC [1]

$$\Delta G_{\text{Cl}^-}=\Delta H_{\text{H}}-T*\Delta S_{\text{H}}=-167.08-298.15*0.0566=-183.955 \text{ kJ/mol};$$

$$G_{\text{Cl}^-}=(-G_{\text{Hg}_2^{2+}}+\Delta G_{\text{eq}_\text{Hg}_2\text{Cl}_2}+(G_{\text{Hg}_2\text{Cl}_2}+3G_{\text{H}_2\text{O}}))/2=-112.825 \text{ kJ/mol};$$

$$\Delta G_{\text{HgO}}=\Delta H_{\text{H}}-T*\Delta S_{\text{H}}=-99.79-298.15*0.07025=2*-60.3675 \text{ kJ/mol};$$

$$\text{CRC [1]} \Delta G_{\text{HgO}}=-58.5 \text{ kJ/mol};$$

$$2G_{\text{HgO}}=2\Delta G_{\text{HgO}}+(2*G_{\text{Hg}}+G_{\text{O}_2})=2*142.2 \text{ kJ/mol}$$

$$G_{\text{HgO}}=\Delta G_{\text{eq}_\text{HgO}}-2G_{\text{H}_2\text{O}}+(G_{\text{Hg}}+2G_{\text{OH}})=147.15 \text{ kJ/mol};$$

$2\text{Hg}+\text{H}_2\text{O}=\text{Hg}_2^{2+}+2\text{e}^-$; Expression of absolute potential has standard $E^\circ_{\text{Classic}}=0.907 \text{ V}$ [18],

water and ΔE° : $E^\circ_{2\text{Hg}}=E^\circ_{\text{Classic}}-0.0591/2*\lg(1/[\text{H}_2\text{O}]^1)+\Delta E^\circ_{2\text{Hg}}=0.907+0.0515+0.10166-0.37239=0.6888 \text{ V}$;

$$\Delta G_{\text{eq}_\text{Hg}}=E^\circ_{2\text{Hg}}*F*2=0.6888*96485*2=132.92 \text{ kJ/mol},$$

$$\Delta G_{\text{eq}_\text{Hg}}=G_{\text{Hg}_2^{2+}}-(2G_{\text{Hg}}+G_{\text{H}_2\text{O}})=G_{\text{Hg}_2^{2+}}-(2*35.8+0)=204.52-(2*35.8+0)=132.92 \text{ kJ/mol};$$

$$G_{\text{Hg}_2^{2+}}=\Delta G_{\text{eq}_\text{Hg}}+(2G_{\text{Hg}}+G_{\text{H}_2\text{O}})=132.92+(2*35.8+0)=204.52 \text{ kJ/mol};$$

Solubility equilibrium $\text{Hg}_2\text{Cl}_2(\text{s})+3\text{H}_2\text{O}=\text{Hg}_2^{2+}+2\text{Cl}^-$; $2\text{Hg}+\text{H}_2\text{O}=\text{Hg}_2^{2+}+2\text{e}^-$; absolute solubility constant :

$$K_{\text{AbsoluteHg}_2\text{Cl}_2}=K_{\text{spHg}_2\text{Cl}_2}/[\text{H}_2\text{O}]^3=[\text{Hg}_2^{2+}][\text{Cl}^-]^2/[\text{Hg}_2\text{Cl}_2(\text{s})]/[\text{H}_2\text{O}]^3=1.43*10^{(-18)}/1/55.3^3=10^{-23.1};$$

$$\Delta G_{\text{eq}_\text{Hg}_2\text{Cl}_2}=-R*T*\ln(K_{\text{AbsoluteHg}_2\text{Cl}_2})=-8.314*298.15*\ln(10^{(-23.1)})=131.85 \text{ kJ/mol};$$

$$\Delta G_{\text{Hg}_2\text{Cl}_2}=G_{\text{Hg}_2^{2+}}+2G_{\text{Cl}^-}-(G_{\text{Hg}_2\text{Cl}_2}+3G_{\text{H}_2\text{O}})=204.52+2G_{\text{Cl}^-}-(276.61+3*0)=204.52+2*101.97-(276.61+3*0)=131.85 \text{ kJ/mol};$$

$$G_{\text{Cl}^-}=(-G_{\text{Hg}_2^{2+}}+\Delta G_{\text{eq}_\text{Hg}_2\text{Cl}_2}+(G_{\text{Hg}_2\text{Cl}_2}+3G_{\text{H}_2\text{O}}))/2=(-204.52+131.85+(276.61+3*0))/2=101.97 \text{ kJ/mol};$$

Formation $2\text{Hg}+\text{Cl}_2=\text{Hg}_2\text{Cl}_2(\text{s})$; $\Delta G^\circ_{\text{Hg}_2\text{Cl}_2\text{Form}}=G_{\text{Hg}_2\text{Cl}_2(\text{s})}-(2G_{\text{Hg}}+G_{\text{Cl}_2})=255,1-(2*35,8+G_{\text{Cl}_2})=-210,7 \text{ kJ/mol}$;

$$G_{\text{Cl}_2}=G_{\text{Hg}_2\text{Cl}_2(\text{s})}-(2G_{\text{Hg}}+\Delta G^\circ_{\text{Hg}_2\text{Cl}_2\text{Form}})=255,1-(2*35,8-210,7)=394,2 \text{ kJ/mol};$$

$2\text{Hg}+2\text{Cl}^-=\text{Hg}_2\text{Cl}_2(\text{s})+2\text{H}_2\text{O}+2\text{e}^-$; Expression of absolute potential has standard $E^\circ_{\text{Classic}}=0.2678 \text{ V}$ [18],

water and ΔE° : $E^\circ_{\text{HgCl}_2}=E^\circ_{\text{Classic}}-0.0591/2*\lg([\text{H}_2\text{O}]^2)+\Delta E^\circ=0.2678-0.103+0.10166-0.37239=-0.1059 \text{ V}$;

$$\Delta G_{\text{eq}_\text{Hg}_2\text{Cl}_2}=E^\circ_{\text{HgCl}_2}*F*2=-0.1059*96485*2=-20.44 \text{ kJ/mol},$$

$$\Delta G_{\text{eq}_\text{Hg}_2\text{Cl}_2}=G_{\text{Hg}_2\text{Cl}_2}+2G_{\text{H}_2\text{O}}-(2G_{\text{Cl}^-}+2G_{\text{Hg}})=255.1+2*0-(2*101.97+2*35.8)=-20.44 \text{ kJ/mol};$$

$$G_{\text{Hg}_2\text{Cl}_2}=\Delta G_{\text{eq}_\text{Hg}_2\text{Cl}_2}-2G_{\text{H}_2\text{O}}+(2G_{\text{Cl}^-}+2G_{\text{Hg}})=-20.44-2*0+(2*101.97+2*35.8)=255.1 \text{ kJ/mol};$$

$$G_{\text{Hg}}=(G_{\text{Hg}_2\text{Cl}_2}+G_{\text{H}_2\text{O}}-(2G_{\text{Cl}^-}+\Delta G_{\text{eq}_\text{Hg}_2\text{Cl}_2}))/2=(255.1+0-(2*101.97-20.44))/2=35.8 \text{ kJ/mol};$$

Solubility equilibrium $\text{Hg}_2\text{SO}_4(\text{s})+2\text{H}_2\text{O}=\text{Hg}_2^{2+}+\text{SO}_4^{2-}$; $2\text{Hg}+2\text{H}_2\text{O}=\text{Hg}_2^{2+}+2\text{e}^-$; absolute solubility constant:

$$K_{\text{AbsoluteHg}_2\text{SO}_4}=K_{\text{spHg}_2\text{SO}_4}/[\text{H}_2\text{O}]^2=[\text{Hg}_2^{2+}][\text{SO}_4^{2-}]/[\text{Hg}_2\text{SO}_4(\text{s})]/[\text{H}_2\text{O}]^2=6.5*10^{(-7)}/1/55.3^2=10^{-9.673};$$

$$\Delta G_{\text{eq}_\text{Hg}_2\text{SO}_4}=-R*T*\ln(K_{\text{AbsoluteHg}_2\text{SO}_4})=-8.314*298.15*\ln(10^{(-9.673)})=55.21 \text{ kJ/mol};$$

$$\Delta G_{\text{eq}_\text{Hg}_2\text{SO}_4}=G_{\text{Hg}_2^{2+}}+G_{\text{SO}_4^{2-}}-(G_{\text{Hg}_2\text{SO}_4}+2G_{\text{H}_2\text{O}})=209.09-747.75-(G_{\text{Hg}_2\text{SO}_4}+2*0)=55.21 \text{ kJ/mol};$$

$$G_{\text{Hg}_2\text{SO}_4}=G_{\text{Hg}_2^{2+}}+G_{\text{SO}_4^{2-}}-(\Delta G_{\text{eq}_\text{Hg}_2\text{SO}_4}+2G_{\text{H}_2\text{O}})=209.09-747.75-(55.21+2*0)=-593.87 \text{ kJ/mol};$$

$$\text{Hg}_2\text{SO}_4(\text{s})+2\text{H}_2\text{O}=\text{Hg}_2^{2+}+\text{SO}_4^{2-}; 2\text{Hg}+\text{H}_2\text{O}=\text{Hg}_2^{2+}+2\text{e}^-;$$

$\text{Hg}_2\text{SO}_4(\text{s})+2\text{H}_2\text{O}-\text{SO}_4^{2-}=\text{Hg}_2^{2+}$; $2\text{Hg}+\text{H}_2\text{O}=\text{Hg}_2^{2+}+2\text{e}^-$; $2\text{Hg}+\text{H}_2\text{O}=\text{Hg}_2\text{SO}_4(\text{s})+2\text{H}_2\text{O}-\text{SO}_4^{2-}+2\text{e}^-$;

$2\text{Hg}+\text{SO}_4^{2-}=\text{Hg}_2\text{SO}_4(\text{s})+\text{H}_2\text{O}+2\text{e}^-$; Expression of absolute potential has standard $E^\circ_{\text{Classic}}=0.614 \text{ V}$ [18],

water and ΔE° : $E^\circ_{\text{HgSO}_4}=E^\circ_{\text{Classic}}-0.0591/2*\lg([\text{H}_2\text{O}]^1)+\Delta E^\circ=0.614-0.0515+0.10166-0.37239=0.2918 \text{ V}$;

$$\Delta G_{\text{eq}_\text{HgSO}_4}=E^\circ_{\text{HgSO}_4}*F*2=0.291772*96485*2=56.30 \text{ kJ/mol},$$

$$\Delta G_{\text{eq}_\text{HgSO}_4}=G_{\text{Hg}_2\text{SO}_4}-(2G_{\text{Hg}}+G_{\text{SO}_4})=-593.87-(2*35.7+G_{\text{SO}_4})=56.30 \text{ kJ/mol};$$

$$G_{\text{SO}_4}=G_{\text{Hg}_2\text{SO}_4}-(2G_{\text{Hg}}+\Delta G_{\text{eq}_\text{HgSO}_4})=-593.87-(2*35.7+56.3)=-721.57 \text{ kJ/mol};$$

Formation $2\text{Hg} + \text{O}_2 \text{ aqua} = 2\text{HgO}$; $2\text{G}_{\text{HgO}} = 2\Delta\text{G}_{\text{HgO}} + (2*\text{G}_{\text{Hg}} + \text{G}_{\text{O}_2}) = 2*(-58.5 + (2*35.8 + 330)) = 2*142.3 \text{ kJ/mol}$;
 $\text{Hg} + 2\text{OH}^- = \text{HgO} + \text{H}_2\text{O} + 2\text{e}^-$, Expression of absolute potential has standard $E^\circ_{\text{Classic}} = 0.098 \text{ V}$ [17],
water and ΔE° : $E^\circ_{\text{HgO}} = E^\circ - 0.0591/2 * \lg([\text{H}_2\text{O}]^1) + \Delta E^\circ = 0.098 - 0.0515 + 0.10166 - 0.37239 = -0.22423 \text{ V}$;

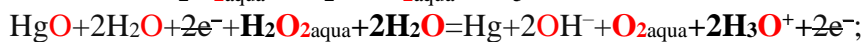
$$\Delta\text{G}_{\text{eqHgO}} = E^\circ_{\text{HgO}} * F * n = -0.22423 * 96485 * 2 = -43.27 \text{ kJ/mol};$$

$$\Delta\text{G}_{\text{eqHgO}} = \text{G}_{\text{HgO}} + \text{G}_{\text{H}_2\text{O}} - (\text{G}_{\text{Hg}} + 2\text{G}_{\text{OH}}) = \text{G}_{\text{HgO}} + 0 - (35.8 + 2*77.36) = 147.25 + 0 - (35.8 + 2*77.36) = -43.27 \text{ kJ/mol};$$

$$\text{G}_{\text{HgO}} = \Delta\text{G}_{\text{eqHgO}} - \text{G}_{\text{H}_2\text{O}} + (\text{G}_{\text{Hg}} + 2\text{G}_{\text{OH}}) = -43.27 - 0 + (35.8 + 2*77.36) = 147.25 \text{ kJ/mol};$$

Reduction $\text{HgO} + 2\text{H}_2\text{O} + 2\text{e}^- = \text{Hg} + 2\text{OH}^-$, inverse standard potential $-E^\circ_{\text{HgO}} = 0.22423 \text{ V}$.

Oxidation $\text{H}_2\text{O}_2 \text{ aqua} + 2\text{H}_2\text{O} = \text{O}_2 \text{ aqua} + 2\text{H}_3\text{O}^+ + 2\text{e}^-$ Nernst's absolute standard potential $E^\circ_{\text{RedH}_2\text{O}_2} = 0.5278 \text{ V}$;



Summary: $\text{HgO} + \text{H}_2\text{O}_2 \text{ aqua} = \text{Hg} + \text{O}_2 \text{ aqua}$ catalase; $\text{G}_{\text{H}_2\text{O}_2} = 279.285 \text{ kJ/mol}$;

$$\Delta\text{G}_{\text{eqRedOx}_\text{H}_2\text{O}_2} = (E^\circ_{\text{H}_2\text{O}_2 \text{ aqRed}} - E^\circ_{\text{HgO}}) * F * n = (0.5278 + 0.22423) * 96485 * 2 = (0.7520) * 96485 * 2 = 145.1 \text{ kJ/mol};$$

$$\Delta\text{G}_{\text{eqRedOx}_\text{H}_2\text{O}_2} = \text{G}_{\text{Hg}} + \text{G}_{\text{O}_2 \text{ aqua}} - (\text{G}_{\text{HgO}} + \text{G}_{\text{H}_2\text{O}_2}) = 35.885 + 330 - (-58.5 + 279.285) = 145.1 \text{ kJ/mol};$$

$$\text{HgO}; \text{G}_{\text{Hg}} = \text{G}_{\text{eqRedOx}_\text{H}_2\text{O}_2} - \text{G}_{\text{O}_2 \text{ aqua}} + (\text{G}_{\text{HgO}} + \text{G}_{\text{H}_2\text{O}_2}) = 145.1 - 330 + (-58.5 + 279.285) = 35.885 \text{ kJ/mol};$$

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Substance	$\Delta H^\circ_{\text{H}}$, kJ/mol	$\Delta S^\circ_{\text{H}}$, J/mol/K	$\Delta G^\circ_{\text{H}}$, kJ/mol	
Pb	$E^\circ_{\text{Pb} \text{Pb}_2^+} =$	-0,34523 V	62,024	$\text{G}_{\text{Pb}} = \text{G}_{\text{Pb}_2^+} - (\Delta\text{G}_{\text{eqPb} \text{Pb}_2^+} + \text{G}_{\text{H}_2\text{O}}) = -4,596 - (-66,62 + 0) = 62,024 \text{ kJ/mol};$
Pb	-	64,8	-	CRC [1]
Pb^{2+}	$E^\circ_{\text{PbO}_2 \text{Pb}_2^+} =$	1,49326 V	-4,596	$\text{G}_{\text{Pb}_2^+} = \text{G}_{\text{PbO}_2} + 4\text{G}_{\text{H}_3\text{O}^+} - (\Delta\text{G}_{\text{eqPbO}_2 \text{Pb}_2^+} + 6\text{G}_{\text{H}_2\text{O}}) = -4,596 \text{ kJ/mol};$
Pb^{2+}	0,92	18,5	-4,596	[1] $\Delta G^\circ_{\text{Pb}_2^+} = \Delta H^\circ_{\text{H}} - T * \Delta S^\circ_{\text{H}} = 0.92 - 298.15 * 0.0185 = -4.596 \text{ kJ/mol};$
$\text{PbO}_2 \downarrow$	-277,4	68,6	-217,3	CRC [1]
$\text{PbO}_2 \downarrow$	$E^\circ_{\text{PbO}_2 \text{Pb}_2^+} =$	1,49326 V	193,794	$\text{G}_{\text{PbO}_2} = \Delta\text{G}_{\text{eqPbO}_2 \text{Pb}_2^+} - 4\text{G}_{\text{H}_3\text{O}^+} + (\text{G}_{\text{Pb}_2^+} + 6\text{G}_{\text{H}_2\text{O}}) = 193,794 \text{ kJ/mol};$
$\text{PbO}_2 \downarrow$	formation	-	147,824	$\text{G}_{\text{PbO}_2} = \Delta\text{G}_{\text{PbO}_2} + (\text{G}_{\text{Pb}} + \text{G}_{\text{O}_2 \text{ gas}}) = 147,824 \text{ kJ/mol};$
Al	-	28.3	-	CRC [1]
Al	$E^\circ_{\text{Al} \text{Al}_3^+} =$	-1.8984 V	108	$\text{G}_{\text{Al}} = \text{G}_{\text{Al}_3^+} - (\Delta\text{G}_{\text{eqAl} \text{Al}_3^+} + \text{G}_{\text{H}_2\text{O}}) = -441.5 - (-549.5 + 0) = 108 \text{ kJ/mol};$
Al^{3+}	-538.4	-325	-441.5	$\Delta G^\circ_{\text{Pb}_2^+} = \Delta H^\circ_{\text{H}} - T * \Delta S^\circ_{\text{H}} = -538.4 - 298.15 * -0.325 = -441.5 \text{ kJ/mol};$
H_2AlO_3^-	$E^\circ_{\text{H}_2\text{AlO}_3 \text{Al}} =$	-2.63506	-345.29	$\text{G}_{\text{H}_2\text{AlO}_3} = \Delta\text{G}_{\text{eqH}_2\text{AlO}_3 \text{Al}} - \text{G}_{\text{H}_2\text{O}} + (\text{G}_{\text{Al}} + 4\text{G}_{\text{OH}}) = -345.29 \text{ kJ/mol};$
$\text{NaAlO}_2 \downarrow$	-1133.2	70.4	-	CRC [1]

$$\text{Formation Pb} + \text{O}_2 \text{ gas} = \text{PbO}_2(\text{s}); \text{G}_{\text{PbO}_2} = \Delta\text{G}_{\text{PbO}_2} + (\text{G}_{\text{Pb}} + \text{G}_{\text{O}_2 \text{ gas}}) = -217,3 + (62,024 + 303,1) = 147,824 \text{ kJ/mol};$$

$\text{Pb}^{2+} + 6\text{H}_2\text{O} = \text{PbO}_2(\text{s}) + 4\text{H}_3\text{O}^+ + 2\text{e}^-$; Expression of absolute potential has standard $E^\circ_{\text{Classic}} = 1.455 \text{ V}$ [18],

water and ΔE° : $E^\circ_{\text{PbO}_2} = E^\circ_{\text{Classic}} - 0.0591/2 * \lg(1/[\text{H}_2\text{O}]^6) + \Delta E^\circ = 1.455 + 0.309 + 0.10166 - 0.37239 = 1.49326 \text{ V}$;

$$\Delta\text{G}_{\text{eqPbO}_2|\text{Pb}_2^+} = E^\circ_{\text{PbO}_2|\text{Pb}_2^+} * F * 3 = 1.49326 * 96485 * 3 = 288.15 \text{ kJ/mol};$$

$$\Delta\text{G}_{\text{eqPbO}_2|\text{Pb}_2^+} = \text{G}_{\text{PbO}_2} + 4\text{G}_{\text{H}_3\text{O}^+} - (\text{G}_{\text{Pb}_2^+} + 6\text{G}_{\text{H}_2\text{O}}) = 193,794 + 4*22,44 - (-4,596 + 6*0) = 288,15 \text{ kJ/mol};$$

$$\text{G}_{\text{PbO}_2} = \Delta\text{G}_{\text{eqPbO}_2|\text{Pb}_2^+} - 4\text{G}_{\text{H}_3\text{O}^+} + (\text{G}_{\text{Pb}_2^+} + 6\text{G}_{\text{H}_2\text{O}}) = 288,15 - 4*22,44 + (-4,596 + 6*0) = 193,794 \text{ kJ/mol};$$

$$\text{G}_{\text{Pb}_2^+} = \text{G}_{\text{PbO}_2} + 4\text{G}_{\text{H}_3\text{O}^+} - (\Delta\text{G}_{\text{eqPbO}_2|\text{Pb}_2^+} + 6\text{G}_{\text{H}_2\text{O}}) = 193,794 + 4*22,44 - (288,15 + 6*0) = -4,596 \text{ kJ/mol};$$

$$E_{\text{PbO}_2|\text{Pb}_2^+} = E^\circ_{\text{PbO}_2|\text{Pb}_2^+} + \frac{0.0591}{2} * \lg \frac{[\text{PbO}_2][\text{H}_3\text{O}^+]^4}{[\text{Pb}^{2+}][\text{H}_2\text{O}]^6} = 1.49326 \text{ V} + \frac{0.0591}{2} * \lg \frac{[\text{PbO}_2][\text{H}_3\text{O}^+]^4}{[\text{Pb}^{2+}][\text{H}_2\text{O}]^6};$$

$\text{Pb} + \text{H}_2\text{O} = \text{Pb}^{2+} + 2\text{e}^-$; pH<7 Expression of absolute potential has standard $E^\circ_{\text{Classic}} = -0.126 \text{ V}$ [18], water logarithm and ΔE° : $E^\circ_{\text{Pb}|\text{Pb}_2^+} = E^\circ_{\text{Classic}} - 0.0591/2 * \lg(1/[\text{H}_2\text{O}]) + \Delta E^\circ = -1.26 + 0.0515 + 0.10166 - 0.37239 = -0.3452 \text{ V}$;

$$\Delta\text{G}_{\text{eqPb}|\text{Pb}_2^+} = E^\circ_{\text{Pb}|\text{Pb}_2^+} * F * n = -0.34523 * 96485 * 2 = -66.62 \text{ kJ/mol};$$

$$\Delta\text{G}_{\text{eqPb}|\text{Pb}_2^+} = \text{G}_{\text{Pb}_2^+} - (\text{G}_{\text{Pb}} + \text{G}_{\text{H}_2\text{O}}) = -4,596 - (62,024 + 0) = -71,59 = -66,62 \text{ kJ/mol};$$

$$\text{G}_{\text{Pb}} = \text{G}_{\text{Pb}_2^+} - (\Delta\text{G}_{\text{eqPb}|\text{Pb}_2^+} + \text{G}_{\text{H}_2\text{O}}) = -4,596 - (-66,62 + 0) = 62,024 \text{ kJ/mol};$$

$\text{Al} + \text{H}_2\text{O} = \text{Al}^{3+} + 3\text{e}^-$; Expression of absolute potential has standard $E^\circ_{\text{Classic}} = -1.662 \text{ V}$ [1], water

logarithm and ΔE° : $E^\circ_{\text{Al}|\text{Al}_3^+} = E^\circ_{\text{Classic}} - 0.0591/2 * \lg(1/[\text{H}_2\text{O}]) + \Delta E^\circ = -1.662 + 0.0343 + 0.10166 - 0.37239 = -1.8984 \text{ V}$;

$$\Delta\text{G}_{\text{eqAl}|\text{Al}_3^+} = E^\circ_{\text{Al}|\text{Al}_3^+} * F * 3 = -1.8984 * 96485 * 3 = -549.5 \text{ kJ/mol};$$

$$\Delta\text{G}_{\text{eqAl}|\text{Al}_3^+} = \text{G}_{\text{Al}_3^+} - (\text{G}_{\text{Al}} + \text{G}_{\text{H}_2\text{O}}) = -441.5 - (108 + 0) = -549.5 \text{ kJ/mol};$$

$$\text{G}_{\text{Al}} = \text{G}_{\text{Al}_3^+} - (\Delta\text{G}_{\text{eqAl}|\text{Al}_3^+} + \text{G}_{\text{H}_2\text{O}}) = -441.5 - (-549.5 + 0) = 108 \text{ kJ/mol};$$

$\text{Al} + 4\text{OH}^- = \text{H}_2\text{AlO}_3^- + \text{H}_2\text{O} + 3\text{e}^-$; Expression of absolute potential has standard $E^\circ_{\text{Classic}} = -1.662 \text{ V}$ [1], water logarithm and ΔE° : $E^\circ_{\text{H}_2\text{AlO}_3|\text{Al}} = E^\circ_{\text{Classic}} - 0.0591/2 * \lg([\text{H}_2\text{O}]) + \Delta E^\circ = -2.33 - 0.0343 + 0.10166 - 0.37239 = -2.63506 \text{ V}$;

$$\Delta\text{G}_{\text{eqH}_2\text{AlO}_3|\text{Al}} = E^\circ_{\text{H}_2\text{AlO}_3|\text{Al}} * F * 3 = -2.63506 * 96485 * 3 = -762.73 \text{ kJ/mol};$$

$$\Delta\text{G}_{\text{eqH}_2\text{AlO}_3|\text{Al}} = \text{G}_{\text{H}_2\text{AlO}_3} + \text{G}_{\text{H}_2\text{O}} - (\text{G}_{\text{Al}} + 4\text{G}_{\text{OH}}) = -345.29 + 0 - (108 + 4*77.36) = -762.73 \text{ kJ/mol};$$

$$\text{G}_{\text{H}_2\text{AlO}_3} = \Delta\text{G}_{\text{eqH}_2\text{AlO}_3|\text{Al}} - \text{G}_{\text{H}_2\text{O}} + (\text{G}_{\text{Al}} + 4\text{G}_{\text{OH}}) = -762.73 - 0 + (108 + 4*77.36) = -345.29 \text{ kJ/mol};$$

$$E_{\text{AlO}_2^-|\text{Al}} = E^\circ_{\text{AlO}_2^-|\text{Al}} + \frac{0.0591}{3} * \lg \frac{[\text{H}_2\text{AlO}_3^-][\text{H}_2\text{O}]}{[\text{Al}][\text{OH}^-]^4} = -2.63506 \text{ V} + \frac{0.0591}{3} * \lg \frac{[\text{H}_2\text{AlO}_3^-][\text{H}_2\text{O}]}{[\text{Al}][\text{OH}^-]^4};$$

Solubility $N_{2(g)}+H_2O+\Delta G=N_{2(aq)}$ increases molar nitrogen energy from $G_{N_{2(g)}}=-9.55$ kJ/mol to $G_{N_{2(aq)}}=18.7$ kJ/mol.

Published content of Alberty dissolve nitrogen **absolute** free energy in one mol is $G_{N_{2(aq)}}=18.7$ kJ/mol, if pure gas mol fraction is one $[N_{2(g)}]=1$. [8] Hundred grams of water dissolve nitrogen gas 0.00175 g/100g H_2O , which has density 996 g/L. [1] Solubility $[N_{2(aq)}]=0.00175/100.00175*996=0.01743/28.02=0.01743=10^{-3.206}$ M and the solubility constant in mol fractions is less than one $K_{sp}=10^{(-3.206)}/[H_2O]=10^{(-3.206)}/55.3=10^{-4.949}$. Free energy change minimum in Prigogine expression for endoergic reaction is

$$\Delta G_{sp}=-R\cdot T\cdot\ln(K_{sp})=-8.3144*298.15*\ln(10^{(-4.949)})=28.25 \text{ kJ/mol.}$$

Hess law energy change coincides $\Delta G_{spHessN_{2(aq)}}=G_{N_{2(aq)}}-(G_{N_{2(g)}}+G_{H_2O})=18.7-(-9.55+0)=28.25$ kJ/mol within absolute free energy scale. One mol $G_{N_{2(g)}}=G_{N_{2(aq)}}-(\Delta G_{spHessN_{2(aq)}}+G_{H_2O})=18.7-(28.25+0)=-9.55$ kJ/mol contains the free energy below the zero reference for water on absolute free energy scale. One mol nitrogen absolute free energy content is positive $G_{N_{2(aq)}}=18.7$ kJ/mol. [8]

Formation from aqua elements $N_{2(aq)}+3H_{2(aq)}>2NH_{3(aq)}$ with absolute energy $G_{N_{2(aq)}}=18.7$ kJ/mol; $G_{H_{2(aq)}}=103.24$ kJ/mol is exoergic reaction $2\Delta G_{Hess_NH_{3(aq)}}=2G_{NH_{3(aq)}}-(G_{N_{2(aq)}}+3*G_{H_{2(aq)}})=2*91.1056-(18.7+3*103.24)=2*-73.1$ kJ/mol. [8]

Formation $N_{2(g)}+3H_{2(g)}>2NH_{3(g)}$ from elements energies $G_{N_{2(g)}}=-9.55$ kJ/mol; $G_{H_{2(g)}}=85.64$ kJ/mol shows negative exoergic $2\Delta G_{Hess_NH_{3(g)}}=2G_{NH_{3(g)}}-(G_{N_{2(g)}}+3*G_{H_{2(g)}})=2G_{NH_{3(g)}}-(-9.55+3*85.64)=2*-16.4=-32.8$ kJ/mol [1].

Two mols $NH_{3(g)}$ has energy content positive at formation from elements $G_{N_{2(g)}}=-9.55$ kJ/mol $G_{H_{2(g)}}=85.64$ kJ/mol $2G_{NH_{3(g)}}=2\Delta G_{Hess_NH_{3(g)}}+(G_{N_{2(g)}}+3*G_{H_{2(g)}})=2*-16.4+(-9.55+3*85.64)=-214.57=2*107.285$ kJ/mol. [1,8]

When dissolving $NH_{3(g)}+H_2O=NH_{3(aq)}$; the energy decreases to $G_{NH_{3(aq)}}=91.1$ kJ/mol [8] from $G_{NH_{3(g)}}=107.285$ kJ/mol.

Dissolution is exothermic $\Delta H_{Hydration}=\Delta H^\circ_{NH_{3(aq)}}-\Delta H^\circ_{NH_{3(g)}}-\Delta H^\circ_{H_2O}=-132.5608+45.94-286.65=373.3$ kJ/mol;

Entropy decreases $S_{Hydration}=\Delta S^\circ_{NH_{3(aq)}}-\Delta S^\circ_{NH_{3(g)}}-\Delta S^\circ_{H_2O}=-739.2922-192.77-69.9565=-1002$ J/mol.K.

Exoergic dissolution $\Delta G_{Hydration}=\Delta H_{Hydration}-T*\Delta S_{Hydration}=-373.3-298.15*-1.002=-74.5537$ kJ/mol is favorable because the constant is greater than one $K_{sp}=\exp(-\Delta G_{Hydration}/R/T)=\exp(74553.7/8.3144/298.15)=10^{13.06}$;

Alberty solutions for ammonia at pH=7.36 $G_{NH_{3(aq)}}=91.1056$ kJ/mol and Hess hydration with change in energy $\Delta G_{Hydrations}=-74.5537$ kJ/mol calculate the absolute energy content of the gas $NH_{3(g)}$ coincidentally at hydration [8]

$$G_{NH_{3(g)}}=G_{NH_{3(aq)}}-(\Delta G_{Hydration}+G_{H_2O})=91.1056-(-74.5537+0)=165.7 \text{ kJ/mol and from free elements [1]}$$

$$G_{NH_{3(g)}}=(2\Delta G_{Hess_NH_{3(g)}}+(G_{N_{2(g)}}+3*G_{H_{2(g)}}))/2=(-32.8+(107.2+3*85.64))/2=165.7 \text{ kJ/mol CRC, Alberty.}$$

Substance	ΔH°_H kJ/mol	ΔS°_H J/mol/K	ΔG°_H kJ/mol
$N_{2(g)}$	$G_{N_{2(g)}}=-$	form NH_3	107.285
$N_{2(aq)}$	-10.54	98.1	18.7
$N_{2(g)}$	$N_{2(g)}+H_2O=N_{2(aq)}$ pH=7,36		-9.55
$NH_{3(g)}$	$\Delta G_{Hydration}$	-74.5537	165.7
$NH_{3(g)}$	[1,8]	formation	107.285
$NH_{3(g)}$	-45.9	192.77	-16.4
$NH_{3(aq)}$	-132.5608	-739.2922	91.1056
$NH_{3(aq)}$	$pK_{beq}=6.49475$		91.1
NH_4^+	$pK_{aeq}=10.99$		50.81

$$G_{N_{2(g)}}=2G_{NH_{3(g)}}-(2\Delta G_{Hess_NH_{3(g)}}+3*G_{H_{2(g)}})=107.2 \text{ kJ/mol;}$$

$$G_{N_{2(g)}}=2*165.6593-(2*-16.4+3*85.64)=107.2 \text{ kJ/mol;}$$

Solution $N_{2(aq)}$ at pH=7.36 [8].

$$G_{N_{2(g)}}=G_{N_{2(aq)}}-(\Delta G_{Hess_N_{2(aq)}}+G_{H_2O})=18.7-(28.25+0)=-9.55 \text{ kJ/mol;}$$

$$G_{NH_{3(g)}}=G_{NH_{3(aq)}}-(\Delta G_{Hydrations}+G_{H_2O})=91.1056-(-74.5537+0)=165.7 \text{ kJ/mol;}$$

$$2G_{NH_{3(g)}}=2\Delta G_{Hess_NH_{3(g)}}+(G_{N_{2(g)}}+3*G_{H_{2(g)}})=2*107.285 \text{ kJ/mol;}$$

$$2G_{NH_{3(g)}}=2*-16.4+(-9.55+3*85.64)=-214.57=2*107.285 \text{ kJ/mol;}$$

Ammonia pH=7.36 [8] Alberty; $NH_{3(aq)}$ formation

$$G_{NH_{3(aq)}}=G_{NH_4^+}+G_{OH^-}-(\Delta G_{beq}+G_{H_2O})=91.1 \text{ kJ/mol; Wikipedia [28]}$$

$$G_{NH_4^+}=G_{NH_{3(aq)}}+G_{H_3O^+}-(\Delta G_{aeq}+G_{H_2O})=91.1+22.44-62.73-0=50.81 \text{ kJ/mol;}$$

The expression for the classical ammonia protolytic base $NH_{3(aq)}+H_2O=NH_4^++OH^-$ constant without accounting for water is $K_b=[NH_4^+]*[OH^-]/[NH_{3(aq)}]=10^{(-4.752)}$ with the exponent value $pK_b=4.752$. [1] The classical base constant is derived from the protolysis equilibrium constant with accounting for water in the reactants as $K_{beq}=K_b/[H_2O]=10^{(-4.752)}/55.3=3.20*10^{(-7)}=10^{(-6.4947)}$. The calculated value of the exponent of the equilibrium constant of ammonia protolysis is $pK_{beq}=6.4947$ endoergic, since the change in absolute free energy in the Prigogine expression and the Hess expression have positive and identical free energy change:

$$\Delta G_{beq}=-R\cdot T\cdot\ln(K_{beq})=-8.3144*298.15*\ln(10^{(-6.4947)})=G_{NH_4^+}+G_{OH^-}-(G_{NH_{3(aq)}}+G_{H_2O})=37.064 \text{ kJ/mol ;}$$

$$\Delta G_{Hess_beq}=G_{NH_4^+}+G_{OH^-}-(G_{NH_{3(aq)}}+G_{H_2O})=50.81+77.36-(91.1056+0)=37.064 \text{ kJ/mol .}$$

The free energy content of a solution of one mole of ammonia in water is $G_{NH_{3(aq)}}=91.1$ kJ/mol

$$G_{NH_{3(aq)}}=G_{NH_4^+}+G_{OH^-}-(\Delta G_{Hess_beq}+G_{H_2O})=50.81+77.36-(37.07+0)=91.1 \text{ kJ/mol .}$$

Endoergic ammonia protolysis accumulates energy in the products $G_{NH_4^+}+G_{OH^-}=50.81+77.36=128.17$ kJ/mol.

The protolysis of the weak acid $G_{NH_4^+}=50.81$ kJ/mol $NH_4^++H_2O=NH_{3(aq)}+H_3O^+$ $pK_{eq}=10.99$ shows an endoergic energy change $\Delta G_{aeq}=-R\cdot T\cdot\ln(K_{aeq})=-8.3144*298.15*\ln(10^{(-10.99)})=G_{NH_{3(aq)}}+G_{H_3O^+}-G_{NH_4^+}-G_{H_2O}=62.73$ kJ/mol. The free energy content of ammonium per mole is

$$G_{NH_4^+}=G_{NH_{3(aq)}}+G_{H_3O^+}-(\Delta G_{aeq}+G_{H_2O})=91.1+22.44-(62.73+0)=50.81 \text{ kJ/mol .}$$

The classic acid $NH_4^+=H^++NH_{3(aq)}$ constant of protolysis $pK_a=9.25$ does not include water accounting.

Formation from elements HNO_2 $\Delta G^\circ_{\text{HNO}_2} = -46 \text{ kJ/mol}$ and HNO_3 $\Delta G^\circ_{\text{HNO}_3} = -250.53 \text{ kJ/mol}$:

$$\text{Formation } G_{\text{HNO}_3} = \Delta G^\circ_{\text{HNO}_3} + (0.5G_{\text{N}_2\text{gas}} + 1.5G_{\text{O}_2\text{gas}} + 0.5G_{\text{H}_2\text{gas}}) = -250.53 + (0.5 \cdot -9.55 + 1.5 \cdot 303) = 199.195 \text{ kJ/mol}$$

$$G_{\text{HNO}_2} = \Delta G^\circ_{\text{HNO}_2} + 0.5G_{\text{N}_2\text{gas}} + G_{\text{O}_2\text{gas}} + 0.5G_{\text{H}_2\text{gas}} = -46 + (0.5 \cdot -9.55 + 303 + 0.5 \cdot 85.6) = 295.025 \text{ kJ/mol};$$

$$G_{\text{N}_2\text{gas}} = -9.55 \text{ kJ/mol}; G_{\text{H}_2\text{gas}} = 85.6 \text{ kJ/mol} [8]; G_{\text{O}_2\text{gas}} = 303 \text{ kJ/mol};$$

$$G_{\text{NO}_2\text{-Form}} = \Delta G^\circ_{\text{NO}_2} + 0.5G_{\text{N}_2\text{gas}} + G_{\text{O}_2\text{gas}} = -33.01 + 0.5 \cdot -9.55 + 1 \cdot 303 = 265.2 \text{ kJ/mol};$$

$$G_{\text{NO}_2\text{-Form}} = \Delta G^\circ_{\text{NO}_2} + 0.5G_{\text{N}_2\text{aq}} + G_{\text{O}_2\text{aq}} = -33.01 + 0.5 \cdot 18.7 + 1 \cdot 330 + 0 = 306.34 \text{ kJ/mol};$$

Acid and protolysis equilibrium constant $K_{\text{eq}} = K_a / [\text{H}_2\text{O}]$ calculate dividing the acid constant by water $[\text{H}_2\text{O}]$.

$$1. \text{HNO}_2 + \text{H}_2\text{O} = \text{NO}_2^- + \text{H}_3\text{O}^+; pK_a = 3.15; K_{\text{eq}} = K_a / [\text{H}_2\text{O}] = 10^{-(3.15)} / 55.3 = 0.00001280;$$

$$\Delta G_{\text{eqHNO}_2} = -R \cdot T \cdot \ln(K_{\text{eq}}) = -8.3144 \cdot 298.15 \cdot \ln(0.0000128) = G_{\text{NO}_2^-} + G_{\text{H}_3\text{O}^+} - (G_{\text{HNO}_2} + G_{\text{H}_2\text{O}}) = 27.927 \text{ kJ/mol};$$

$$\Delta G_{\text{eqHNO}_2} = G_{\text{NO}_2^-} + G_{\text{H}_3\text{O}^+} - (G_{\text{HNO}_2} + G_{\text{H}_2\text{O}}) = 82.618 + 22.44 - (77.131 + 0) = 27.927 \text{ kJ/mol};$$

$$G_{\text{NO}_2^-} = \Delta G_{\text{eqHNO}_2} - G_{\text{H}_3\text{O}^+} + (G_{\text{HNO}_2} + G_{\text{H}_2\text{O}}) = 27.927 - 22.44 + (77.131 + 0) = 82.618 \text{ kJ/mol};$$

$$G_{\text{HNO}_2} = G_{\text{NO}_2^-} + G_{\text{H}_3\text{O}^+} - (\Delta G_{\text{eqHNO}_2} + G_{\text{H}_2\text{O}}) = 82.618 + 22.44 - (27.927 + 0) = 77.131 \text{ kJ/mol};$$

$$2. \text{HNO}_3 + \text{H}_2\text{O} = \text{NO}_3^- + \text{H}_3\text{O}^+; pK_a = -1.4; K_{\text{eq}} = K_a / [\text{H}_2\text{O}] = 10^{(1.4)} / 55.3 = 0.4542;$$

$$\Delta G_{\text{eqHNO}_3} = -R \cdot T \cdot \ln(K_{\text{eq}}) = -8.3144 \cdot 298.15 \cdot \ln(0.4542) = G_{\text{NO}_3^-} + G_{\text{H}_3\text{O}^+} - (G_{\text{HNO}_3} + G_{\text{H}_2\text{O}}) = 1.956 \text{ kJ/mol};$$

$$\Delta G_{\text{eqHNO}_3} = G_{\text{NO}_3^-} + G_{\text{H}_3\text{O}^+} - (G_{\text{HNO}_3} + G_{\text{H}_2\text{O}}) = 340.2 + 22.44 - (360.684 + 0) = 1.956 \text{ kJ/mol};$$

$$G_{\text{HNO}_3} = G_{\text{NO}_3^-} + G_{\text{H}_3\text{O}^+} - (\Delta G_{\text{eqHNO}_3} + G_{\text{H}_2\text{O}}) = 340.2 + 22.44 - (1.956 + 0) = 360.7 \text{ kJ/mol};$$

$$G_{\text{NO}_3^-} = \Delta G_{\text{eqHNO}_3} - G_{\text{H}_3\text{O}^+} + (G_{\text{HNO}_3} + G_{\text{H}_2\text{O}}) = 1.956 - 22.44 + (199.195 + 0) = 340.2 \text{ kJ/mol};$$

Substance	$\Delta H^\circ_{\text{H}}$ kJ/mol	$\Delta S^\circ_{\text{H}}$ J/mol/K	$\Delta G^\circ_{\text{H}}$ kJ/mol
HNO_2	$E^\circ_{\text{NO}_3^-/\text{H}_3\text{O}^+} = 0.8753 \text{ V}$		77.131
HNO_2	-	$pK_a = 3.15$	238.42
HNO_2	-79.5	254.1	-46.0
HNO_2	-	formation	295.025
$\text{pH}=7.36 \text{NO}_2^-$	-104.19	-238.7	-33.01
NO_2^-	$0.5G_{\text{N}_2\text{gas}} + G_{\text{O}_2\text{gas}}$		265.2
NO_2^-	$0.5G_{\text{N}_2\text{aq}} + G_{\text{O}_2\text{aq}}$		306.34
NO_2^-	$E^\circ_{\text{NO}_3^-/\text{OH}^-} = -0.3122 \text{ V}$		84.236
NO_2^-	$E^\circ_{\text{NO}_2^-} = 0.7188 \text{ V}$		84.446
NO_2^-		$pK_a = 3.15$	82.618
HNO_3	-207	146	-250.53
HNO_3	-	formation	199.195
HNO_3	-	$pK_a = -1.4$	199.195
$\text{pH}=7.36 \text{NO}_3^-$	-204.59	-318.8	-109.55
NO_3^-	$E^\circ_{\text{NO}_3^-/\text{H}_3\text{O}^+} = 0.8753 \text{ V}$		178.711
NO_3^-	$E^\circ_{\text{NO}_2^-} = 0.7188 \text{ V}$		155.83
NO_3^-	$E^\circ_{\text{NH}_4^+/\text{H}_2\text{O}} = 0.7677 \text{ V}$		601.06
NO_3^-	-206.85	146.7	-250.5886
NO_3^-	-	$pK_a = -1.4$	340.2
NO_3^-	$E^\circ_{\text{NO}_3^-/\text{OH}^-} = -0.3122 \text{ V}$		178.711
NO_{gas}	91.3	210.8	87.6
NO_{gas}	Solubility product -		61.024
NO_{aq}	-	$\text{pH}=7.36$	86.55
NO_{aq}	$E^\circ_{\text{NO(g)}/\text{H}_3\text{O}^+} = -0.8266$		49.695

$$G_{\text{HNO}_2} = G_{\text{NO}_3^-} + 3G_{\text{H}_3\text{O}^+} - (\Delta G_{\text{eqNO}_3} + 4G_{\text{H}_2\text{O}}) = 77.131 \text{ kJ/mol};$$

$$G_{\text{HNO}_2} = G_{\text{NO}_2^-} - G_{\text{H}_3\text{O}^+} + (\Delta G_{\text{eqHNO}_2} + G_{\text{H}_2\text{O}}) = 238.42 \text{ kJ/mol};$$

CRC [1]

$$G_{\text{HNO}_2\text{gas}} = \Delta G^\circ_{\text{HNO}_2\text{gas}} + 0.5G_{\text{N}_2\text{gas}} + G_{\text{O}_2\text{gas}} + 0.5G_{\text{H}_2\text{gas}} = 295.025 \text{ kJ/mol}$$

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$$G_{\text{NO}_2\text{-form}} = \Delta G^\circ_{\text{NO}_2\text{aq}} + 0.5G_{\text{N}_2\text{gas}} + G_{\text{O}_2\text{gas}} = 265.2 \text{ kJ/mol};$$

$$G_{\text{NO}_2\text{-Form}} = \Delta G^\circ_{\text{NO}_2} + 0.5G_{\text{N}_2\text{aq}} + G_{\text{O}_2\text{aq}} = 306.34 \text{ kJ/mol};$$

$$G_{\text{NO}_2^-} = G_{\text{NO}_3^-} + G_{\text{H}_2\text{O}} - (\Delta G_{\text{eqNO}_3\text{-OH}} + 2G_{\text{OH}^-}) = 84.236 \text{ kJ/mol};$$

$$G_{\text{NO}_2^-} = G_{\text{NO}_3^-} + 3G_{\text{H}_3\text{O}^+} - (\Delta G_{\text{eqNO}_2^-} + 3G_{\text{H}_2\text{O}}) = 84.446 \text{ kJ/mol};$$

$$G_{\text{NO}_2^-} = \Delta G_{\text{eqHNO}_2} - G_{\text{H}_3\text{O}^+} + (G_{\text{HNO}_2} + G_{\text{H}_2\text{O}}) = 82.618 \text{ kJ/mol};$$

$$[1] G^\circ_{\text{NO}_3^-} = \Delta H_{\text{H}} - T \cdot \Delta S_{\text{H}} = -207 - 298.15 \cdot 0.146 = -250.5886 \text{ kJ/mol}; [1]$$

$$G_{\text{HNO}_3\text{Form}} = \Delta G^\circ_{\text{HNO}_3} + (0.5G_{\text{N}_2\text{gas}} + 1.5G_{\text{O}_2\text{gas}} + 0.5G_{\text{H}_2\text{gas}}) = 199.195 \text{ kJ/mol};$$

$$G_{\text{HNO}_3} = G_{\text{NO}_3^-} + G_{\text{H}_3\text{O}^+} - (\Delta G_{\text{eqHNO}_3} + G_{\text{H}_2\text{O}}) = 199.195 \text{ kJ/mol};$$

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$$G_{\text{NO}_3^-} = \Delta G_{\text{eqNO}_3} - 3G_{\text{H}_3\text{O}^+} + (G_{\text{HNO}_2} + 4G_{\text{H}_2\text{O}}) = 178.711 \text{ kJ/mol};$$

$$G_{\text{NO}_3^-} = \Delta G_{\text{eqNO}_2^-} - 3G_{\text{H}_3\text{O}^+} + (G_{\text{NO}_2^-} + 3G_{\text{H}_2\text{O}}) = 155.833 \text{ kJ/mol};$$

$$G_{\text{NO}_3^-} = \Delta G_{\text{eqNH}_4^+/\text{H}_2\text{O}} - 10G_{\text{H}_3\text{O}^+} + (G_{\text{NH}_4^+} + 13G_{\text{H}_2\text{O}}) = 601.06 \text{ kJ/mol};$$

$$\Delta G^\circ_{\text{NO}_3^-} = \Delta H_{\text{H}} - T \cdot \Delta S_{\text{H}} = -206.85 - 298.15 \cdot 0.1467 = -250.5886 \text{ kJ/mol}; [1]$$

$$G_{\text{NO}_3^-} = \Delta G_{\text{eqHNO}_3} - G_{\text{H}_3\text{O}^+} + (G_{\text{HNO}_3} + G_{\text{H}_2\text{O}}) = 340.2 \text{ kJ/mol};$$

$$G_{\text{NO}_3^-} = \Delta G_{\text{eqNO}_3\text{-OH}} - G_{\text{H}_2\text{O}} + (G_{\text{NO}_2^-} + 2G_{\text{OH}^-}) = 178.711 \text{ kJ/mol};$$

CRC [1]

$$G_{\text{NO}_{\text{gas}}} = G_{\text{NO}_{\text{aq}}} - (G_{\text{H}_2\text{O}} + \Delta G_{\text{sp}}) = 86.55 - (0 + 25.526) = 61.024 \text{ kJ/mol};$$

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$$G_{\text{NO}_{\text{aq}}} = G_{\text{HNO}_3} + 4G_{\text{H}_3\text{O}^+} - (\Delta G_{\text{eqNO(g)}/\text{H}_3\text{O}^+} + 5G_{\text{H}_2\text{O}}) = 49.695 \text{ kJ/mol};$$

Nernst's potential $\text{NO}_3^-/\text{NO}_2^-$ red-ox system behaving in acidic H_3O^+ water and basic OH^- medium

$\text{HNO}_2 + 4\text{H}_2\text{O} = \text{NO}_3^- + 3\text{H}_3\text{O}^+ + 2e^-$; $\text{pH} < 3.15$; Expression of potential has standard $E^\circ_{\text{Classic}} = 0.94 \text{ V}$ [18], water logarithm and ΔE° : $E^\circ_{\text{NO}_3^-/\text{H}_3\text{O}^+} = E^\circ_{\text{Classic}} - 0.0591/2 \cdot \lg(1/[\text{H}_2\text{O}]^4) + \Delta E^\circ = 0.94 + 0.206 + 0.10166 - 0.37239 = 0.8753 \text{ V}$;

$$E_{\text{NO}_3^-/\text{H}_3\text{O}^+} = E^\circ_{\text{NO}_3^-/\text{H}_3\text{O}^+} + \frac{0.0591}{2} \cdot \log \frac{[\text{NO}_3^-] \cdot [\text{H}_3\text{O}^+]^3}{[\text{HNO}_2] \cdot [\text{H}_2\text{O}]^4} = 0.8753 \text{ V} + \frac{0.0591}{2} \cdot \log \frac{[\text{NO}_3^-] \cdot [\text{H}_3\text{O}^+]^3}{[\text{HNO}_2] \cdot [\text{H}_2\text{O}]^4}$$

$$\Delta G_{\text{eqNO}_3} = E^\circ_{\text{NO}_3} \cdot F \cdot 2 = 0.8753 \cdot 96485 \cdot 2 = 168.9 \text{ kJ/mol};$$

$$\Delta G_{\text{eqNO}_3} = G_{\text{NO}_3^-} + 3G_{\text{H}_3\text{O}^+} - (G_{\text{HNO}_2} + 4G_{\text{H}_2\text{O}}) = 178.711 + 3 \cdot 22.44 - (77.131 + 4 \cdot 0) = 168.9 \text{ kJ/mol};$$

$$G_{\text{HNO}_2} = G_{\text{NO}_3^-} + 3G_{\text{H}_3\text{O}^+} - (\Delta G_{\text{eqNO}_3} + 4G_{\text{H}_2\text{O}}) = 178.711 + 3 \cdot 22.44 - (168.9 + 4 \cdot 0) = 77.131 \text{ kJ/mol};$$

$$G_{\text{NO}_3^-} = \Delta G_{\text{eqNO}_3} - 3G_{\text{H}_3\text{O}^+} + (G_{\text{HNO}_2} + 4G_{\text{H}_2\text{O}}) = 168.9 - 3 \cdot 22.44 + (77.131 + 4 \cdot 0) = 178.711 \text{ kJ/mol}.$$

$\text{NO}_2^- + 2\text{OH}^- = \text{NO}_3^- + \text{H}_2\text{O} + 2\text{e}^-$; $\text{pH} > 7$; Expression of potential has standard $E^\circ_{\text{Classic}} = 0.01 \text{ V}$ [17], H_2O water logarithm and ΔE° : $E^\circ_{\text{NO}_3-\text{OH}} = E^\circ_{\text{Classic}} - 0.0591/2 \cdot \lg([\text{H}_2\text{O}]) + \Delta E^\circ = 0.01 - 0.0515 + 0.10166 - 0.37239 = -0.3122 \text{ V}$;

$$E_{\text{NO}_3-\text{OH}} = E^\circ_{\text{NO}_3-\text{OH}} + \frac{0.0591}{2} \cdot \log \frac{[\text{NO}_3^-] \cdot [\text{H}_2\text{O}]}{[\text{NO}_2^-] \cdot [\text{OH}^-]^2} = -0.3122 \text{ V} + \frac{0.0591}{2} \cdot \log \frac{[\text{NO}_3^-] \cdot [\text{H}_2\text{O}]}{[\text{NO}_2^-] \cdot [\text{OH}^-]^2}$$

$$\Delta G_{\text{eqNO}_3-\text{OH}} = E^\circ_{\text{NO}_3-\text{OH}} \cdot F \cdot 2 = -0.3122 \cdot 96485 \cdot 2 = -60.245 \text{ kJ/mol};$$

$$\Delta G_{\text{eqNO}_3-\text{OH}} = G_{\text{NO}_3^-} + G_{\text{H}_2\text{O}} - (G_{\text{NO}_2^-} + 2G_{\text{OH}^-}) = 178.711 + 0 - (84.446 + 2 \cdot 77.36) = -60.245 \text{ kJ/mol},$$

$$G_{\text{NO}_3^-} = \Delta G_{\text{eqNO}_3-\text{OH}} - G_{\text{H}_2\text{O}} + (G_{\text{NO}_2^-} + 2G_{\text{OH}^-}) = -60.2455 - 0 + (84.446 + 2 \cdot 77.36) = 178.711 \text{ kJ/mol},$$

$$G_{\text{NO}_2^-} = G_{\text{NO}_3^-} + G_{\text{H}_2\text{O}} - (\Delta G_{\text{eqNO}_3-\text{OH}} + 2G_{\text{OH}^-}) = 178.711 + 0 - (-60.245 + 2 \cdot 77.36) = 84.446 \text{ kJ/mol};$$

$\text{NO}_2^- + 3\text{H}_2\text{O} = \text{NO}_3^- + 2\text{H}_3\text{O}^+ + 2\text{e}^-$; $\text{pH} > 3.51$ Expression of absolute potential has standard $E^\circ_{\text{Classic}} = 0.835 \text{ V}$ [21], water logarithm and ΔE° : $E^\circ_{\text{NO}_2} = E^\circ - 0.0591/2 \cdot \lg(1/[\text{H}_2\text{O}]^3) + \Delta E^\circ = 0.835 + 0.1545 + 0.10166 - 0.371339 = 0.7188 \text{ V}$

$$\Delta G_{\text{eqNO}_2} = E^\circ_{\text{NO}_2} \cdot F \cdot 2 = 0.7188 \cdot 96485 \cdot 2 = 138.707 \text{ kJ/mol},$$

$$\Delta G_{\text{eqNO}_2} = G_{\text{NO}_3^-} + 3G_{\text{H}_3\text{O}^+} - (G_{\text{NO}_2^-} + 3G_{\text{H}_2\text{O}}) = 155.833 + 3 \cdot 22.44 - (84.446 + 3 \cdot 0) = 138.707 \text{ kJ/mol},$$

$$G_{\text{NO}_3^-} = \Delta G_{\text{eqNO}_2} - 3G_{\text{H}_3\text{O}^+} + (G_{\text{NO}_2^-} + 3G_{\text{H}_2\text{O}}) = 138.707 - 3 \cdot 22.44 + (84.446 + 3 \cdot 0) = 155.833 \text{ kJ/mol},$$

$$G_{\text{NO}_2^-} = G_{\text{NO}_3^-} + 3G_{\text{H}_3\text{O}^+} - (\Delta G_{\text{eqNO}_2} + 3G_{\text{H}_2\text{O}}) = 155.833 + 3 \cdot 22.44 - (138.707 + 3 \cdot 0) = 84.446 \text{ kJ/mol},$$

Molarity $M_{\text{NO}} = 30.006 \text{ g/mol}$; solubility $\text{NO}^{(\text{g})} 0.00562 \text{ g/99.6g } 20 \text{ C}$; $w\% = 0.00562 / (0.00562 + 99.6) \cdot 100 = 0.00562\%$;

product $[\text{NO}_{\text{aq}}] = (0.00562 / 100 \cdot 996) / 30.006 = 0.001865 \text{ M}$, if pure gas mol fraction is one $[\text{NO}^{(\text{g})}] = 1$;

Equilibrium $\text{NO}_{\text{gas}} + \text{H}_2\text{O} = \text{NO}_{\text{aq}}$ constant is $K_{\text{eq}} = [\text{NO}_{\text{aq}}] / [\text{NO}^{(\text{g})}] / [\text{H}_2\text{O}] = 0.001865 / 1 / 55.3 = 10^{(-4.472)}$.

Equilibrium standard is $\Delta G_{\text{eq}} = -R \cdot T \cdot \ln(K_{\text{eq}}) = -8.3144 \cdot 298.15 \cdot \ln(10^{(-4.472)}) = -8.3144 \cdot 298.15 \cdot -10.297 = 25.526 \text{ kJ/mol}$;

Equilibrium Hess expression for standard is $\Delta G_{\text{eq}} = G_{\text{NO}_{\text{aq}}} - (G_{\text{H}_2\text{O}} + G_{\text{NO}_{\text{gas}}}) = 86.55 - (0 + G_{\text{NO}_{\text{gas}}}) = 25.526 \text{ kJ/mol}$;

$G_{\text{NO}_{\text{gas}}} = G_{\text{NO}_{\text{aq}}} - (G_{\text{H}_2\text{O}} + \Delta G_{\text{eq}}) = 86.55 - (0 + 25.526) = 61.024 \text{ kJ/mol}$, if equilibrium minimum is $\Delta G_{\text{eq}} = 25.526 \text{ kJ/mol}$;

Solubility of gas NO_{gas} compensate water molecule from $6\text{H}_2\text{O}$ to $5\text{H}_2\text{O}$ and from $5\text{H}_2\text{O}$ to $4\text{H}_2\text{O}$:

$\text{NO}_{\text{aq}} + 5\text{H}_2\text{O} = \text{NO}_3^- + 4\text{H}_3\text{O}^+ + 3\text{e}^-$; $\text{pH} > 1.4$; Expression of potential has standard $E^\circ_{\text{Classic}} = 0.96 \text{ V}$ [18], water logarithm, ΔE° : $E^\circ_{\text{NO}^{(\text{g})}\text{H}_3\text{O}^+} = E^\circ_{\text{Classic}} - 0.0591/3 \cdot \lg(1/[\text{H}_2\text{O}]^5) + \Delta E^\circ = 0.96 + 0.1717 + 0.10166 - 0.37239 = 0.8609 \text{ V}$;

$$E_{\text{NO}^{(\text{g})}\text{H}_3\text{O}^+} = E^\circ_{\text{NO}^{(\text{g})}\text{H}_3\text{O}^+} + 0.0591/3 \cdot \log \frac{[\text{NO}_3^-] \cdot [\text{H}_3\text{O}^+]^4}{[\text{NO}_{\text{aq}}] \cdot [\text{H}_2\text{O}]^5} = 0.8609 \text{ V} + 0.0197 \cdot \log \frac{[\text{NO}_3^-] \cdot [\text{H}_3\text{O}^+]^4}{[\text{NO}_{\text{aq}}] \cdot [\text{H}_2\text{O}]^5}$$

$$\Delta G_{\text{eqNO}^{(\text{g})}\text{H}_3\text{O}^+} = E^\circ_{\text{NO}^{(\text{g})}\text{H}_3\text{O}^+} \cdot F \cdot 3 = 0.86093 \cdot 96485 \cdot 3 = 249.20 \text{ kJ/mol},$$

$$\Delta G_{\text{eqNO}^{(\text{g})}\text{H}_3\text{O}^+} = G_{\text{NO}_3^-} + 4G_{\text{H}_3\text{O}^+} - (G_{\text{NO}_{\text{aq}}} + 5G_{\text{H}_2\text{O}}) = 178.711 + 4 \cdot 22.44 - (19.271 + 5 \cdot 0) = 249.20 \text{ kJ/mol},$$

$$G_{\text{NO}_{\text{aq}}} = G_{\text{NO}_3^-} + 4G_{\text{H}_3\text{O}^+} - (\Delta G_{\text{eqNO}^{(\text{g})}\text{H}_3\text{O}^+} + 5G_{\text{H}_2\text{O}}) = 178.711 + 4 \cdot 22.44 - (249.20 + 5 \cdot 0) = 19.271 \text{ kJ/mol},$$

$\text{NO}_{\text{aq}} + 4\text{H}_2\text{O} = \text{HNO}_3^- + 3\text{H}_3\text{O}^+ + 3\text{e}^-$; $\text{pH} < 1.4$ Expression of potential has standard $E^\circ_{\text{Classic}} = 0.96 \text{ V}$ [18], water logarithm and ΔE° : $E^\circ_{\text{NO}^{(\text{g})}\text{H}_3\text{O}^+} = E^\circ_{\text{Classic}} - 0.0591/3 \cdot \lg(1/[\text{H}_2\text{O}]^4) + \Delta E^\circ = 0.96 + 0.1373 + 0.10166 - 0.37239 = 0.8266 \text{ V}$;

$$E_{\text{NO}^{(\text{g})}\text{H}_3\text{O}^+} = E^\circ_{\text{NO}^{(\text{g})}\text{H}_3\text{O}^+} + 0.0591/3 \cdot \log \frac{[\text{HNO}_3^-] \cdot [\text{H}_3\text{O}^+]^3}{[\text{NO}_{\text{aq}}] \cdot [\text{H}_2\text{O}]^4} = 0.8266 \text{ V} + 0.0197 \cdot \log \frac{[\text{HNO}_3^-] \cdot [\text{H}_3\text{O}^+]^3}{[\text{NO}_{\text{aq}}] \cdot [\text{H}_2\text{O}]^4}$$

$$\Delta G_{\text{eqNO}^{(\text{g})}\text{H}_3\text{O}^+} = E^\circ_{\text{NO}^{(\text{g})}\text{H}_3\text{O}^+} \cdot F \cdot 3 = 0.8266 \cdot 96485 \cdot 3 = 239.26 \text{ kJ/mol},$$

$$\Delta G_{\text{eqNO}^{(\text{g})}\text{H}_3\text{O}^+} = G_{\text{HNO}_3^-} + 4G_{\text{H}_3\text{O}^+} - (G_{\text{NO}_{\text{aq}}} + 5G_{\text{H}_2\text{O}}) = 199.195 + 4 \cdot 22.44 - (49.695 + 5 \cdot 0) = 239.26 \text{ kJ/mol},$$

$$G_{\text{NO}_{\text{aq}}} = G_{\text{HNO}_3^-} + 4G_{\text{H}_3\text{O}^+} - (\Delta G_{\text{eqNO}^{(\text{g})}\text{H}_3\text{O}^+} + 5G_{\text{H}_2\text{O}}) = 199.195 + 4 \cdot 22.44 - (239.26 + 5 \cdot 0) = 49.695 \text{ kJ/mol},$$

$\text{NH}_3\text{gas} + \text{H}_2\text{O} = \text{NH}_3\text{aq}$ brīvā enerģija $G_{\text{NH}_3\text{aq}} = 91.1 \text{ kJ/mol}$; $\text{NH}_3\text{aq} + \text{H}_2\text{O} = \text{NH}_4^+ + \text{OH}^-$;

$\text{NH}_4^+ + 13\text{H}_2\text{O} + \text{OH}^- = \text{NO}_3^- + 10\text{H}_3\text{O}^+ + \text{OH}^- + 8\text{e}^-$; $\text{H}_3\text{O}^+ + \text{OH}^- = 2\text{H}_2\text{O}$;

$\text{NH}_4^+ + 11\text{H}_2\text{O} + \text{OH}^- = \text{NO}_3^- + 9\text{H}_3\text{O}^+ + 8\text{e}^-$; $\text{H}_3\text{O}^+ + \text{OH}^- = 2\text{H}_2\text{O}$;

$\text{NH}_4^+ + 13\text{H}_2\text{O} = \text{NO}_3^- + 10\text{H}_3\text{O}^+ + 8\text{e}^-$; $\text{pH} > 3.15$ Expression of potential has standard $E^\circ_{\text{Classic}} = 0.87 \text{ V}$ [17], water logarithm and ΔE° : $E^\circ_{\text{NH}_4+\text{H}_2\text{O}} = E^\circ_{\text{Classic}} - 0.0591/8 \cdot \lg(1/[\text{H}_2\text{O}]^{13}) + \Delta E^\circ = 0.87 + 0.16737 + 0.10166 - 0.371339 = 0.7667 \text{ V}$;

$$E_{\text{NH}_4+\text{H}_2\text{O}} = E^\circ_{\text{NH}_4+\text{H}_2\text{O}} + 0.0591/8 \cdot \log \frac{[\text{NO}_3^-] \cdot [\text{H}_3\text{O}^+]^{10}}{[\text{NH}_4^+] \cdot [\text{H}_2\text{O}]^{13}} = 0.7666879 \text{ V} + 0.00739 \cdot \log \frac{[\text{NO}_3^-] \cdot [\text{H}_3\text{O}^+]^{10}}{[\text{NH}_4^+] \cdot [\text{H}_2\text{O}]^{13}}$$

$$\Delta G_{\text{eqNH}_4+\text{H}_2\text{O}} = E^\circ_{\text{NH}_4+\text{H}_2\text{O}} \cdot F \cdot 8 = 0.7666879 \cdot 96485 \cdot 8 = 592.56 \text{ kJ/mol},$$

$$\Delta G_{\text{eqNH}_4+\text{H}_2\text{O}} = G_{\text{NO}_3^-} + 10G_{\text{H}_3\text{O}^+} - (G_{\text{NH}_4^+} + 13G_{\text{H}_2\text{O}}) = 601.06 + 10 \cdot 22.44 - (232.9 - 13 \cdot 0) = 592.56 \text{ kJ/mol},$$

$$G_{\text{NO}_3^-} = \Delta G_{\text{eqNH}_4+\text{H}_2\text{O}} - 10G_{\text{H}_3\text{O}^+} + (G_{\text{NH}_4^+} + 13G_{\text{H}_2\text{O}}) = 592.56 - 10 \cdot 22.44 + (232.9 - 13 \cdot 0) = 601.06 \text{ kJ/mol}.$$

Nernst's potential studies $\underline{5(Pt)H} + MnO_4^-$ on hydroxonium H_3O^+ and water H_2O account

Inverse Nernst's standard potential: $MnO_4^- + 8H_3O^+ + 5e^- = Mn^{2+} + 12H_2O$; $-E^\circ_{Mn2+/MnO4^-} = -1.4865V$.

Twelve water molecules account $[H_2O] = 55.3 M = (996 \frac{g}{L}) / (18 \frac{g}{mol})$ increase potential to:

$$E^\circ_{Mn2+/MnO4^-} = E^\circ - 0.0591/5 \cdot \log(1/[H_2O]^{12}) = 1.51 - 0.0591/5 \cdot \log(1/55.3^{12}) + 0.10166 - 0.37239 = 1.4865 V.$$

Concentration $[H_2O]^{12}$ exponent 12 included in classic standard potential $E_o = 1.51 V$ as logarithm.

Reductant oxidation Nernst's: $\underline{5(Pt)H} + 5H_2O = 5H_3O^+ + 5e^-$; absolute standard potential $E^\circ_H = -0.27073 V$.

$$E_{MnO4^-} = -1.4865 V + 0.0591/5 \cdot \log([H_2O]^{12} \cdot [Mn^{2+}] / [MnO_4^-] \cdot [H_3O^+]^8) =$$

$$E_H = E^\circ_H + 0,0591 \cdot \log([H_3O^+] / [H_2O]) = -0,27073 V + 0,0591 \cdot \log([H_3O^+] / [H_2O]);$$

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

$$\Delta G_{HessPtH} = \Delta G^\circ_{Mn2+} + 7\Delta G^\circ_{H2O} - (\Delta G^\circ_{MnO4^-} + 3\Delta G^\circ_{H3O^+} + 5G_{(Pt)H}) = -228,1 + 7 \cdot (-237,191) - (3 \cdot (-213,2746) - 447,2 + 5 \cdot 48,56) = -1044,21 \text{ kJ/mol};$$

$$\Delta G_{HessCRC} = \Delta G^\circ_{Mn2+} + 7\Delta G^\circ_{H2O} - (\Delta G^\circ_{MnO4^-} + 3\Delta G^\circ_{H3O^+} + 5/2\Delta G^\circ_{H2}) = -228,1 + 7 \cdot (-237,191) - (3 \cdot (-213,2746) - 447,2 + 5 \cdot 99,13/2) = -1049 \text{ kJ/mol};$$

$$\Delta G_{Alberty} = \Delta G^\circ_{Mn2+} + 7\Delta G^\circ_{H2O} - (\Delta G^\circ_{MnO4^-} + 3\Delta G^\circ_{H3O^+} + 5/2G_{H2}) = -228,1 + 7 \cdot (-237,191) - (3 \cdot (-213,2746) - 447,2 + 5 \cdot 103,24/2) = -1059,5 \text{ kJ/mol};$$

Substan	$\Delta H^\circ_H, \text{ kJ/mol}$	$\Delta S^\circ_H, \text{ J/mol/K}$	$\Delta G^\circ_H, \text{ kJ/mol}$
H₂O	-285.85	69.9565	-237.191
H₂O	-286.65	-453.188	-151.549
H₃O⁺	-285.81	-3.854	-213.2746
H₂(aq)	23.4	-130	99.13
H₂(aq)	-5.02	-363.92	103.24
H(Pt)(aq)	-	-	48.56
MnO₄⁻	-541.4	-191.2	-447.2
Mn²⁺	-220.8	-73.6	-228.1
O₂aqua	-11.7	-94.2	16.4

CRC Handbook of Chemistry and Physics, 2010. D.Lide [1]
 Biochem. Thermodyn., Massachusetts Technology Inst. [8] pH=7,36
 $\Delta G^\circ_{H3O^+}, \text{ kJ/mol}$ Mischenko 1972, Himia, Leningrad [26]
 CRC [1]
 Biochem. Thermodyn., Massachusetts Technology Inst. [8] pH=7,36
 $\Delta G_{eq} = -847.7 \text{ kJ/mol}$; $\Delta G_{HessOxRed} = -1044.2 \text{ kJ/mol}$
 CRC [1]
 $|\Delta G_{eq} = -847.7 \text{ kJ/mol}| < |\Delta G_{Hess} = -1044.2 \text{ kJ/mol}|$;
 Biochem. Thermodyn., Massachusetts Technology Inst. [8] pH=7,36

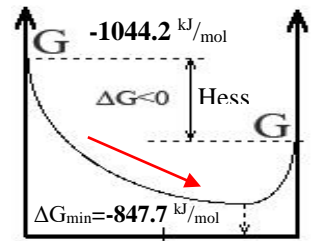
$$\Delta G_{eqH/MnO4^-} = (E^\circ_H - E^\circ_{MnO4^-}) \cdot F \cdot 1 \cdot 5 = (-0,27073 - 1,4865) \cdot 96485 \cdot 5 = -1,757 \cdot 96485 \cdot 5 = -847,7 \text{ kJ/mol}.$$

$$K_{eq} = \exp(-\Delta G_{eqH/MnO4^-} / R/T) = \exp(847732 / 8,3144 / 298,15) = \exp(341,96) = 10^{148,5};$$

Exothermic and exoergic MnO_4^- reduction by $\underline{5(Pt)H}$ Hess free energy change negative $\Delta G_{Hess} = \Delta G_{OxRed} = -1043.7 \text{ kJ/mol}$, but minimizes $\Delta G_{min} = \Delta G_{eqOxRed} = -847.7 \text{ kJ/mol}$ reaching

$$\text{equilibrium mixture } 10^{148.5} = K_{eq} = \frac{[H_2O]^7 \cdot [Mn^{2+}]}{[(Pt)H]^5 \cdot [MnO_4^-] \cdot [H_3O^+]^3};$$

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



5A + B + 3C 50% D + 8E
 reactants $\underline{5(Pt)H} + MnO_4^- + 3H_3O^+$
 products $Mn^{2+} + 7H_2O$

$MnO_2 + 4OH^- = MnO_4^- + 2H_2O + 3e^-$; Reductant Nernst's absolute standard potential: $E^\circ_{MnO2/MnO4^-} = 0.26465 V$,

$E^\circ_{MnO2/MnO4^-} = E^\circ - 0.0591/3 \cdot \log([H_2O]^2) + 0.10166 - 0.37239 = 0.603 - 0.0591/3 \cdot \log(55.3^2) + 0.10166 - 0.37239 = 0.26465 V$;

$MnO_4^{2-} = MnO_4^- + e^-$; Reductant Nernst's absolute standard potential: $E^\circ_{MnO2/MnO4^-} = 0.2883 V$;

$E^\circ_{MnO4/MnO4^-} = E^\circ - 0.0591/3 \cdot \log([H_2O]^0) + 0.10166 - 0.37239 = 0.558 - 0.0591/3 \cdot \log(55.3^0) + 0.10166 - 0.37239 = 0.2883 V$;

2) Carbonic anhydrase CA generate free energy from zero $G_{CO2+2H2O} = 0 \text{ kJ/mol}$ to $G_{H3O+HCO3^-} = 78,52 \text{ kJ/mol}$.

Solubility in water creates free energy from zero level $CO_{2gas} + H_2O = CO_{2aqua}$ to $G_{CO2aqua} = 18,38 \text{ kJ/mol}$ constant:

$$K_{eqCO2aqua} = [CO_{2aqua}] / [CO_{2gas}] \cdot [H_2O] = \exp(-G_{CO2aqua} / R/T) = \exp(-18382,746 / 8,3144 / 298,15) = 0,000601808$$

increasing free energy by $\Delta G_{CO2aqua} = -R \cdot T \cdot \ln(K_{eqCO2aqua}) = -8,3144 \cdot 298,15 \cdot \ln(0,000601808) = 18,38 \text{ kJ/mol}$.

Reaction $CO_{2aqua} + 2H_2O + \Delta G + Q = v_1^{CA} > H_3O^+ + HCO_3^-$ velocity constant is

$k_{1CO2aqua} = 1,5 \times 10^8 \text{ M}^{-1} \text{ s}^{-1}$ and protolytic acid CO_{2aqua} equilibrium value of constant is

$$\frac{[HCO_3^-]_{aqua} \cdot [H_3O^+]}{[CO_2]_{aqua} \cdot [H_2O]^2} = K_{eqCAHCO3aqua} = K_{a_CO2aqua} / [H_2O]^2 = 10^{-7,0512} / 55,3^2 = 2,906 \cdot 10^{-11}. [9]$$

CA high rate protolysis constant accumulate free energy in products $H_3O^+ + HCO_3^-$ activating its:

$$\Delta G_{eqCACO2aqua} = -R \cdot T \cdot \ln(K_{eqCACO2aqua}) = -8,3144 \cdot 298,15 \cdot \ln(2,906 \cdot 10^{(-11)}) / 1000 = 60,14 \text{ kJ/mol}.$$

Total free energy increases by activation reaching equilibrium state with high rate protolysis and solubility:

$$G_{H3O+HCO3^-} = G_{H3O^+} + G_{HCO3^-} = 22,44 + 56,08 = G_{CO2aqua} + \Delta G_{eqCACO2aqua} = 18,38 + 60,14 = 78,52 \text{ kJ/mol}. [1,8,14]$$

High rate protolysis attractor is pH=7,36. Deviation from the attractor disrupts the order of irreversible homeostasis processes, creating disorder and chaos.

Carbonic anhydrase CA synthesis indispensable active Biosphere attractor.

The reactivity of carbonic anhydrase and the equilibrium-attractor value of the generated physiological buffer solution protolysis pH=7.36 is a self-organizing biosphere attractor. The accumulated free energy of the reaction $\text{CO}_2+2\text{H}_2\text{O}$ in the products (CO_2aqua) $\text{H}_3\text{O}^++\text{HCO}_3^-$ accumulate free energy $G_{\text{H}_3\text{O}^++\text{HCO}_3^-}=18.38+60.14=78.38$ kJ/mol is necessary for the functional activity of the bicarbonate buffer system for the perfect order of reactions in the complex processes of irreversible homeostasis.

CO_2 no reaction with water H_2O at absence of CA. CO_2 is weak soluble and slow react with OH^- ions. Wikipedia [27] mol mas $M_{\text{CO}_2}=44.009$ g/mol. Solubility $\text{CO}_2\text{gas}+\text{H}_2\text{O}=\text{CO}_2\text{aqua}$ 1.45 g/L at 0.99 atm and at 1 atm $m_{\text{CO}_2}=100*1.45/99=1.4646$ g/L has concentration $[\text{CO}_2\text{aqua}]=m_{\text{CO}_2}/M_{\text{CO}_2}=1.4646/44.009=0.03328$ M.

Solubility product is $K_{\text{spCO}_2\text{aqua}}=[\text{CO}_2\text{aqua}]/[\text{CO}_2\text{gas}]=0.03328$ M but equilibrium constant in mol fractions is $K_{\text{eqCO}_2\text{aqua}}=[\text{CO}_2\text{aqua}]/[\text{CO}_2\text{gas}]/[\text{H}_2\text{O}]=K_{\text{spCO}_2\text{aqua}}/[\text{H}_2\text{O}]=0.03328/55.3=0.000601808$.

Free energy $\Delta G_{\text{eqCO}_2\text{aqua}}=-R\cdot T\cdot\ln(K_{\text{eqCO}_2\text{aqua}})=-8.3144\cdot 298.15\cdot\ln(0.000601808)/1000=18.38$ kJ/mol has minimum value at solubility equilibrium $G_{\text{CO}_2\text{aqua}}=\Delta G_{\text{eqCO}_2\text{aqua}}+(G_{\text{CO}_2\text{gas}}+G_{\text{H}_2\text{O}})=18.38+(0+0)=18.38$ kJ/mol.

From air 0.04 % mol fraction $[\text{CO}_2\text{gas}]=0.0004$ creates dissolve concentration:

$$[\text{CO}_2\text{aqua}]=K_{\text{eqCO}_2\text{aqua}}\cdot[\text{H}_2\text{O}]\cdot[\text{CO}_2\text{gas}]=0.000601808\cdot 55.3457\cdot 0.0004=0.000753$$
 M.

Carbon dioxide CO_2aqua reacts with OH^- ions times $10^{16.54}$ slower as bicarbonate HCO_3^- neutralization reaction: $\text{H}_3\text{O}^++\text{HCO}_3^-=\text{CO}_2\text{aqua}+2\text{H}_2\text{O}$, because neutralization velocity constant is $k_2=5.16885\cdot 10^{18}$ M⁻²s⁻¹, but OH^- ions $\text{CO}_2\text{aqua}+\text{OH}^-=\text{HCO}_3^-$ have velocity constant $k_{1\text{OH}}=1.5\cdot 10^2$ M⁻²s⁻¹. Reaction has favored equilibrium constant:

$$\Delta G_{\text{HessHCO}_3^-}=G_{\text{HCO}_3^-}-(G_{\text{CO}_2\text{aqua}}+G_{\text{OH}^-})=56.08-(18.38+77.36)=-39.66$$
 kJ/mol

$$k_{1\text{OH}}/k_{2\text{HCO}_3^-}=[\text{HCO}_3^-]/[\text{CO}_2\text{aqua}]/[\text{OH}^-]=K_{\text{eqHCO}_3^-}=\text{EXP}(-\Delta G_{\text{eqHCO}_3^-}/R/T)=\text{EXP}(39660/8.3144/298.15)=8875.3$$

and produce exothermic heat Q: $\Delta H_{\text{Hess}}=\Delta H^\circ_{\text{HCO}_3^-}-\Delta H^\circ_{\text{CO}_2}-\Delta H^\circ_{\text{OH}^-}=-48.68$ kJ/mol. Inverse $\text{HCO}_3^-=\text{CO}_2\text{aqua}+\text{OH}^-$

reaction has $k_{2\text{HCO}_3^-}=k_{1\text{OH}}/K_{\text{eqHCO}_3^-}=1.5\cdot 10^2/8875.3=0.0169$ unfavored constant. Decomposition HCO_3^-

=> $\text{CO}_2\text{aqua}+\text{OH}^-$ velocity constant $k_{2\text{HCO}_3^-}$ is then billion 10^{10} times slower as CA velocity constant

$$k_{1\text{CO}_2\text{aqua}}=1.5\cdot 10^8$$
 M⁻¹s⁻¹. [9]

CA protolytic reactivity creates functional active bicarbonate buffer self-organizing attractor pH=7.36 with generate concentrations gradients for transport of H_3O^+ , HCO_3^- , CO_2aqua and of O_2aqua , H_2O by osmose through aquaporin channels. [9]

CA high rate protolysis require CO_2aqua react with two water molecules:

$\text{CO}_2\text{aqua}+2\text{H}_2\text{O}+\Delta G+Q=v\cdot 1^{\text{CA}}>\text{H}_3\text{O}^++\text{HCO}_3^-$, which velocity constant is: $k_{1\text{CO}_2\text{aqua}}=1.5\cdot 10^8$ M⁻¹s⁻¹. [9]

Neutralization $\text{H}_3\text{O}^++\text{HCO}_3^-=\text{CO}_2\text{aqua}+2\text{H}_2\text{O}$ velocity constant is CA independent times $10^{10.54}$ greater about CA velocity constant: $k_2/k_{1\text{CO}_2\text{aqua}}=5.16885\cdot 10^{18}/1.5/10^8=34407299853=10^{10.54}$.

CA protolysis equilibrium constant evaluate ratio of velocity constants in expression:

$$K_{\text{eqCAHCO}_3\text{aqua}}=k_{1\text{CO}_2\text{aqua}}/k_2=K_{\text{aCO}_2\text{aqua}}/[\text{H}_2\text{O}]^2=10^{(-7.0512)}/55.3^2=2.906\cdot 10^{-11}=10^{-10.54}$$

Bicarbonate buffer acid protolysis constant $\text{pK}_{\text{aCO}_2\text{aqua}}=7.0512$ is friendly to attractor value pH=7.36:

$$K_{\text{aCO}_2\text{aqua}}=K_{\text{eqCAHCO}_3\text{aqua}}\cdot[\text{H}_2\text{O}]^2=\frac{[\text{HCO}_3^-]_{\text{aqua}}\cdot[\text{H}_3\text{O}^+]}{[\text{CO}_2]_{\text{aqua}}}=10^{-7.0512}=10^{-\text{pK}_{\text{aCO}_2\text{aqua}}}$$
. Original $\text{pK}_{\text{aCO}_2\text{aqua}}=7.0512$ value

obtained and calculated for BUFFER solutions. Hess free energy change is exoergic negative:

$$\Delta G_{\text{Hess}}=2\Delta G^\circ_{\text{H}_2\text{O}}+\Delta G^\circ_{\text{CO}_2}-(\Delta G^\circ_{\text{H}_3\text{O}^+}+\Delta G^\circ_{\text{HCO}_3^-})=2\cdot(-237.191)-385.98-(-213.2746-544.9688)=-102$$
 kJ/mol. [1]

Neutralization: $\text{H}_3\text{O}^++\text{HCO}_3^-=\text{CO}_2\text{aqua}+2\text{H}_2\text{O}$ constant is inverse to protolysis and favored:

$$K_{\text{eqNeutralization}}=1/K_{\text{eqCAHCO}_3\text{aqua}}=[\text{HCO}_3^-]\cdot[\text{H}_3\text{O}^+]/[\text{CO}_2\text{aqua}]/[\text{H}_2\text{O}]^2=1/2.90636/10^{(-11)}=34407299853$$

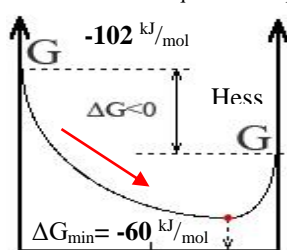
$$\Delta G_{\text{Absolute_Neutralization}}=2G_{\text{H}_2\text{O}}+G_{\text{CO}_2\text{aqua}}-G_{\text{H}_3\text{O}^+}-G_{\text{HCO}_3^-}=2\cdot 0+18.38-22.44-56.08=-60.14$$
 kJ/mol and

enthalpy Hess change in reaction is exothermic: $\Delta H_{\text{Hess}}=2\Delta H^\circ_{\text{H}_2\text{O}}+\Delta H^\circ_{\text{CO}_2}-\Delta H^\circ_{\text{H}_3\text{O}^+}-\Delta H^\circ_{\text{HCO}_3^-}=-7.2$ kJ/mol.

Neutralization is favored reaction. Free energy change on minimum expression is negative:

$$\Delta G_{\text{eqNeutralization}}=-R\cdot T\cdot\ln(K_{\text{eqNeutralization}})=-8.3144\cdot 298.15\cdot\ln(34407299853)=-60.14$$
 kJ/mol, but CO_2aqua protolysis minimum as inverse reaction of neutralization is positive:

$$\Delta G_{\text{eqCAHCO}_3\text{aqua}}=-R\cdot T\cdot\ln(K_{\text{eqCAHCO}_3\text{aqua}})=-8.3144\cdot 298.15\cdot\ln(1/34407299853)=60.14$$
 kJ/mol.



A+B 50 % C+2D.

Attractor Fig. 2. Exothermic and exoergic neutralization Hess free energy change $\Delta G_{\text{HessNeutralization}}$ is negative -102 kJ/mol, bet $\Delta G_{\text{eqNeutralization}}=-60.14$ kJ/mol minimized reaching equilibrium mixture $K_{\text{eq}}=34407299853$ at presence of CA carbonic anhydrase. Carbon dioxide reaction with hydroxide anions is slow, because of small factors: $k_{1\text{OH}}=1.5\cdot 10^2$ M⁻²s⁻¹ velocity constant and concentrations $[\text{CO}_2\text{aqua}]=0.0007512$ M, $[\text{OH}^-]=10^{-6.64}$ M. Carbonic anhydrase synthesis resolves perfect order of bioenergetic homeostasis as self-organization attractor. [3.4]

Reactants $\text{H}_3\text{O}^++\text{HCO}_3^-$, products $\text{CO}_2\text{aqua}+2\text{H}_2\text{O}$.

2CO₂ / H₂C₂O₄ / CH_{4gas} solubility and protolysis require hydroxonium H₃O⁺ and water H₂O account.

The standard free energy change for the formation of carbon dioxide from free elements C_{gr}+O_{2gas}=CO_{2gas} is negative ΔG°_{Hess_CO2gas}=G_{CO2gas}-(G_{gr}+G_{O2gas})=-394,36 kJ/mol. [1] If the background level for the absolute energy scale of biochemistry is zero G_{CO2gas}=0 kJ/mol, then by Hess's law the absolute free energy content of one mole of graphite is G_{gr}=G_{CO2gas}-(ΔG°_{Hess_CO2gas}+G_{O2gas})=0-(-394,36+303,1)=91,26 kJ/mol.

The standard free energy change for methane formation from free elements C_{gr}+2H_{2gas}>CH_{4gas} [1,8] is

$$\Delta G^{\circ}_{\text{Hess_CH4gas}} = G_{\text{CH4gas}} - (G_{\text{Cgr}} + 2 * G_{\text{H2}}) = G_{\text{CH4gas}} - (91.26 + 2 * 85.64) = -50.5 \text{ kJ/mol}$$

and the free energy content per mol of methane remaining unused from free elements in Hess's law is

$$G_{\text{CH4gas}} = \Delta G^{\circ}_{\text{Hess_CH4gas}} + (G_{\text{Cgr}} + 2 * G_{\text{H2}}) = -50.5 + (91.26 + 2 * 85.64) = 212.04 \text{ kJ/mol}$$

This allows us to calculate the absolute free energy per mol of the element graphite on absolute free energy scale:

$$G_{\text{CgrCH4gas}} = G_{\text{CH4gas}} - \Delta G^{\circ}_{\text{Hess_CH4gas}} - 2 * G_{\text{H2gas}} = 212.04 - (-50.5 + 2 * 85.64) = 91.26 \text{ kJ/mol}$$

which coincides with the zero of gas and water G_{CO2gas}=G_{H2O}=0 kJ/mol on the biochemistry absolute energy scale.

The solubility of methane CH_{4gas}+H_{2O}=CH_{4aq}

is 22.7 mg/L and the molar mass of methane is M_{CH4}=16.043 g/mol. The water account [H_{2O}]=996/18=55.3 M calculates the solubility constant K_{eq}=K_{sp}/[H_{2O}]=0.001414947 M/55.3 M=10^{-(4.592)}.

For the equilibrium solubility of methane [CH₄]=0,0227/16,043=0,001414947 M, the absolute free energy change is ΔG_{eq}=-R•T•ln(K_{eq})=-8.3144*298.15*ln(10^{-(4.592)})=-8.3144*298.15*-10.573=26.21 kJ/mol.

Alberty data calculates the solubility energy change

$$\Delta G_{\text{eqCH4gas}} = G_{\text{CH4aq}} - (G_{\text{CH4gas}} + G_{\text{H2O}}) = 238.25 - (212.04 + 0) = 26.21 \text{ kJ/mol}$$

allows us to calculate the absolute free energy content of methane in water (aqua):

$$G_{\text{CH4aq}} = \Delta G_{\text{eqCH4}} + (G_{\text{H2O}} + G_{\text{CH4gas}}) = 26.21 + (0 + 212.04) = 238.25 \text{ kJ/mol}$$

Substance	ΔH° _H kJ/mol	ΔS° _H J/mol/K	ΔG° _H kJ/mol	ΔG _{H2C2O4} =ΔH _H -T*ΔS _H =-829.9-298.15*-0.1098=-747.75 kJ/mol;
H ₂ O	-285.85	69.9565	-237.191	CRC [1]
H ₃ O ⁺	-285.81	-3.854	-213.2746	CRC [1] Mischenko 1972, Himia, Leningrad [26]
H ₂ C ₂ O _{4cr}	-829.9	-109.8	-797.16	CRC [1]
H ₂ C ₂ O _{4cr}	formation	-797.16	76.96	G _{H2C2O4cr} =ΔG° _{H2C2O4crForm} +(2G _{Cgr} +2G _{O2gas} +G _{H2gas})=76.96 kJ/mol;
H ₂ C ₂ O _{4aq}	ΔG _{eq_sp} =	9.0161	85.976	G _{H2C2O4aq} =ΔG _{eq_sp} +(G _{H2O} +G _{H2C2O4cr})=85.976 kJ/mol;
H ₂ C ₂ O _{4aq}	E° _{H2C2O4} =	-0.6577 V	171.78	G _{H2C2O4} =2G _{CO2} +2G _{H3O} -(ΔG _{eqH2C2O4} +2G _{H2O})=171.78 kJ/mol;
HC ₂ O ₄ ⁻	17.08	pK _{a2} =1.25	80.618	G _{HC2O4} =ΔG _{eq1H2C2O4} -G _{H3O} +(G _{H2C2O4} +ΔG _{H2O})=80.618 kJ/mol ;
HC ₂ O ₄ ⁻	E° _{HC2O4} =	-0.7092 V	159.028	G _{HC2O4} =2G _{CO2} +G _{H3O} -(ΔG _{eqHC2O4} +G _{H2O})=159.028 kJ/mol;
C ₂ O ₄ ²⁻	-	-pH=7,36	-677.14	Alberty 2006 Biochem.Thermodyn Massachusetts Techn. Inst.
C ₂ O ₄ ²⁻	33.578	pK _{a2} =4.14	91.756	G _{C2O4} =ΔG _{eq2HC2O4} -G _{H3O} +(G _{HC2O4} +G _{H2O})=91.756 kJ/mol ;
C ₂ O ₄ ²⁻	E° _{C2O4} =	-0.7607 V	146.79	G _{C2O4} =2G _{CO2} -(ΔG _{eqC2O4})=2*0-(-146.79)=146.79 kJ/mol;
CH _{4gas}	-74.6	186.3	-50.5	=ΔG° _{Hess_CO2gas} =G _{CO2gas} -(G _{gr} +G _{O2gas}) Wikipedia CRC [1]
CH _{4gas}	formation	-50.5	212.04	G _{CH4gas} =ΔG° _{Hess_CH4gas} +(G _{Cgr} +2*G _{H2})=212.04 kJ/mol;
CH _{4gas}	pH=7,36	Alberty [8]	120.56	Alberty 2006 Biochem.Thermodyn Massachusetts Techn. Inst.
CH _{4aq}	Solubility	26.21	238.25	G _{CH4aq} =G _{CH4gas} + G _{CH4sp} =212.04+26.21=238.25 kJ/mol;
CH _{4aq}	[8]	-pH=7,36	136.95	Alberty 2006 Biochem.Thermodyn Massachusetts Techn. Inst.
C _{gr}	background	Biochemistry	91.26	G _{gr} =G _{CO2gas} -(ΔG° _{Hess_CO2gas} +G _{O2gas})=91,26 kJ/mol; pH=7.36
CO _{2gas}	-393.509	213.74	-394.359	CRC [1]
CO _{2aq}	-413.798	117.5704	-385.98	CRC [1]
CO _{2aq}	E° _{H2C2O4} =	-0.6577 V	-42.90	2G _{CO2} = ΔG _{eqH2C2O4} -2G _{H3O} +(G _{H2C2O4} +2G _{H2O})=2*-42.902 kJ/mol;
CO _{2aq}	E° _{HC2O4} =	-0.7092 V	-97.514	2G _{CO2} = ΔG _{eqHC2O4} -G _{H3O} +(G _{HC2O4} +G _{H2sO})=2*-97.514 kJ/mol;
CO _{2aq}	E° _{C2O4} =	-0.7607 V	-27.517	2G _{CO2} =ΔG _{eqC2O4} +(G _{C2O4})=-27.517 kJ/mol;
CO _{2aq}	K _{eqCO2aqua}	Solubility	18.38	G _{CO2aqua} =ΔG _{eqCO2aqua} +(G _{CO2gas} +G _{H2O})=18.38+(0+0)=18.38 kJ/mol .

Formation from free elements $2C_{gr}+2O_{2gas}+H_{2gas}=H_2C_2O_{4cr}$ and solubility $H_2C_2O_4^{cr}+H_2O=H_2C_2O_{4aq}$:
 $G_{H_2C_2O_{4cr}}=\Delta G^\circ_{H_2C_2O_{4cr}Form}+(2G_{C_{gr}}+2G_{O_{2gas}}+G_{H_{2gas}})=-797.16+(2*91.26+2*303+85.6)=76.96$ kJ/mol.

Solubility of oxalic acid 118 g/L $H_2C_2O_4^{cr}+H_2O=H_2C_2O_{4aq}$ constant is calculated from [1,29] data with density 1.072 g/mL :

$$K_{eq_sp}=[H_2C_2O_{4aq}]/[H_2C_2O_4^{cr}]/[H_2O]=1.3106/1/49.77=0.026329.$$

Molar mass $M_{H_2C_2O_4}=90.034$ g/mol; $[H_2O]=982/18=49.777$ M; concentration $[H_2C_2O_4]=118/90.034=1.3106$ M and mass fraction in percent $w\%=118/(118+982)*100=10.7272\%$, if pure solid mol fraction is one $[H_2C_2O_4^{cr}]=1$.

Oxalic acid solubility free energy change for unfavored equilibrium $K_{eq_sp}=0.026329$ is positive:

$$\Delta G_{eq_sp}=-R\cdot T\cdot\ln(K_{eq_sp})=-8.3144*298.15*\ln(0.026329)=-8.3144*298.15*-3.637=9.0161$$
 kJ/mol .

In Hess law expression $\Delta G_{eq_sp}=G_{H_2C_2O_{4aq}}-(G_{H_2O}+G_{H_2C_2O_4^{cr}})=G_{H_2C_2O_{4aq}}-(0+76.96)=9.0161$ kJ/mol was calculated the one mol free energy content $G_{H_2C_2O_{4aq}}=\Delta G_{eq_sp}+(G_{H_2O}+G_{H_2C_2O_4^{cr}})=9.0161+(0+76.96)=85.976$ kJ/mol. [29]

1. Weak acid protolysis $H_2C_2O_4+H_2O=HC_2O_4^-+H_3O^+$; $pK_{a1}=1.25$; $K_{eq1}=K_{a1}/[H_2O]=10^{-(1.25)}/55.3=0.0010169$;
 $\Delta G_{eq1H_2C_2O_4}=-R\cdot T\cdot\ln(K_{eq1})=-8.3144*298.15*\ln(0.0010169)=\Delta G_{HC_2O_4}+\Delta G_{H_3O}-(\Delta G_{H_2C_2O_4}+\Delta G_{H_2O})=17.08$ kJ/mol;
 $\Delta G_{eq1H_2C_2O_4}=G_{HC_2O_4}+G_{H_3O}-(G_{H_2C_2O_4}+\Delta G_{H_2O})=G_{HC_2O_4}+22.44-(85.976+0)=17.082$ kJ/mol;
 $G_{HC_2O_4}=\Delta G_{eq1H_2C_2O_4}-G_{H_3O}+(G_{H_2C_2O_4}+\Delta G_{H_2O})=17.082-22.44+(85.976+0)=80.618$ kJ/mol;

2. Weak acid protolysis $HC_2O_4^-+H_2O=C_2O_4^{2-}+H_3O^+$; $pK_{a2}=4.14$; $K_{eq2}=K_{a2}/[H_2O]=10^{-(4.14)}/55.3=0.000001310$;
 $\Delta G_{eq2HC_2O_4}=-R\cdot T\cdot\ln(K_{eq2})=-8.3144*298.15*\ln(0.000001310)=\Delta G_{C_2O_4}+\Delta G_{H_3O}-(\Delta G_{HC_2O_4}+\Delta G_{H_2O})=33.578$ kJ/mol;
 $\Delta G_{eq2HC_2O_4}=G_{C_2O_4}+G_{H_3O}-(G_{HC_2O_4}+\Delta G_{H_2O})=G_{C_2O_4}+22.44-(80.618+0)=33.578$ kJ/mol;
 $G_{C_2O_4}=\Delta G_{eq2HC_2O_4}-G_{H_3O}+(G_{HC_2O_4}+\Delta G_{H_2O})=33.578-22.44+(80.618+0)=91.756$ kJ/mol;

$pH\leq 1.25$ $H_2C_2O_4+2H_2O=2CO_2+2H_3O^++2e^-$; Expression composition contains the potential classic standard $E^\circ_{Classic}=-0.49$ V [17], water logarithm $-0.0591/2\cdot\log(1/[H_2O]^1)=0.103$ and $\Delta E^\circ=0.10166-0.37239$:

$$E^\circ_{H_2C_2O_4}=E^\circ_{Classic}-0.0591/2*\lg(1/[H_2O]^2)+\Delta E^\circ=-0.49+0.103+0.10166-0.37239=-0.6577$$
 V;

Absolute Nernst's Standard potential $E^\circ_{H_2C_2O_4}=-0.6577$ V; Suchotina [17]

$$E_{H_2C_2O_4}=E^\circ_{H_2C_2O_4}+\frac{0.0591}{2}\cdot\lg\frac{[CO_2]^2\cdot[H_3O^+]^2}{[H_2C_2O_4]\cdot[H_2O]^2}=-0.6577$$
 V + $\frac{0.0591}{2}\cdot\lg\frac{[CO_2]^2\cdot[H_3O^+]^2}{[H_2C_2O_4]\cdot[H_2O]^2}$

$$\Delta G_{eqH_2C_2O_4}=E^\circ_{H_2C_2O_4}\cdot F\cdot 2=-0.6577*96485*2=-126.9$$
 kJ/mol;

$$\Delta G_{eqH_2C_2O_4}=2G_{CO_2}+2G_{H_3O}-(G_{H_2C_2O_4}+2G_{H_2O})=2*0+2*22.44-(85.976+2*0)=-126.9$$
 kJ/mol ;

$$G_{H_2C_2O_4}=2G_{CO_2}+2G_{H_3O}-(\Delta G_{eqH_2C_2O_4}+2G_{H_2O})=2*0+2*22.44-(-126.9+2*0)=171.78$$
 kJ/mol ;

$1.25<pH\leq 4.14$; $HC_2O_4^-+H_2O=2CO_2+H_3O^++2e^-$; Expression composition contains the potential classic standard $E^\circ_{Classic}=-0.49$ V [17], water logarithm $-0.0591/2\cdot\log(1/[H_2O]^1)=0.0515$ and $\Delta E^\circ=0.10166-0.37239$:

$$E^\circ_{HC_2O_4}=E^\circ_{Classic}-0.0591/2*\lg(1/[H_2O]^1)+\Delta E^\circ=-0.49+0.0515+0.10166-0.37239=-0.709$$
 V;

$$\Delta G_{eqHC_2O_4}=E^\circ_{HC_2O_4}\cdot F\cdot 2=-0.7092*96485*2=-136.85$$
 kJ/mol;

$$\Delta G_{eqHC_2O_4}=2G_{CO_2}+G_{H_3O}-(G_{HC_2O_4}+G_{H_2O})=2*0+22.44-(80.618+0)=-136.85$$
 kJ/mol;

$$G_{HC_2O_4}=2G_{CO_2}+G_{H_3O}-(\Delta G_{eqHC_2O_4}+G_{H_2O})=2*0+22.44-(-136.85+0)=159.028$$
 kJ/mol;

$4.14 < pH$; $C_2O_4^{2-}=2CO_2+2e^-$; Expression composition contains the potential classic standard $E^\circ_{Classic}=-0.49$ V [17], water logarithm zero 0 and $\Delta E^\circ=0.10166-0.37239$:

$$E^\circ_{C_2O_4}=E^\circ_{Classic}-0.0591/2*\lg([1/H_2O]^0)+\Delta E^\circ=-0.49+0+0.10166-0.37239=-0.7607$$
 V;

$$\Delta G_{eqC_2O_4}=E^\circ_{C_2O_4}\cdot F\cdot 2=-0.7607*96485*2=-146.79$$
 kJ/mol;

$$\Delta G_{eqC_2O_4}=2G_{CO_2}-(G_{C_2O_4})=2*0-(G_{C_2O_4})=-146.79$$
 kJ/mol;

$$G_{C_2O_4}=2G_{CO_2}-(\Delta G_{eqC_2O_4})=2*0-(-146.79)=146.79$$
 kJ/mol;

Nernst's potential studies reducing with vitamin B₃ ethanal H₃CCH=O and oxidizing H₃CCH₂OH ethanol



$$\Delta G_{Hess} = \Delta G^{\circ}_{H_3O} + \Delta G^{\circ}_{CH_3CHO} + \Delta G^{\circ}_{NADH} - (\Delta G^{\circ}_{CH_3CH_2OH} + \Delta G^{\circ}_{H_2O} + \Delta G^{\circ}_{NAD^+}) = 159.1 \text{ kJ/mol};$$

$$\Delta G_{Hess} = 32.2824 + 1175.5732 - 151.549 - (75.2864 + 1059.11 - 237.191) = 159.1 \text{ kJ/mol endoergic. [1]}$$

Ox NAD⁺ + H⁺(H⁺+2e⁻)=NADH; Expression of inverse absolute potential has standard -E^o_{Classic}=0.113 V [22], water zero 0 and ΔE^o=0.10166-0.37239: -E^o_{NADH}=-E^o_{Classic}+0+ΔE^o=0.113+0+0.10166-0.37239)=**0.38373 V**

Red CH₃CH₂OH+H₂O=CH₃CHO+H₃O⁺+H⁺(2e⁻); Expression of absolute potential has standard E^o_{Classic}=0.19 V [19], water logarithm -0.0591/2•log(1/[H₂O])¹)=0.0515 and ΔE^o=0.10166-0.37239:

$$E^{\circ}_{C_2H_5OH} = E^{\circ}_{Classic} = -0.0591/2 \cdot \log(1/[H_2O])^1 + \Delta E^{\circ} = 0.19 + 0.0515 + 0.10166 - 0.37239 = -0.02923 \text{ V};$$

$$\text{Sum: } E^{\circ}_{C_2H_5OH} - E^{\circ}_{NAD^+} = -0.02923 + 0.38373 = 0.3545 \text{ V, } n=2; \Delta G_{eq} = \Delta E^{\circ} \cdot F \cdot n = 0.3545 \cdot 96485 \cdot 2 = 68.4 \text{ kJ/mol};$$

By convention balanced n=2=m number of electrons 2e⁻ donors E^o_{NADH}=-0.38373 V plus acceptors of electrons E^o_{C₂H₅OH}=-0.02923 V, as -E^o_{NAD⁺}=0.38373 V accepting electrons from ethanol E^o_{C₂H₅OH}=-0.02923 V:

$$\Delta G_{eq} = -R \cdot T \cdot \ln(K_{eq}) = 68.4 \text{ kJ/mol}; K_{eq} = \frac{[NADH] \cdot [CH_3CHO] \cdot [H_3O^+]}{[NAD^+] \cdot [CH_3CH_2OH] \cdot [H_2O]} = e^{-\frac{\Delta G_{eq}}{R \cdot T}} = e^{-\frac{68408}{8.314 \cdot 298.15}} = 1.036 \cdot 10^{-12} = 10^{-11.985}$$



$$\Delta G_{Hess} = \Delta G^{\circ}_{CH_3CH_2OH} + \Delta G^{\circ}_{H_2O} + \Delta G^{\circ}_{NAD^+} - \Delta G^{\circ}_{H_3O} - \Delta G^{\circ}_{CH_3CHO} - \Delta G^{\circ}_{NADH} = -159.1 \text{ kJ/mol};$$

$$\Delta G_{Hess} = 75.2864 + 1059.11 - 237.191 - (32.2824 + 1175.5732 - 151.549) = -159.1 \text{ kJ/mol endoergic; [1]}$$

Red NADH=NAD⁺+H⁺(2e⁻); Expression of absolute potential has standard E^o_{Classic}=-0.113 V [22], water zero 0 and ΔE^o=0.10166-0.37239: E^o_{NADH}=E^o_{Classic}+0+ΔE^o=-0.113+0+0.10166-0.37239=-**0.38373 V**;

Ox CH₃CHO+2H₃O⁺+H⁺(2e⁻)=CH₃CH₂OH+ 2 H₂O; inverse standard potential -E^o_{CH₃CHO}=**0.02923 V**; [19];

Sum:

$$\Delta E^{\circ} = E^{\circ}_{NADH} - E^{\circ}_{CH_3CHO} = -0.38373 + 0.02923 = -0.3545 \text{ V, } \Delta G_{eq} = \Delta E^{\circ} \cdot F \cdot n = -0.3545 \text{ V} \cdot 2 \text{ mol} \cdot 96485 \text{ C/mol} = -68.4 \text{ kJ/mol};$$

By convention balanced n=2=m number of electrons 2e⁻ ΔE^o donors E^o_{NADH}=-0.38373 V plus electrons acceptor -E^o_{CH₃CHO}=0.02923 V, as -E^o_{CH₃CHO}=0.02923 V accepting electrons from vitamin E^o_{NADH}=-0.38373 V .

$$\Delta G_{eq} = -R \cdot T \cdot \ln(K_{eq}) = -68.408 \text{ kJ/mol}; K_{eq} = \frac{[NAD^+] \cdot [CH_3CH_2OH] \cdot [H_2O]}{[NADH] \cdot [CH_3CHO] \cdot [H_3O^+]} = e^{-\frac{\Delta G_{eq}}{R \cdot T}} = e^{-\frac{-68408}{8.314 \cdot 298.15}} = 9.65 \cdot 10^{11} = 10^{11.985}.$$

In aerobic organisms NADH oxidase with O₂_{aqua} perform ratio [NAD⁺]/[NADH]=10⁶;

$$\Delta G_{Homeostasis} = 68.408 + R \cdot T \cdot \ln(1 \cdot 10^{(-7.36)} / 10^6 / 1 / 55.3) = 68.408 - 86.2 = -17.8 \text{ kJ/mol}.$$

Aerobic due to ratio is [NAD⁺]/[NADH]=10³; ΔG_{Homeostasis}=68.408-69.08=-0.674 kJ/mol.

Equilibrium is shifted far to reactants as aerobic constant K_{eq}=10^{-11.985} and inverse

anaerobic constant K_{eq}=10^{11.985}. Aerobic endothermic and endoergic vitamin B₃ ethanol

oxidation Hess law free energy change positive ΔG_{Hess}=159 kJ/mol and inverse ethanal

anaerobic reduction negative ΔG_{Hess}=-159 kJ/mol, but minimizes reaching equilibrium

aerobic ΔG_{min}=ΔG_{eq}=68.4 kJ/mol and anaerobic

ΔG_{min}=ΔG_{eq}=-68.4 kJ/mol reaching equilibrium mixture

constants within inverse symmetry 10^{-11.985}=K_{eq} aerobic and anaerobic 10^{11.985}=K_{eq}.

Prigogine attractor is free energy change absolute minimum ΔG_{min} reaching

$$\text{equilibrium } \Delta G_{min} = 68.4 \text{ kJ/mol} = |\Delta G_{eq}| < |\Delta G_{Hess}| = 159 \text{ kJ/mol}.$$

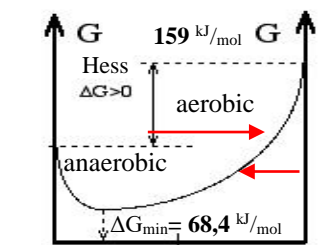
Anaerobic H₃C-CH=O+NADH+H₃O⁺=>H₃C-CH₂-OH+NAD⁺+H₂O+ΔG+Q;

Anaerobic ΔG_{eq}=ΔE^o•F•n=-0.3545 V•2 mol•96485 C/mol=-**68.408 kJ/mol** favored.

Insufficient low O₂_{aqua} concentration hypoxia to anaerobic alcohol oxidation unflavored

but ethanal reduction to ethanol favored [H₃CCH₂OH]/[H₃CCH=O]=1/10 reduction with

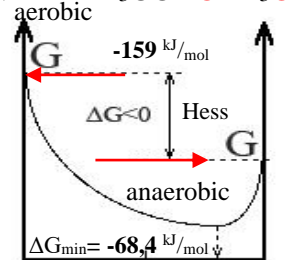
NADH reductase enzyme as negative free energy change ΔG_{Homeostasis}=-27.86 kJ/mol



A+B+C 50% D+E+F

reactants_ NAD⁺+H₃CCH₂OH+H₂O

products_ NADH+H₃CCHO+H₃O⁺



D+E+F 50% A+B+C

NADH+H₃CCHO+H₃O⁺

NAD⁺+H₃CCH₂OH+H₂O

Anaerobic homeostasis ratio [NADH]/[NAD⁺]=10 over [NAD⁺] favors reduction:

$$\Delta G_{Anaerobic} = -68.41 + 8.3144 \cdot 298.15 \cdot \ln(1 \cdot 1 \cdot 55.3 / 10 / 10 / 10^{(-7.36)}) = -27.86 \text{ kJ/mol};$$

Aerobic organisms K_{Aerobic} = $\frac{[NADH] \cdot [CH_3CHO] \cdot [H_3O^+]}{[NAD^+] \cdot [CH_3CH_2OH] \cdot [H_2O]}$ oxidation homeostasis ratio is [NADH]/[NAD⁺]=1/770;

$$\Delta G_{Homeostasis} = 68.408 + 8.3144 \cdot 298.15 \cdot \ln(1/770 \cdot 1/1 \cdot 10^{(-7.36)} / 55.3) = -0.026 \text{ kJ/mol}.$$

Table 1. Nernst's half reactions Standard Electrodes Potentials classic, Thermodynamic, Absolute Volts.

	Reduced form = Oxidized form + n e ⁻ ;	H ₂ O disaccount classic zero E _o	Thermodynamic scale on H ₂ O account	Absolute scale -0.37239
H	$\underline{\text{H(Pt)}} + \text{H}_2\text{O} = \text{H}_3\text{O}^+ + (\text{Pt}) + \text{e}^-$; scale reference potential [1]	classic zero 0	0.10166	-0.27072
	$\underline{\text{H(Pt)}} + \text{OH}^- = \text{H}_2\text{O} + (\text{Pt}) + \text{e}^-$; classic CRC [1]	-0.8277	-0.8282	-1.200576
	$\underline{\text{H(Pt)}} + \text{OH}^- = \text{H}_2\text{O} + (\text{Pt}) + \text{e}^-$; correction -0.10449 of classic [1]	-0.93219	-0.9326	-1.30507
	$\text{H}_{2\text{aq}} + 2\text{H}_2\text{O} = 2\text{H}_3\text{O}^+ + 2\text{e}^- + \text{H}_2\text{O}$; graphite electrode	0.4687	0.6733	0.302
O	$5\text{H}_2\text{O} = \text{O}_{2\text{aq}} + 4\text{H}_3\text{O}^+ + 4\text{e}^-$;	1.2288	1.4592	1.0868
	$\text{H}_2\text{O}_2 + 2\text{H}_2\text{O} = \text{O}_{2\text{aq}} + 2\text{H}_3\text{O}^+ + \text{e}^-$; David Harris [21]	1.2764	1.4811	1.1087
	$4\text{H}_2\text{O} = \text{H}_2\text{O}_2 + 2\text{H}_3\text{O}^+ + 2\text{e}^-$; Suchotina [17]	1.776	2.0837	1.7113
	$\text{H}_2\text{O}_{2\text{aq}} + 2\text{H}_2\text{O} = \text{O}_{2\text{aq}} + 2\text{H}_3\text{O}^+ + 2\text{e}^-$; University Alberta [19]	0.6945	0.8992	0.5268
	$\text{H}_2\text{O}_{2\text{aq}} + 2\text{H}_2\text{O} = \text{O}_{2\text{aq}} + 2\text{H}_3\text{O}^+ + 2\text{e}^-$; University Alberta [19]	0.6945	0.8477	0.4753
CHO	$\text{C}_6\text{H}_{12}\text{O}_6 + 42\text{H}_2\text{O} = 24\text{H}_3\text{O}^+ + 6\text{H}_3\text{O}^+ + 6\text{HCO}_3^- + 24\text{e}^-$; Kaksis	-0.04809	0.2338	-0.13858
	$\text{HOO} + \text{H}_2\text{O} = \text{O}_{2\text{aq}} + \text{H}_3\text{O}^+ + 2\text{e}^-$; Kaksis	0.3155	0.4429	0.07052
N	$\text{NO}_2^- + 2\text{OH}^- = \text{NO}_3^- + \text{H}_2\text{O} + 2\text{e}^-$; pH>3.15 Suchotina [17]	0.01	0.0602	-0.3122
	$\text{HNO}_2 + 4\text{H}_2\text{O} = \text{NO}_3^- + 3\text{H}_3\text{O}^+ + 2\text{e}^-$; pH<3.15 Kortly, Shucha [18]	0.94	1.2477	0.8753
	$\text{NO}_{\text{aq}} + 4\text{H}_2\text{O} = \text{HNO}_3 + 3\text{H}_3\text{O}^+ + 3\text{e}^-$; pH<1,4 Kortly, Shucha [18]	0.96	1.19899	0.8266
	$\text{NH}_4^+ + 13\text{H}_2\text{O} = \text{NO}_3^- + 10\text{H}_3\text{O}^+ + 8\text{e}^-$; Suchotina [17]	0.87	1.1391	0.7667
Br	$2\text{Br}^- = \text{Br}_2(\text{aq}) + 2\text{e}^-$; CRC [1]	1.0873	1.18896	0.8176
Bi	$\text{BiO}^+ + 6\text{H}_2\text{O} = \text{BiO}_3^- + 4\text{H}_3\text{O}^+ + 2\text{e}^-$; 1<pH<7 Suchotina [17]	1.80	2.21065	1.8383
Mn H ⁺	$\text{Mn}^{2+} + 12\text{H}_2\text{O} = \text{MnO}_4^- + 8\text{H}_3\text{O}^+ + 5\text{e}^-$; Kortly, Shucha [18]	1.51	1.85885	1.4865
H ₂ O	$\text{MnO}_2 + 4\text{OH}^- = \text{MnO}_4^- + 2\text{H}_2\text{O} + 3\text{e}^-$; Suchotina [17]	0.603	0.6360	0.2636
OH ⁻	$\text{MnO}_4^{2-} = \text{MnO}_4^- + \text{e}^-$; Suchotina [17]	0.558	0.65966	0.2873
Pb	$\text{Pb}^{2+} + 6\text{H}_2\text{O} = \text{PbO}_2(\text{s}) + 4\text{H}_3\text{O}^+ + 2\text{e}^-$; Kortly, Shucha [18]	1.455	1.86565	1.4933
	$\text{Pb} + \text{H}_2\text{O} = \text{Pb}^{2+} + 2\text{e}^-$; pH<7 Kortly, Shucha [18]	-0.126	0.02716	-0.3452
S	$\text{H}_2\text{SO}_{3\text{aq}} + 4\text{H}_2\text{O} = \text{HSO}_4^- + 3\text{H}_3\text{O}^+ + 2\text{e}^-$; pH<2 Suchotina [17]	0.172	0.47965	0.10726
	$\text{HSO}_3^- + 4\text{H}_2\text{O} = \text{SO}_4^{2-} + 3\text{H}_3\text{O}^+ + 2\text{e}^-$; Suchotina [17] 2=<pH<7	0.172	0.47965	0.10726
	$\text{SO}_3^{2-} + 2\text{OH}^- = \text{SO}_4^{2-} + \text{H}_2\text{O} + 2\text{e}^-$; Suchotina [17] pH > 7	-0.93	-0.87984	-1.2522
	$\text{S}^{2-} = \text{S}_{\text{rombic}} + \text{H}_2\text{O} + 2\text{e}^-$; CRC2010 [1]	-0.4763	-0.4261	-0.7985
	$\text{HS}^- + \text{OH}^- = \text{S}_{\text{rombic}} + 2\text{H}_2\text{O} + 2\text{e}^-$; CRC 2010 [1]	-0.478	-0.4793	-0.8517
	$\text{H}_2\text{S}_{\text{aq}} + 2\text{H}_2\text{O} = \text{S}_{\text{rombic}} + 2\text{H}_3\text{O}^+ + 2\text{e}^-$; CRC 2010 [1] Suchotina [17]	0.142	0.3467	-0.025735
	$2\text{S}_2\text{O}_3^{2-} = \text{S}_4\text{O}_6^{2-} + 2\text{e}^-$; Suchotina [17]	0.08	0.1817	-0.1907
Fe	$\text{Fe}^{2+} = \text{Fe}^{3+} + \text{e}^-$; Suchotina [17]	0.769	0.8707	0.4983
	$\text{Fe}(\text{s}) + \text{H}_2\text{O} = \text{Fe}^{2+} + 2\text{e}^-$; Suchotina [17]	-0.4402	-0.2870	-0.6594
Ag	$\text{Ag} + \text{H}_2\text{O} = \text{Ag}^+ + \text{e}^-$; Kortly, Shucha [18]	0.7994	1.00406	0.6327
	$\text{Ag}(\text{s}) + \text{Cl}^- = \text{AgCl}(\text{s}) + \text{H}_2\text{O} + \text{e}^-$; Kortly, Shucha [18]	0.2223	0.2210	-0.1514
	$\text{Ag} + 2\text{NH}_{3\text{aq}} = \text{Ag}(\text{NH}_3)_2^+ + \text{H}_2\text{O} + \text{e}^-$; Suchotina [17]	0.373	0.57766	0.2053
	$2\text{Ag} + 2\text{OH}^- = \text{Ag}_2\text{O}(\text{s}) + \text{H}_2\text{O} + 2\text{e}^-$; Suchotina [17]	0.345	0.49816	0.1258
Hg	$2\text{Hg} + \text{H}_2\text{O} = \text{Hg}_2^{2+} + 2\text{e}^-$; Kortly, Shucha [18]	0.907	1.0602	0.6888
	$2\text{Hg} + 2\text{Cl}^- = \text{Hg}_2\text{Cl}_2(\text{s}) + 2\text{H}_2\text{O} + 2\text{e}^-$; Suchotina ; [17]	0.2676	0.2663	-0.1059
	$2\text{Hg} + \text{SO}_4^{2-} = \text{Hg}_2\text{SO}_4(\text{s}) + \text{H}_2\text{O} + 2\text{e}^-$; Kortly, Shucha ; [18]	0.614	0.6642	0.2918
	$\text{Hg} + 2\text{OH}^- = \text{HgO} + \text{H}_2\text{O} + 2\text{e}^-$; Suchotina ; [17]	0.098	0.1482	-0.2242
I	$3\text{I}^- = \text{I}_3^- + 2\text{e}^-$; Kortly, Shucha [18]	0.6276	0.72926	0.35687
Cu	$\text{Cu}(\text{Hg}) + \text{H}_2\text{O} = \text{Cu}^{2+} + (\text{Hg}) + 2\text{e}^-$; Kortly, Shucha [18]	0.3435	0.4967	0.1243
F	$2\text{F}^- = \text{F}_2(\text{g}) + 2\text{e}^-$; Kortly, Shucha [18]	2.87	2.97166	2.5993
Cl	$2\text{Cl}^- = \text{Cl}_2(\text{g}) + 2\text{e}^-$; Kortly, Shucha [18]	1.358	1.45966	1.0873
Cl	$\text{Cl}_2(\text{g}) + 4\text{H}_2\text{O} = 2\text{HOCl} + 2\text{H}_3\text{O}^+ + 2\text{e}^-$; Kortly, Shucha [18]	1.63	1.93765	1.5653
Cr	$2\text{Cr}^{3+} + 21\text{H}_2\text{O} = \text{Cr}_2\text{O}_7^{2-} + 14\text{H}_3\text{O}^+ + 6\text{e}^-$; 1<pH<7 [18]	1.33	1.7921	1.41975
	$\text{Cr}^{3+} + 11\text{H}_2\text{O} = \text{HCrO}_4^- + 7\text{H}_3\text{O}^+ + 3\text{e}^-$; pH>7 Kortly, Shucha [18]	1.20	1.6793	1.30692
	$\text{Cr}(\text{OH})_3 + 5\text{OH}^- = \text{CrO}_4^{2-} + 4\text{H}_2\text{O} + 3\text{e}^-$; pH>9 ; Suchotina [17]	-0.13	-0.1657	-0.53806
C	$\text{H}_2\text{C}_2\text{O}_4 + 2\text{H}_2\text{O} = 2\text{CO}_2 + 2\text{H}_3\text{O}^+ + 2\text{e}^-$; pH<1,25 Suchotina [17]	-0.49	-0.2853	-0.6577
Cr	$\text{Cr} + \text{H}_2\text{O} = \text{Cr}^{3+} + 3\text{e}^-$; Suchotina [17]	-0.744	-0.60801	-0.97935
Zn	$\text{Zn} + \text{H}_2\text{O} = \text{Zn}^{2+} + 2\text{e}^-$; Kortly, Shucha [18]	-0.7628	-0.6096	-0.98098
Al	$\text{Al} + \text{H}_2\text{O} = \text{Al}^{3+} + 3\text{e}^-$; CRC [1]	-1.662	-1.5260	-1.8984
	$\text{Al} + 4\text{OH}^- = \text{H}_2\text{AlO}_3^- + \text{H}_2\text{O} + 3\text{e}^-$; CRC[1]	-2.33	-2.2627	-2.63506

$\underline{\text{H(Pt)}} + \text{OH}^- = \text{H}_2\text{O} + (\text{Pt}) + \text{e}^-$; CRC [1]

$E^\circ_{\text{H-OH}} = E^\circ - 0.0591/1 * \lg([\text{H}_2\text{O}]^1) + 0.10166 - 0.37239 = -0.8277 - 0.0591/1 * \lg(53.5^1) + 0.10166 - 0.37239 = -1.200576 \text{ V}$

$\Delta G_{\text{Hess, H(Pt)_OH}} = G_{\text{H}_2\text{O}} - (G_{\text{PtH}} + G_{\text{OH}}) = 0 - (48.56 + 77.36) = -125.92 \text{ kJ/mol}$;

$\Delta G_{\text{eqH-OH}} = E^\circ_{\text{H-OH}} \cdot F \cdot 1 = -1.2005757 * 96485 * 1 = -125.92 \text{ kJ/mol}$;

Corrected $E^\circ_{\text{H-OH}} = \Delta G_{\text{eqH-OH}} / F = -125920 / 96485 = -1.30507 \text{ V}$;

Correction $\Delta E^\circ_{\text{H-OH}} = (-1.30507 - 1.2005757) = -0.10449 \text{ V}$ on absolute potential scale synchronized on Alberty data at pH=7,36 of absolute free energy scale related to the zero free energy content of water $G_{\text{H}_2\text{O}} = 0 \text{ kJ/mol}$.

Table 1. Nernst's and inverse half-reactions	Standard potentials E° Data from [1-24]	Classic water disaccount 0	Thermodynamic. scale 0.10166 V	Absolute -0.37239
$\text{OH}^- = \text{HO} + e^-$	CRC	2.020	2.1217	1.750321
$4\text{H}_2\text{O} = \text{H}_2\text{O}_{2\text{aq}} + 2\text{H}_3\text{O}^+ + 2e^-$	Suchotina	1.776	2.0837	1.7113
$\text{H}_2\text{O}_2 + 2\text{H}_2\text{O} = \text{O}_{2\text{aq}} + 2\text{H}_3\text{O}^+ + e^-$	David Harris	1.276	1.4811	1.1087
$5\text{H}_2\text{O} = \text{O}_{2\text{aq}} + 4\text{H}_3\text{O}^+ + 4e^-$;		1.2288	1.4592	1.0868
$\text{HN}\text{O}_2 + 4\text{H}_2\text{O} = \text{NO}_3^- + 3\text{H}_3\text{O}^+ + 2e^-$; pH<3.15	Kortly, Shucha	0.94	1.2477	0.8753
$\text{NO}_2^- + 3\text{H}_2\text{O} = \text{NO}_3^- + 2\text{H}_3\text{O}^+ + 2e^-$	David Harris [21]	0.835	1.09115	0.7188
Hydroquinone+2H ₂ O=p-quinone+2H ₃ O ⁺ +2e ⁻		0.699	0.9041	0.5327
$\text{H}_2\text{O}_{2\text{aq}} + 2\text{H}_2\text{O} = \text{O}_{2\text{aq}} + 2\text{H}_3\text{O}^+ + 2e^-$	University Alberta	0.695	0.8992	0.5268
$\text{H}_2\text{O}_{2\text{aq}} + \text{H}_2\text{O} = \text{O}_{2\text{aq}} + 2\text{H}_3\text{O}^+ + 2e^-$	University Alberta	0.695	0.8477	0.4753
$\text{Fe}^{2+} = \text{Fe}^{3+} + e^-$	University Alberta	0.769	0.8707	0.4983
Ubiquinol+2H ₂ O=Ubiquinone+2H ₃ O ⁺ +2e ⁻		0.459	0.6638	0.2924
$\text{Succinate}^{2-} + 2\text{H}_2\text{O} = \text{Fumarate}^{2-} + 2\text{H}_3\text{O}^+ + 2e^-$		0.4447	0.6494	0.2780
$\text{ButyrylCoA} + 2\text{H}_2\text{O} = \text{CrotonylCoA} + 2\text{H}_3\text{O}^+ + 2e^-$		0.399	0.6038	0.2056
$\text{AscorbicAcid} + 2\text{H}_2\text{O} = \text{C}_6\text{H}_6\text{O}_6 + 2\text{H}_3\text{O}^+ + 2e^-$	DC.Harris [22]	0.390	0.5947	0.1965
glycolate+2H ₂ O=Glyoxylate+H ⁺ +H ₃ O ⁺	D.C.Harris	0.324	0.5287	0.1305
$\text{C}_6\text{H}_{12}\text{O}_6 + 42\text{H}_2\text{O} = 24\text{H}_3\text{O}^+ + 6\text{H}_3\text{O}^+ + 6\text{HCO}_3^- + 24e^-$;		-0.0491	0.2338	-0.1386
$\text{HO}_2^- + \text{H}_2\text{O} = \text{O}_{2\text{aq}} + \text{H}_3\text{O}^+ + 2e^-$	Aris Kaksis	0.3155	0.4429	0.07052
$\text{Fe}^{2+} = \text{Cytochrome F Fe}^{3+} + e^-$	David Harris	0.365	0.4667	0.0953
$[\text{Fe}^{\text{II}}(\text{CN})_6]^{4-} = [\text{Fe}^{\text{III}}(\text{CN})_6]^{3-} + e^-$	University Alberta	0.356	0.4574	0.0860
$\text{Malate}^{2-} + 2\text{H}_2\text{O} = \text{Oxalo-acetate}^{2-} + 2\text{H}_3\text{O}^+ + 2e^-$		0.248	0.4528	0.0814
$\text{Fe}^{2+} = \text{Cytochrome a3 Fe}^{3+} + e^-$		0.350	0.4517	0.0803
$\text{Lactate}^- + \text{H}_2\text{O} = \text{Pyruvate}^- + \text{H}_3\text{O}^+ + \text{H}^+ (\text{H}^+ + 2e^-)$		0.229	0.3823	0.0109
$\text{FADH}_2 + 2\text{H}_2\text{O} = \text{FADfree} + 2\text{H}_3\text{O}^+ + 2e^-$;		0.195	0.3998	0.0284
$\text{CH}_3\text{COO}^- + 2\text{H}_2\text{O} = \text{glycolate} + \text{H}^- + \text{H}_3\text{O}^+$;	D.C.Harris	0.1605	0.3652	-0.00618
$\text{H}_2\text{S}_{\text{aq}} + 2\text{H}_2\text{O} = \text{S}_{\text{rhombic}} + 2\text{H}_3\text{O}^+ + 2e^-$;	CRC 2010	0.142	0.3467	-0.025735
$\text{CH}_3\text{CH}_2\text{OH} + \text{H}_2\text{O} = \text{CH}_3\text{CHO} + \text{H}_3\text{O}^+ + \text{H}^- (\text{H}^+ + 2e^-)$;		0.19	0.3432	-0.02923
$\text{Fe}^{2+} = \text{Cytochrome a Fe}^{3+} + e^-$		0.2900	0.3917	0.02032
$2\text{GlutathSH} + 2\text{H}_2\text{O} = \text{GlutaS-Sthione} + 2\text{H}_3\text{O}^+ + 2e^-$		0.1841	0.3888	0.01742
$\text{Fe}^{2+} = \text{Cytochrome c Fe}^{3+} + e^-$		0.2540	0.3557	-0.01568
$\text{LipSHSH} + 2\text{H}_2\text{O} = \text{LipoicAcidS-S} + 2\text{H}_3\text{O}^+ + 2e^-$		0.1241	0.3288	-0.04258
$\text{Fe}^{2+} = \text{Cytochrome c1 Fe}^{3+} + e^-$		0.2200	0.3217	-0.04968
$\beta\text{-OH Butyrate}^- + 2\text{H}_2\text{O} = \text{AcetoAcetate}^- + 2\text{H}_3\text{O}^+ + 2e^-$		0.0681	0.2728	-0.09858
$\text{isocitrate}^{2-} + 2\text{H}_2\text{O} = \alpha\text{-Ketoglutarate}^{2-} + \text{CO}_2 + 2\text{H}_3\text{O}^+ + 2e^-$		0.0341	0.2388	-0.13258
Nernst's $\text{H}_{2\text{aq}} + \text{H}_2\text{O} = 2\text{H}_3\text{O}^+ + 2e^-$; $\Delta G_{\text{Hess, H}_3\text{O}^+} = -58.36 \text{ kJ/mol}$		on graphite electrode oxidation		-0.302
Inverse: $2\text{H}_3\text{O}^+ + 2e^- = \text{H}_{2\text{aq}} + \text{H}_2\text{O}$; $\Delta G_{\text{Hess, H}_{2\text{aq}}} = 58.36 \text{ kJ/mol}$		on graphite electrode reduction		0.302
$\text{H}_{2\text{aq}} = 2\text{H}(\text{Pt}) + \text{H}_2\text{O}$; $\Delta G_{\text{Sp, H}(\text{Pt})} = 2G_{\text{H}(\text{Pt})} + G_{\text{H}_2\text{O}} - (G_{\text{H}_{2\text{aq}}}) = -6.12 \text{ kJ/mol}$		$K_{\text{Sp, H}(\text{Pt})} = \frac{[\text{H}(\text{Pt})]^2 * [\text{H}_2\text{O}]}{[\text{H}_{2\text{aq}}]} = 11.8$		
$\text{H}(\text{Pt}) + \text{H}_2\text{O} = \text{H}_3\text{O}^+ + e^-$; classic zero; at $[\text{H}_2\text{SO}_4] = 1 \text{ M}$, PH=0		0.0000	0.10166	-0.27072
$\text{Luciferin} + \text{OH}^- = ?\text{luciferin} + \text{CO}_2 + \text{O}_2 + \text{OH}^- + 3\text{H} (3\text{H}^+ + 3e^-) + e^-$		0	0.1017	-0.27073
$\text{Fe}^{2+} = \text{Cytochrome b Fe}^{3+} + e^-$		0.0770	0.1787	-0.1937
$\text{CH}_3\text{CHO} + 3\text{H}_2\text{O} = \text{CH}_3\text{COOH} + 2\text{H}_3\text{O}^+ + 2e^-$	Suchotina	-0.1180	0.1382	-0.2342
$\text{Glycaldeh3-P}^{2-} + \text{H}_2\text{O} + \text{HPO}_4^{2-} = 13\text{PGlycerate}^{4-} + \text{H}_3\text{O}^+ + \text{H}^-$;		-0.1314	0.0218	-0.3506
$\text{NADPH} = \text{NADP}^+ + \text{H}^+ (\text{H}^+ + 2e^-)$;		-0.1170	-0.0153	-0.3877
$\text{NADH} = \text{NAD}^+ + \text{H}^+ (\text{H}^+ + 2e^-)$;	David Harris	-0.1130	-0.0113	-0.3837
$\text{O}_{2\text{aq}} = \text{O}_{2\text{aq}} + e^-$	Suchotina	-0.2450	-0.1433	-0.5157
$\text{Ferredoxin Fe}^{2+} = \text{Ferredoxin Fe}^{3+} + e^-$		-0.4320	-0.3303	-0.7027
$\text{C}_6\text{H}_{12}\text{O}_6 + 4\text{H}_2\text{O} = 2\text{C}_3\text{H}_4\text{O}_3 + 4\text{H}_3\text{O}^+ + 4e^-$	Stryer	-0.5427	-0.3380	-0.7104
$\text{S}^{2-} = \text{S}_{\text{rhombic}} + 2e^-$;	CRC 2010	-0.4763	-0.3746	-0.7470
$\text{HS}^- + \text{OH}^- = \text{S}_{\text{rhombic}} + \text{H}_2\text{O} + 2e^-$;	CRC 2010	-0.4780	-0.4278	-0.8002
$\text{H}(\text{Pt}) + \text{OH}^- = \text{H}_2\text{O} + e^-$ [17] corrected (-0.8277+-0.10449)=		-0.9322	-0.9335	-1.3059
$\text{Ubiquinol6} + 2\text{H}_2\text{O} = \text{Ubiquinone6} + 2\text{H}_3\text{O}^+ + 2e^-$	CRC 2012	-1.0500	-0.8453	-1.2177

$\Delta G_{\text{Alberty H-OH}} = G_{\text{H}_2\text{O}} - (G_{\text{H}(\text{Pt})} + G_{\text{OH}^-}) = 0 - (48.56 + 77.36) = -125.92 \text{ kJ/mol}$, $E^\circ_{\text{H}} = \Delta G_{\text{Eq}} / F / 1 = -125920 / 96485 / 1 = -1.30508 \text{ V}$
data corrected $\Delta G_{\text{Eq, H-OH}} = E^\circ_{\text{H-OH}} \cdot F \cdot 1 = -1.30508 * 96485 * 1 = -125.92 \text{ kJ/mol}$ to $E^\circ_{\text{H}} = -0.8277 - 0.10556 = -0.9322 \text{ V}$.

Table 2. Nernst's reactions Standard Electrodes Potentials classic, Thermodynamic and absolute Volts

	Reduced form = Oxidized form	H ₂ O disaccount classic zero E°=0	Thermodynamic. scale E°=0.10166 V	Absolut scale E° -0.37239 V
H	H(Pt)+H₂O=H₃O⁺+(Pt)+e⁻ ; scale reference potential [1]	classic zero 0	0.10166	-0.27072
N	NO₂⁻+2OH⁻=NO₃⁻+H₂O+2e⁻ ; pH>3.15 Suchotina [17]	0.01	0.0602	-0.3122
	HN₂O₂+4H₂O=NO₃⁻+3H₃O⁺+2e⁻ ; pH<3.15 Kortly, Shucha	0.94	1.2477	0.8753
	NO_{aq}+4H₂O=HN₂O₂+3H₃O⁺+3e⁻ ; pH<1,4 Kortly, Shucha	0.96	1,19899	0,8266
	NH₄⁺+13H₂O=NO₃⁻+10H₃O⁺+8e⁻ ; Suchotina [17]	0.87	1.1391	0.7667
Br	2Br⁻=Br₂(aq)+2e⁻ ; CRC	1.0873	1.18896	0.8176
Bi	BiO⁺+6H₂O=BiO₃+4H₃O⁺+2e⁻ ; 1<pH<7 Suchotina [17]	1.80	2.21065	1.8393
Mn H⁺	Mn²⁺+12H₂O=MnO₄+8H₃O⁺+5e⁻ ; Kortly, Shucha [18]	1.51	1.85885	1.4865
	MnO₂↓+4OH⁻=MnO₄⁻+2H₂O+3e⁻ ; Suchotina	0.603	0.6360	0.2636
	MnO₄²⁻=MnO₄⁻+e⁻ ; Suchotina	0.558	0.65966	0.2873
Pb	Pb²⁺+6H₂O=PbO₂(s)+4H₃O⁺+2e⁻ ; Kortly, Shucha	1.455	1.86565	1.4933
S	H₂SO_{3aq}+3H₂O=HSO₄⁻+3H₃O⁺+2e⁻ ;	0.172	0.47965	0.10726
	HSO₃⁻+4H₂O=SO₄²⁻+3H₃O⁺+2e⁻ ; Suchotina 2=<pH<7	0.172	0.47965	0.10726
	SO₃²⁻+2OH⁻=SO₄²⁻+H₂O+2e⁻ ; Suchotina pH > 7	-0.93	-0.87984	-1.2522
	S²⁻=S_{rombic}+H₂O + 2 e⁻ ; CRC2010	-0.4763	-0.4261	-0.7985
	H₂S_{aq}+2H₂O=S_{rombic}+2H₃O⁺+2e⁻ ; CRC 2010: Suchotina	0.142	-0.4793	-0.8517
2S₂O₃²⁻=S₄O₆²⁻+2e⁻ ; Suchotina	0.08	0.3467	-0.025735	
Fe	Fe²⁺=Fe³⁺+e⁻ ; Suchotina [17]	0.769	0.8707	0.4983
	Fe(s)+H₂O=Fe²⁺+2e⁻ ; Suchotina	-0.4402	-0.2870	-0.6594
Ag	Ag+H₂O=Ag⁺+e⁻ ; Kortly, Shucha [18]	0.7994	1.00406	0.6327
	Ag(s)+Cl⁻=AgCl(s)+H₂O+e⁻ ; Kortly, Shucha	0.2223	0.2210	-0.1514
	Ag+2NH_{3aq}=Ag(NH₃)₂⁺+H₂O+e⁻ ; Suchotina	0.373	0,57766	0,2053
	2Ag+2OH⁻=Ag₂O(s)+H₂O+2e⁻ ; Suchotina	0.345	0,49816	0,1258
I	3I⁻=I₃⁻+2e⁻ ; Kortly, Shucha	0.6276	0.72926	0.35687
Cu	Cu(Hg)+H₂O=Cu²⁺+(Hg)+2e⁻ ; Kortly, Shucha	0.3435	0.4967	0.1243
F	2F⁻=F₂(g)+2e⁻ ; Kortly, Shucha	2.87	2.97166	2.5993
Cl	2Cl⁻=Cl₂(g)+2e⁻ ; Kortly, Shucha	1.358	1.45966	1.0873
	Cl₂(g)+4H₂O=2HOCl+2H₃O⁺+2e⁻ ; Kortly, Shucha	1.63	1.93765	1.5653
Cr	2Cr³⁺+21H₂O=Cr₂O₇²⁻+14H₃O⁺+6e⁻ ; 1<pH<7 [18]	1.33	1.7921	1.41975
	Cr³⁺+11H₂O=HCrO₄⁻+7H₃O⁺+3e⁻ ; pH>7 Kortly, Shucha	1.20	1.6793	1.30692
	Cr(OH)₃↓+5OH⁻=CrO₄²⁻+4H₂O+3e⁻ ; pH>9 ; Suchotina	-0.13	-0.1657	-0.53806
C	H₂C₂O₄+2H₂O=2CO₂+2H₃O⁺+2e⁻ ; pH<1.25 Suchotina [17]	-0.49	-0.2853	-0.6577
Cr	Cr+H₂O=Cr³⁺+3e⁻ ; Suchotina	-0.744	-0.60801	-0.97935
Zn	Zn+H₂O=Zn²⁺+2e⁻ ; Kortly, Shucha	-0.7628	-0.6096	-0.98098
H	H(Pt)+OH⁻=H₂O+(Pt)+e⁻ ; corrected (-0.8277+-0.10449)=	-0.9322	-0.93375	-1.30508

Hess **zero** standard values of free elements on Biochemistry absolute free energy scale actually are positive.

$G_{H_2\text{gas}}=85.6 \text{ kJ/mol}$ [Alberty](#) referring to homeostasis products water and $C_{O_2\text{gas}}$ zero $G_{H_2O}=G_{CO_2\text{gas}}=0 \text{ kJ/mol}$.

The free energy contents of the presented metabolites at homeostasis pH=7.36, which refers to zero values of water and $C_{O_2\text{gas}}$ gas on the energy scale, are:

Glucose $G_{C_6H_{12}O_6}=1978 \text{ kJ/mol}$ > deprotonate peroxide anion $G_{HO_2^-}=338.8 \text{ kJ/mol}$ > $G_{O_2\text{aqua}}=330 \text{ kJ/mol}$ >

> $G_{O_2\text{gas}}=303 \text{ kJ/mol}$ > peroxide $G_{H_2O_2}=284.3 \text{ kJ/mol}$ >

> protolysis of water pH=pOH=7 $G_{H_3O^++OH^-}=G_{H_3O^+}+G_{OH^-}=22.44+77.36=99.8 \text{ kJ/mol}$ >

> $G_{NH_3\text{aq}}=91.1 \text{ kJ/mol}$ > $G_{O_2\text{Biochem_arterial}}=88.22 \text{ kJ/mol}$ > $G_{H_2\text{gas}}=85.6 \text{ kJ/mol} \equiv G_{H_2O_Biochemistry}=85.6 \text{ kJ/mol}$ >

> protolysis of $C_{O_2\text{aqua}}$ solution by Carbonic Anhydrase $G_{H_3O^+}+G_{HCO_3^-}=G_{H_3O^+}+G_{HCO_3^-}=22.44+56.08=78.5 \text{ kJ/mol}$ >

> $G_{H_2S\text{aqua}}=53.4 \text{ kJ/mol}$ > $G_{NH_4^+}=50.81 \text{ kJ/mol}$ > $G_{H(Pt)}=48.56 \text{ kJ/mol}$ > $G_{N_2\text{aqua}}=18.7 \text{ kJ/mol}$ > $G_{CO_2\text{aqua}}=18.38 \text{ kJ/mol}$ >

> $G_{S\text{rhombohedral}}=3.54 \text{ kJ/mol}$ > homeostasis products zero values $G_{H_2O}=G_{CO_2\text{gas}}=0 \text{ kJ/mol}$ > $G_{N_2\text{gas}}=-9.55 \text{ kJ/mol}$;

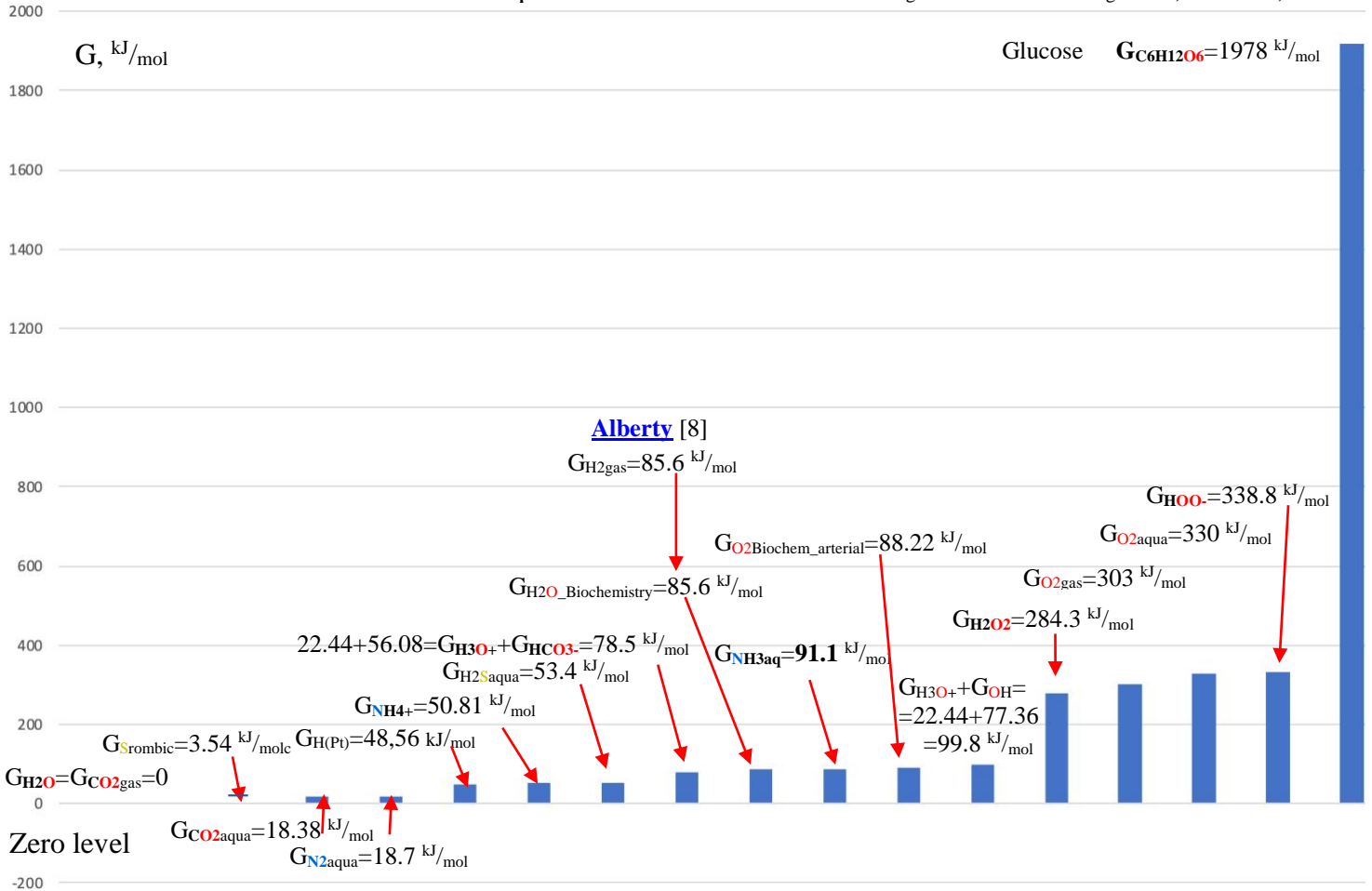


Figure 1. Ascending **Absolute** Free Energy of metabolites relative to $G_{H_2O}=G_{CO_2\text{gas}}=0 \text{ kJ/mol}$ zero values.

Discovery of **Absolute potential scale** is instrument coincident with **Absolute** Free Energy for sciences.

The discovery in science of **Absolute Potentials scale** coincides with **Absolute** Free Energy meaning.

The water and hydroxonium disaccount in reactions including protolysis and electrochemistry Nernst's half reactions restrict the scientific studies of Thermodynamic, Physical Chemistry and Biochemistry. [8,14,15]

The thermodynamic property of **inversion symmetry** is a direct reaction between reactants and products that flips in the opposite direction, initially meaning products as reactants and leaving reactants as final products. Water to oxygen oxidation reduction $5H_2O=O_{2\text{aqua}}+4H_3O^++4e^-$ Nernst's half reaction has **Absolute standard Potential**: $E^{\circ}_{O_2\text{Absolute}}=1.0868 \text{ V}$. About $O_{2\text{aqua}}+4H_3O^++4e^-=5H_2O$ **inverse** reaction implication in **Absolute Potential** it has the same number with opposite sign $-E^{\circ}_{O_2\text{Absolute}}=-1.0868 \text{ V}$ negative.

Discovered the **Absolute Potential scale** for Nernst's or **inverse** reactions is coincident with **absolute** Free Energy property the **inverse symmetry**. [8, 14, 15] **Inverse symmetry** property of Nernst's or **inverse** reactions with **identical values** but with **opposite sign** manifests itself mutually in **Absolute Potential scale** with **Absolute** Free Energy is coincident thermodynamic property for protolytic, Nernst's half or **inverse** reaction. Corrected Thermodynamic standard potential reference of metal hydrogen 0.10166 Volts in few years give the impulse for sciences get **Absolute** thermodynamic values Free Energy of elements and molecules. Behalf of Alberty given data about Hydrogen **Absolute** Free Energy $G_{H_2\text{gas}}=85.6 \text{ kJ/mol}$, $G_{H_2\text{aqua}}=103 \text{ kJ/mol}$ is detected

Absolute standard Potential as general reference of hydrogen electrode $E^\circ_{\text{H}}=-0.27073$ Volts. Table 1. presents 50 in Biochemistry used Nernst's oxidation half and reduction **inverse** reactions.

In three columns we can observe the development hydrogen general reference scale from classic zero $E^\circ_{\text{H}}=0$ V with water disaccount. Accounting the water and hydroxonium cation corrected the general hydrogen thermodynamic standard potential scale reference to $E^\circ_{\text{H}}=0.10166$ Volts. Third Alberty data finally lead to **Absolute standard Potential** value $E^\circ_{\text{H}}=-0.27073$ Volts of hydrogen electrode.

$$\text{H}_2\text{O}_2 \text{ formation } 41^{\text{st}} \text{ page } \text{H}_{2\text{gas}} + \text{O}_{2\text{gas}} \Rightarrow \text{H}_2\text{O}_2; \Delta G^\circ_{\text{UnivAlberty}} = -134.03 \text{ kJ/mol}; \Delta G^\circ_{\text{Alberty}} = -48.39 \text{ kJ/mol};$$

$$\Delta G_{\text{Alberty}} = G_{\text{H}_2\text{O}_2} - (G_{\text{O}_2\text{gas}} + G_{\text{H}_2\text{gas}}) = 284 - (85.64 + 303) = -104.64 \text{ kJ/mol} (-134.03 \text{ kJ/mol}) = (-48.39 \text{ kJ/mol})$$

Viela	$\Delta H^\circ_{\text{H}}$ kJ/mol	$\Delta S^\circ_{\text{H}}$ J/mol/K	$\Delta G^\circ_{\text{H}}$ kJ/mol
H₂O₂_{aqua}	-191.99	-481.688	-48.39
H ₂ O ₂ _{aqua}	-191.17	143.9	-134.03
Succinat²⁻	-908.69	-1295.576	-522.414
Fumarate²⁻	-776.56	-862.288	-519.4688

$G_{\text{H}_2\text{O}_2} = 279,29$ kJ/mo Alberty zero $G_{\text{H}_2\text{O}} = 0$ kJ/mol; reference University Alberta
 $G_{\text{SuccinatFor}} = -522.4 + (4*91.26 + 2*85.6 + 2*303) = 619.8$ kJ/mol;
 $G_{\text{Succinat}} = 650.8$ kJ/mol;
 $G_{\text{FumaricFor}} = -519.5 + (4*91.26 + 85.6 + 2*303) = 537.1$ kJ/mol;
 $G_{\text{Fumarat}} = 554.75$ kJ/mol;

Succinat²⁻ Formation $4\text{C} + 2\text{H}_{2\text{gas}} + 2\text{O}_{2\text{gas}} \Rightarrow (\text{CH}_2)_2(\text{CO}_2^-)(\text{CO}_2^-)$; $\Delta G_{\text{Succinat}} = -522.4$ kJ/mol Alberty;

$$\Delta G_{\text{SuccinatFor}} = G_{\text{SuccinatFor}} - (4G_{\text{Cgraph}} + 2*G_{\text{H}_2\text{gas}} + 2*G_{\text{O}_2\text{gas}}) = -522.4 \text{ kJ/mol};$$

$$G_{\text{SuccinatFor}} = -522.4 + (4*91.26 + 2*85.6 + 2*303) = 619.8 \text{ kJ/mol};$$

Fumarate²⁻ Formation $4\text{C} + \text{H}_{2\text{gas}} + 2\text{O}_{2\text{gas}} \Rightarrow (\text{CH})_2(\text{CO}_2^-)(\text{CO}_2^-)$; $\Delta G_{\text{Fumarat}} = -519.5$ kJ/mol Alberty;

$$\Delta G_{\text{Fumarat}} = G_{\text{FumaratFor}} - (4G_{\text{Cgraph}} + G_{\text{H}_2\text{gas}} + 2*G_{\text{O}_2\text{gas}}) = -519.5 \text{ kJ/mol};$$

$$G_{\text{FumaratFor}} = -519.5 + (4*91.26 + 85.6 + 2*303) = 537.1 \text{ kJ/mol}; \text{ formation } 73^{\text{rd}} \text{ page}$$

Inverse $\text{O}_{2\text{aqua}} + 2\text{H}_3\text{O}^+ + 2\text{e}^- = \text{H}_2\text{O}_{2\text{aqua}} + 2\text{H}_2\text{O}$; standard potential $E^\circ_{\text{OxO}_2\text{H}_2\text{O}_2} = -0.5278$ V University Alberta;

$$\Delta G_{\text{AlbertyHessOxO}_2\text{H}_2\text{O}_2} = G_{\text{H}_2\text{O}_2} + 2*G_{\text{H}_2\text{O}} - (G_{\text{O}_2\text{aqua}} + 2*G_{\text{H}_3\text{O}^+}) = 279,29 + 2*0 - (330 + 2*22.44) = -95.59 \text{ kJ/mol};$$

$$\Delta G_{\text{eqAlbertyAbsoluteOxO}_2\text{H}_2\text{O}_2} = E^\circ_{\text{eqOxO}_2\text{H}_2\text{O}_2} * F * 1 * 2 = -0.5278 * 96485 * 2 = -101,85 \text{ kJ/mol};$$

Succinat²⁻ + O₂_{aqua} => fumarate²⁻ + H₂O₂_{aqua} + Q + ΔG; $\Delta G_{\text{min}} = \Delta G_{\text{eqSuccinat}_\text{H}_2\text{O}_2} = -38.3$ kJ/mol;

$$\Delta G_{\text{Hess}} = \Delta G^\circ_{\text{H}_2\text{O}_2} + \Delta G^\circ_{\text{fumarat}} - \Delta G^\circ_{\text{O}_2} - \Delta G^\circ_{\text{Succinat}} = -48.39 - 519.4688 - (16.4 - 522.414) = -61.845 \text{ kJ/mol};$$

$$\Delta G_{\text{min}} = \Delta G_{\text{eq}} = (E^\circ_{\text{RedSuccinate}} - E^\circ_{\text{OxO}_2}) * F * n = (0.2512 - 0.4495) * 96485 * 2 = (-0.1983) * 96485 * 2 = -38.3 \text{ kJ/mol};$$

$$\text{Alberty Hess } \Delta G_{\text{Succinat}_\text{H}_2\text{O}_2} = G_{\text{Fumarat}} + G_{\text{H}_2\text{O}_2} - (G_{\text{Succinat}} + G_{\text{O}_2\text{aqua}}) = 537.1 + 279,29.24 - (619.8 + 330) = -128.5 \text{ kJ/mol};$$

$$K_{\text{eq}} = \exp(-\Delta G_{\text{eq}}/R/T) = \exp(38270/8.3144/298.15) = 5065991 \text{ spontaneous } 58^{\text{th}} \text{ page}$$

The concepts of **Absolute** thermodynamic parameters temperature, free energy and potentia. are **absolutely** reciprocal tools for revealing the structural details of parallel and sequential complex reactions by exploiting inversion symmetry properties.

1. **Absolute** temperature T in Kelwin degree is standard value 298.15 K (25 ° C),

Lord Kelvin



2. On Alberty based **Absolute** free energy content

$G_{\text{H}_2\text{gas}} = 85.6$ kJ/mol for hydrogen gas, it's solution in water $G_{\text{H}_2\text{aqua}} = 103$ kJ/mol and

for [metal](#) hydrogen $G_{\text{H(Pt)}} = 48,46$ kJ/mol

referring to zero reference $G_{\text{H}_2\text{O}} = G_{\text{CO}_2\text{gas}} = 0$ kJ/mol as background

in water and carbon dioxide gas $\text{CO}_{2\text{gas}}$.

Alberty Robert



3. Discovery **Absolute Potential** scale.

Absolute Potential scale based on a general reference

of metal hydrogen **Absolute** standard **Potential** $E^\circ_{\text{H}} = -0.2965$ Volts. [8, 14, 15]

feasible

CH₃CH₂OH ethanol formation from elements:

$$2\text{C}+3\text{H}_{2\text{gas}}+1/2\text{O}_{2\text{gas}}\Rightarrow\text{CH}_3\text{CH}_2\text{OH}; \Delta G^\circ_{\text{Alberty}}=75.2864 \text{ kJ/mol}; \Delta G^\circ_{\text{HessCRC}}=-181 \text{ kJ/mol};$$

$$\Delta G^\circ_{\text{Alberty}}=G_{\text{CH}_3\text{CH}_2\text{OH}}-(2G_{\text{Cgraph}}+3G_{\text{H}_2\text{gas}}+1/2G_{\text{O}_2\text{gas}})=75.2864 \text{ kJ/mol};$$

$$\Delta G^\circ_{\text{CRC}}=G_{\text{CH}_3\text{CH}_2\text{OH}}-(2G_{\text{Cgraph}}+3G_{\text{H}_2\text{gas}}+1/2G_{\text{O}_2\text{gas}})=-181 \text{ kJ/mol};$$

$$\Delta G^\circ_{\text{Alberty}}+(2G_{\text{Cgraph}}+3G_{\text{H}_2\text{gas}}+1/2G_{\text{O}_2\text{gas}})=75.2864+(2*91.26+3*85.6+1/2*303)=G_{\text{CH}_3\text{CH}_2\text{OH}}=666.106 \text{ kJ/mol};$$

$$\Delta G^\circ_{\text{CRC}}+(2G_{\text{Cgraph}}+3G_{\text{H}_2\text{gas}}+1/2G_{\text{O}_2\text{gas}})=-181+(2*91.26+3*85.6+1/2*303)=G_{\text{CH}_3\text{CH}_2\text{OH}}=409.82 \text{ kJ/mol};$$

CH₃CHO acetaldehyde formation from elements: $2\text{C}+2\text{H}_{2\text{gas}}+1/2\text{O}_{2\text{gas}}\Rightarrow\text{CH}_3\text{CHO};$

$$\Delta G^\circ_{\text{Alberty}}=G_{\text{CH}_3\text{CHO}}-(2G_{\text{Cgraph}}+2G_{\text{H}_2\text{gas}}+1/2G_{\text{O}_2\text{gas}})=32.282 \text{ kJ/mol};$$

$$\Delta G^\circ_{\text{CRC}}=G_{\text{CH}_3\text{CHO}}-(2G_{\text{Cgraph}}+2G_{\text{H}_2\text{gas}}+1/2G_{\text{O}_2\text{gas}})=24.06 \text{ kJ/mol};$$

$$\Delta G^\circ_{\text{Alberty}}+(2G_{\text{Cgraph}}+2G_{\text{H}_2\text{gas}}+1/2G_{\text{O}_2\text{gas}})=32.282+(2*91.26+2*85.6+1/2*303)=G_{\text{CH}_3\text{CHO}}=537.5 \text{ kJ/mol};$$

$$\Delta G^\circ_{\text{CRC}}+(2G_{\text{Cgraph}}+2G_{\text{H}_2\text{gas}}+1/2G_{\text{O}_2\text{gas}})=24.06+(2*91.26+2*85.6+1/2*303)=G_{\text{CH}_3\text{CHO}}=529.28 \text{ kJ/mol};$$

CH₃CH₂OH+H₂O=CH₃CHO+H₃O⁺+H⁻(H⁺+2e⁻); absolute potential E^o_{CH₃CH₂OH}=-0.055 V; Kortly, Shucha;

[19]

$$\Delta G_{\text{eqCH}_3\text{CH}_2\text{OH}}=E^\circ_{\text{eqNernsCH}_3\text{CH}_2\text{OH}}\cdot F\cdot 2=-0.055\cdot 96485\cdot 2=-10.6 \text{ kJ/mol};$$

$$\Delta G_{\text{HessCH}_3\text{CH}_2\text{OH}}=G_{\text{CH}_3\text{CHO}}+G_{\text{H}_3\text{O}^+}+G_{\text{H}^-}-(G_{\text{CH}_3\text{CH}_2\text{OH}}+G_{\text{H}_2\text{O}})=537.5+22.44+G_{\text{H}^-}-(409.82+0)=-10.6 \text{ kJ/mol}.$$

$$\Delta G_{\text{HessCH}_3\text{CH}_2\text{OH}}=G_{\text{CH}_3\text{CHO}}+G_{\text{H}_3\text{O}^+}+G_{\text{H}^-}-(G_{\text{CH}_3\text{CH}_2\text{OH}}+G_{\text{H}_2\text{O}_{\text{Biochem}}})=537.5+22.44+G_{\text{H}^-}-(409.82+85.64)=-10.6 \text{ kJ/mol}.$$

$$\Delta G_{\text{HessCH}_3\text{CH}_2\text{OH}}-G_{\text{CH}_3\text{CHO}}-G_{\text{H}_3\text{O}^+}+(G_{\text{CH}_3\text{CH}_2\text{OH}}+G_{\text{H}_2\text{O}})=G_{\text{H}^-}=-10.6-537.5-22.44+(409.82+0)=-160.7 \text{ kJ/mol}.$$

$$\Delta G_{\text{HessCH}_3\text{CH}_2\text{OH}}-G_{\text{CH}_3\text{CHO}}-G_{\text{H}_3\text{O}^+}+(G_{\text{CH}_3\text{CH}_2\text{OH}}+G_{\text{H}_2\text{O}_{\text{Biochem}}})=G_{\text{H}^-}=-10.6-537.5-22.44+(409.82+85.64)=-75.08 \text{ kJ/mol}.$$

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Substance	$\Delta H^\circ_{\text{H}}$ kJ/mol	$\Delta S^\circ_{\text{H}}$ J/mol/K	$\Delta G^\circ_{\text{H}}$ kJ/mol
H ₃ C-CH=O	-212.23	-281.84	24.06
H ₃ C-CH=O	-213.88	-825.64	32.2824
NADH	-41.41	-4465.708	1175.5732
NADH	-1036.66	-140.50	1120.09
H ₃ O ⁺	-285.81	-3.854	-213.275
NAD ⁺	-10.30	-3766.008	1112.534
NAD ⁺	-1007.48	-183	1059.11
H ₃ CCH ₂ OH	-290.77	-1227.764	75.2864
H ₃ CCH ₂ OH _a q	-288.3	-357.7394	-181.64
H ₂ O	-285.85	69.9565	-237.191
H ₂ O	-286.65	-453.188	-151.549

$$G_{\text{CH}_3\text{CHO}}=529.28 \text{ kJ/mol};$$

$$G_{\text{CH}_3\text{CHO}}=537.5 \text{ kJ/mol};$$

$$\text{BioThermodynamic06};$$

BioThermodynamic,2006,Massachusetts Tecnology Institute

$$\text{Alberty } G_{\text{CH}_3\text{CH}_2\text{OH}}=666.106 \text{ kJ/mol};$$

$$\text{CRC } G_{\text{CH}_3\text{CH}_2\text{OH}}=409.82 \text{ kJ/mol};$$

$$G_{\text{H}_2\text{O}}=0 \text{ kJ/mol}; G_{\text{H}^-}=-10.6-537.5-22.44+(409.82+0)=-160.7 \text{ kJ/mol}.$$

$$G_{\text{H}_2\text{O}_{\text{Biochem}}}=85.64 \text{ kJ/mol}. G_{\text{H}^-}=-10.6-537.5-22.44+(409.82+85.64)=-75.08 \text{ kJ/mol}$$

NADH = NAD⁺ + H⁻(H⁺+2e⁻); inverse potential -E^o_{NADH}=0.4095 V; absolute David Harris; [22]

NAD⁺+H⁻(H⁺+2e⁻)+CH₃CH₂OH+H₂O=NADH+CH₃CHO+H₃O⁺+H⁻(H⁺+2e⁻);

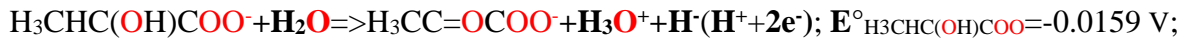
NAD⁺+CH₃CH₂OH+H₂O=NADH+CH₃CHO+H₃O⁺;

sum: **E^o_{eqNernsCH₃CH₂OH}-E^o_{NAD⁺}=-0.055+0.4095=0.4562;**

$$\Delta G_{\text{min}}=\Delta G_{\text{eq}}=(E^\circ_{\text{eqNernsCH}_3\text{CH}_2\text{OH}}-E^\circ_{\text{NAD}^+})\cdot F\cdot n=(-0.055+0.4095)\cdot 96485\cdot 2=(0.4562)\cdot 96485\cdot 2=68.408 \text{ kJ/mol};$$

$$\Delta G_{\text{HessAlbertyCH}_3\text{CH}_2\text{OH}}=G_{\text{NADH}}+G_{\text{H}_3\text{O}^+}+G_{\text{CH}_3\text{CHO}}-(G_{\text{NAD}^+}+G_{\text{CH}_3\text{CH}_2\text{OH}}+G_{\text{H}_2\text{O}})=68.02 \text{ kJ/mol}.$$

$$=1112.534+22.44+32.282-(1175.5+75.2864-151.549)=68.02 \text{ kJ/mol}.$$



$$\Delta G_{\text{eqH}_3\text{CHC}(\text{OH})\text{COO}^-} = \text{E}^\circ_{\text{eqH}_3\text{CHC}(\text{OH})\text{COO}^-} \cdot \text{F} \cdot 2 = -0.0159 \cdot 96485 \cdot 2 = -3.068 \text{ kJ/mol};$$

$$\Delta G_{\text{HessCH}_3\text{CH}_2\text{OH}} = G_{\text{H}_3\text{CC}=\text{OCOO}^-} + G_{\text{H}_3\text{O}^+} + G_{\text{H}^-} - (G_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-} + G_{\text{H}_2\text{O}}) = 534.2 + 22.44 + G_{\text{H}^-} - (668.8 + 0) = -3.068 \text{ kJ/mol}.$$

$$\Delta G_{\text{HessCH}_3\text{CH}_2\text{OH}} = G_{\text{H}_3\text{CC}=\text{OCOO}^-} + G_{\text{H}_3\text{O}^+} + G_{\text{H}^-} - (G_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-} + G_{\text{H}_2\text{O}_{\text{Biochem}}}) = 534.2 + 22.44 + G_{\text{H}^-} - (668.8 + 85.64) = -3.068 \text{ kJ/mol}.$$

$$\Delta G_{\text{HessCH}_3\text{CH}_2\text{OH}} - G_{\text{H}_3\text{CC}=\text{OCOO}^-} - G_{\text{H}_3\text{O}^+} + (G_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-} + G_{\text{H}_2\text{O}}) = G_{\text{H}^-} = -3.068 - 534.2 - 22.44 + (668.8 + 0) = 109.092 \text{ kJ/mol}.$$

$$\Delta G_{\text{HessCH}_3\text{CH}_2\text{OH}} - G_{\text{H}_3\text{CC}=\text{OCOO}^-} - G_{\text{H}_3\text{O}^+} + (G_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-} + G_{\text{H}_2\text{O}_{\text{Biochem}}}) = G_{\text{H}^-} = -3.068 - 534.2 - 22.44 + (668.8 + 85.64) = 194.7 \text{ kJ/mol}.$$

$$I = 0.25 \text{ M, BioTherm06, pH} = 7.36, \Delta G_{\text{H}} = G^\circ_{\text{H}_3\text{CC}=\text{OCOO}^-} + G^\circ_{\text{H}_3\text{O}^+} + G_{\text{H}^-} - G_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-} - G_{\text{H}_2\text{O}} = \text{kJ/mol};$$

$$\text{Viola} \quad \Delta H^\circ_{\text{H}} \text{ kJ/mol} \quad \Delta S^\circ_{\text{H}} \text{ J/mol/K} \quad \Delta G^\circ_{\text{H}} \text{ kJ/mol};$$

PyruvEnolP³⁻	-1400	-1100	-1189.73
H₃CC=OCOO⁻	-597.4	-850	-350.78
H₃CC=OCOO⁻	-603.7	-433.54	-474.44
H₃CC=OCOO⁻	-597.04	-846.66	-344.62
H₃O⁺	-285.81	-3.854	-213.275
H₂O	-285.85	69.9565	-237.191
H₂O	-286.65	-453.188	-151.549
H₃CHC(OH)COO⁻	-688.29	-1290.9	-303.4

$$G_{\text{H}_2\text{O}} = 0 \text{ kJ/mol}; G_{\text{H}^-} = -3.068 - 534.2 - 22.44 + (668.8 + 0) = 109.092 \text{ kJ/mol}$$

$$G_{\text{H}_2\text{O}_{\text{Biochem}}} = 85.64 \text{ kJ/mol}; G_{\text{H}^-} = -3.068 - 534.2 - 22.44 + (668.8 + 85.64) = 194.7 \text{ kJ/mol}$$

$$G_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-} = 534.2 \text{ kJ/mol}; pK_a = 2.5;$$

$$G_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-} = 668.8 \text{ kJ/mol}; pK_a = 3.86;$$

$$pK_a = 3.86; \Delta H_c^\circ = 1361.9 \text{ kJ/mol}; G_{\text{H}_3\text{CHC}(\text{OH})\text{COOH}} = 2271 \text{ kJ/mol}; \text{H}_3\text{CHC}(\text{OH})\text{COOH} + 3\text{O}_2\text{gas} = 3\text{CO}_2\text{gas} + 3\text{H}_2\text{O};$$

$$\Delta H_c^\circ = 3G_{\text{CO}_2\text{gas}} + 3G_{\text{H}_2\text{O}} - (G_{\text{H}_3\text{CHC}(\text{OH})\text{COOH}} + 3G_{\text{O}_2\text{gas}}) = 3 \cdot 0 + 3 \cdot 0 - (2271 + 3 \cdot 303) = 1361.9 \text{ kJ/mol};$$

$$G_{\text{H}_3\text{CHC}(\text{OH})\text{COOH}} = 3G_{\text{CO}_2\text{gas}} + 3G_{\text{H}_2\text{O}} - (3G_{\text{O}_2\text{gas}}) = 3 \cdot 0 + 3 \cdot 0 - (3 \cdot 303) - 1361.9 = G_{\text{H}_3\text{CHC}(\text{OH})\text{COOH}} = 2271 \text{ kJ/mol};$$

Lactic acid Formation 71st page $3\text{C} + 3\text{H}_2\text{gas} + 1.5\text{O}_2\text{gas} \Rightarrow \text{H}_3\text{CHC}(\text{OH})\text{COOH}$; $G_{\text{H}_3\text{CHC}(\text{OH})\text{COOH}} = -303.4 \text{ kJ/mol}$ [8];

$$\Delta G_{\text{H}_3\text{CHC}(\text{OH})\text{COOH}} = G_{\text{H}_3\text{CHC}(\text{OH})\text{COOH}} - (3G_{\text{Cgraph}} + 3 \cdot G_{\text{H}_2\text{gas}} + 1.5 \cdot G_{\text{O}_2\text{gas}}) = -303.4 \text{ kJ/mol};$$

$$G_{\text{H}_3\text{CHC}(\text{OH})\text{COOH}} = -303.4 + (3 \cdot 91.26 + 3 \cdot 85.6 + 1.5 \cdot 303) = 681.7 \text{ kJ/mol};$$

Lactic acid $\text{H}_3\text{CHC}(\text{OH})\text{COOH} + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{CHC}(\text{OH})\text{COO}^- + \text{H}_3\text{O}^+$; $pK_a = 3.86$;

$$K_{\text{eq}} = [\text{H}_3\text{CHC}(\text{OH})\text{COO}^-] \cdot [\text{H}_3\text{O}^+] / [\text{H}_3\text{CHC}(\text{OH})\text{COOH}] \cdot [\text{H}_2\text{O}] = K_a / [\text{H}_2\text{O}] = 10^{-(3.86)} / 55.3 = 10^{-(5.603)};$$

$$\Delta G_{\text{eqH}_3\text{CHC}(\text{OH})\text{COOH}} = -R \cdot T \cdot \ln(K_{\text{aeq}}) = -8.3144 \cdot 298.15 \cdot \ln(10^{-(5.603)}) / 1000 = 31.98 \text{ kJ/mol}.$$

$$\Delta G_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-} = G_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-} + 2G_{\text{H}_3\text{O}^+} - (G_{\text{LacticAc}} + 2G_{\text{H}_2\text{O}}) = G_{\text{Succinat}} + 2 \cdot 22.44 - (681.7 + 2 \cdot 0) = 31.98 \text{ kJ/mol};$$

$$G_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-} = \Delta G_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-} - 2G_{\text{H}_3\text{O}^+} + (G_{\text{LacticAc}} + 2G_{\text{H}_2\text{O}}) = 31.98 - 2 \cdot 22.44 + (681.7 + 2 \cdot 0) = 668.8 \text{ kJ/mol};$$

Pyruvic acid Formation 71st page $3\text{C} + 2\text{H}_2\text{gas} + 1.5\text{O}_2\text{gas} \Rightarrow \text{H}_3\text{CC}=\text{OCOOH}$; $\Delta G_{\text{Succinat}} = -344.62 \text{ kJ/mol}$ Alberty;

$$\Delta G_{\text{Fumarat}} = G_{\text{Fumarat}} - (3G_{\text{Cgraph}} + 2G_{\text{H}_2\text{gas}} + 1.5 \cdot G_{\text{O}_2\text{gas}}) = -344.62 \text{ kJ/mol};$$

$$G_{\text{Fumarat}} = -344.62 + (3 \cdot 91.26 + 2 \cdot 85.6 + 1.5 \cdot 303) = 554.86 \text{ kJ/mol};$$

Pyruvic acid $\text{H}_3\text{CC}=\text{OCOOH} + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{CHC}(\text{OH})\text{COO}^- + \text{H}_3\text{O}^+$; $pK_a = 2.5$;

$$K_{\text{eq}} = [\text{H}_3\text{CHC}(\text{OH})\text{COO}^-] \cdot [\text{H}_3\text{O}^+] / [\text{H}_3\text{CC}=\text{OCOOH}] \cdot [\text{H}_2\text{O}] = K_a / [\text{H}_2\text{O}] = 10^{-(2.5)} / 55.3 = 2.5 \cdot 10^{-(6)} = 10^{-(4.243)};$$

$$\Delta G_{\text{eqH}_3\text{CC}=\text{OCOOH}} = -R \cdot T \cdot \ln(K_{\text{aeq}}) = -8.3144 \cdot 298.15 \cdot \ln(10^{-(4.243)}) / 1000 = 24.22 \text{ kJ/mol}.$$

$$\Delta G_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-} = G_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-} + 2G_{\text{H}_3\text{O}^+} - (G_{\text{LacticAc}} + 2G_{\text{H}_2\text{O}}) = G_{\text{Succinat}} + 2 \cdot 22.44 - (554.86 + 2 \cdot 0) = 24.22 \text{ kJ/mol};$$

$$G_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-} = \Delta G_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-} - 2G_{\text{H}_3\text{O}^+} + (G_{\text{LacticAc}} + 2G_{\text{H}_2\text{O}}) = 24.22 - 2 \cdot 22.44 + (554.86 + 2 \cdot 0) = 534.2 \text{ kJ/mol};$$

$\text{NADH} = \text{NAD}^+ + \text{H}^-(\text{H}^+ + 2\text{e}^-)$; $\text{E}^\circ_{\text{NADH}} = -0.4095 \text{ V}$; absolute Lehninger; [6]

Red lactate $+\text{H}_2\text{O} \rightleftharpoons \text{pyruvate}^- + \text{H}_3\text{O}^+ + \text{H}^-(\text{H}^+ + 2\text{e}^-)$; absolute potential $\text{E}^\circ_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-} = -0.0159 \text{ V}$;

Ox $\text{NAD}^+ + \text{H}^-(2\text{e}^-) = \text{NADH}$; $\text{E}^\circ = -0.4095 \text{ V}$; OksRed $\text{NAD}^+ + \text{lactate}^- + \text{H}_2\text{O} = \text{NADH} + \text{pyruvate}^- + \text{H}_3\text{O}^+$;

Balanced $n=2=m$ with 2e^- electrons ΔE° NAD^+ accept electrons from lactate:

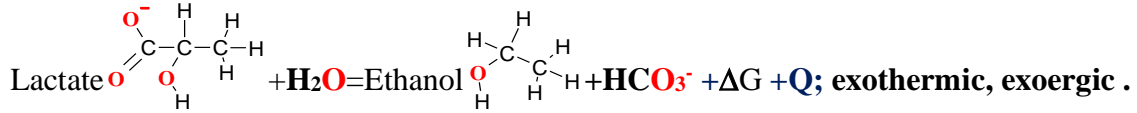
$$\Delta G_{\text{eqAerobic}} = \Delta \text{E}^\circ \cdot \text{F} \cdot n = (\text{E}^\circ_{\text{Red}} - \text{E}^\circ_{\text{Ox}}) \cdot \text{F} \cdot n = (-0.0159 - 0.4095) \cdot 96485 \cdot 2 = (0.3936) \cdot 2 = 75.95 \text{ kJ/mol}$$

$$K_{\text{eqAerobic}} = \text{EXP}(-\Delta G_{\text{eqAerobic}} / R/T) = \text{EXP}(-75950 / 8.3144 / 298.15) = 10^{-13.3};$$

$$K_{\text{eqAerobic}} = \frac{[\text{NADH}] \cdot [\text{pyruvate}^-] \cdot [\text{H}_3\text{O}^+]}{[\text{NAD}^+] \cdot [\text{lactate}^-] \cdot [\text{H}_2\text{O}]} = e^{-\frac{\Delta G_{\text{eqAerobic}}}{R \cdot T}} = e^{-\frac{75950}{8.314 \cdot 298.15}} = 10^{-13.3};$$

$$\Delta G_{\text{Hess}} = \Delta H_{\text{Hess}} - T \cdot \Delta S_{\text{Hess}} = 45.764 - 298.15 \cdot 0.5479605 = 209.14 \dots \text{ kJ/mol endoergic; formation 62}^{\text{nd}}, 75^{\text{th}} \text{ pages}$$

Pyruvate $\text{H}_3\text{CC}=\text{O}\text{COO}^-$ decarboxylation $\text{H}_3\text{CCHO}+\text{HCO}_3^-$; $\text{H}_3\text{CC}=\text{O}\text{COO}^-+\text{H}_2\text{O}\Delta\text{G}+\text{Q}\Rightarrow\text{H}_3\text{CCHO}+\text{HCO}_3^-$



$$\Delta\text{G}_{\text{Hess}}=\Delta\text{G}^{\circ}_{\text{H}_3\text{CCH}_2\text{OH}}+\Delta\text{G}^{\circ}_{\text{HCO}_3^-}-\Delta\text{G}^{\circ}_{\text{H}_2\text{O}}-\Delta\text{G}^{\circ}_{\text{H}_3\text{CCH}_2\text{OHCoo}}=\underline{75.2864-544.9688-(-151.549-303.4256)}=-14.71 \text{ kJ/mol}$$

$$\Delta\text{G}_{\text{Alberty}}=\Delta\text{G}_{\text{H}_3\text{CCH}_2\text{OH}}+\Delta\text{G}_{\text{HCO}_3^-}-\Delta\text{G}_{\text{H}_2\text{O}}-\Delta\text{G}_{\text{H}_3\text{CCH}_2\text{OHCoo}}=\underline{666.1+46.08-(0+668.8)}=\underline{43.38} \text{ kJ/mol}$$

$$\Delta\text{G}_{\text{Alberty_Biochem}}=\Delta\text{G}_{\text{H}_3\text{CCH}_2\text{OH}}+\Delta\text{G}_{\text{HCO}_3^-} \text{G}_{\text{H}_2\text{O_Biochem}}-\Delta\text{G}_{\text{H}_3\text{CCH}_2\text{OHCoo}}=\underline{666.1+46.08-(85.64+668.8)}=\underline{-42.26} \text{ kJ/mol}$$

$$\Delta\text{H}_{\text{Hess}}=\Delta\text{H}^{\circ}_{\text{H}_3\text{CCH}_2\text{OH}}+\Delta\text{H}^{\circ}_{\text{HCO}_3^-}-\Delta\text{H}^{\circ}_{\text{H}_2\text{O}}-\Delta\text{H}^{\circ}_{\text{H}_3\text{CCH}_2\text{OHCoo}}=\underline{-290.77-692.4948-(-286.65-688.29)}=\underline{-8.325} \text{ kJ/mol}$$

$$\Delta\text{S}_{\text{dispersed}}=-\Delta\text{H}_{\text{Hess}}/\text{T}=\underline{8.325/298.15}=\underline{27.9} \text{ J/K/mol};$$

$$\Delta\text{S}_{\text{Hess}}=\Delta\text{S}^{\circ}_{\text{H}_3\text{CCH}_2\text{OH}}+\Delta\text{S}^{\circ}_{\text{HCO}_3^-}-\Delta\text{S}^{\circ}_{\text{H}_2\text{O}}-\Delta\text{S}^{\circ}_{\text{H}_3\text{CCH}_2\text{OHCoo}}=\underline{21.51} \text{ J/mol/K};$$

$$=\underline{-1227.764-494.768-(-453.188-1290.852)}=\underline{21.51} \text{ J/mol/K}....$$

$$\Delta\text{S}_{\text{total}}=\Delta\text{S}_{\text{Hess}}+\Delta\text{S}_{\text{dispersed}}=\underline{21.51+27.9}=\underline{49.41} \text{ J/mol/K};$$

$$\Delta\text{G}_{\text{Hess}}=\Delta\text{H}_{\text{Hess}}-\text{T}\cdot\Delta\text{S}_{\text{Hess}}=\underline{-8.325-298.15\cdot0.02151}=\underline{-14.738} \text{ kJ/mol exoergic}.....$$

$$\text{T}\cdot\Delta\text{S}_{\text{total}}=\underline{0.04941}\cdot298.15 \text{ K}=\underline{14.73} \text{ kJ/mol}; \text{bound T}\Delta\text{S}_{\text{n}} ; \text{dispersed-lost energy spontaneous}$$

Lactic acid Formation 71st page $3\text{C}+3\text{H}_2\text{gas}+1.5\text{O}_2\text{gas}\Rightarrow\text{H}_3\text{CHC}(\text{OH})\text{COOH}$; $\text{G}_{\text{H}_3\text{CHC}(\text{OH})\text{COOH}}=-303.4 \text{ kJ/mol}$ [8];

$$\Delta\text{G}_{\text{H}_3\text{CHC}(\text{OH})\text{COOH}}=\text{G}_{\text{H}_3\text{CHC}(\text{OH})\text{COOH}}-(3\text{G}_{\text{Cgraph}}+3\cdot\text{G}_{\text{H}_2\text{gas}}+1.5\cdot\text{G}_{\text{O}_2\text{gas}})=\underline{-303.4} \text{ kJ/mol};$$

$$\text{G}_{\text{H}_3\text{CHC}(\text{OH})\text{COOH}}=-303.4+(3\cdot91.26+3\cdot85.6+1.5\cdot303)=\underline{681.7} \text{ kJ/mol};$$

Lactic acid $\text{H}_3\text{CHC}(\text{OH})\text{COOH}+\text{H}_2\text{O}\rightleftharpoons\text{H}_3\text{CHC}(\text{OH})\text{COO}^-+\text{H}_3\text{O}^+$; $\text{pK}_a=3.86$;

$$\text{K}_{\text{eq}}=[\text{H}_3\text{CHC}(\text{OH})\text{COO}^-][\text{H}_3\text{O}^+]/[\text{H}_3\text{CHC}(\text{OH})\text{COOH}][\text{H}_2\text{O}]=\text{K}_a/[\text{H}_2\text{O}]=10^{(-3.86)}/55.3=10^{(-5.603)};$$

$$\Delta\text{G}_{\text{eqH}_3\text{CHC}(\text{OH})\text{COOH}}=-\text{R}\cdot\text{T}\cdot\ln(\text{K}_{\text{aeq}})=-8.3144\cdot298.15\cdot\ln(10^{(-5.603)})/1000=\underline{31.98} \text{ kJ/mol} .$$

$$\Delta\text{G}_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-}=\text{G}_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-}+2\text{G}_{\text{H}_3\text{O}^+}-(\text{G}_{\text{LacticAc}}+2\text{G}_{\text{H}_2\text{O}})=\text{G}_{\text{Succinat}}+2\cdot\underline{22.44}-(\underline{681.7}+2\cdot0)=\underline{31.98} \text{ kJ/mol};$$

$$\text{G}_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-}=\Delta\text{G}_{\text{H}_3\text{CHC}(\text{OH})\text{COO}^-}-2\text{G}_{\text{H}_3\text{O}^+}+(\text{G}_{\text{LacticAc}}+2\text{G}_{\text{H}_2\text{O}})=\underline{31.98}-2\cdot\underline{22.44}+(\underline{681.7}+2\cdot0)=\underline{668.8} \text{ kJ/mol};$$

CH₃CH₂OH ethanol formation from elements:

$$2\text{C}+3\text{H}_2\text{gas}+1/2\text{O}_2\text{gas}\Rightarrow\text{CH}_3\text{CH}_2\text{OH} ; \Delta\text{G}^{\circ}_{\text{Alberty}}=\underline{75.2864} \text{ kJ/mol} ; \Delta\text{G}^{\circ}_{\text{HessCRC}}=-181 \text{ kJ/mol} ;$$

$$\Delta\text{G}^{\circ}_{\text{Alberty}}=\text{G}_{\text{CH}_3\text{CH}_2\text{OH}}-(2\text{G}_{\text{Cgraph}}+3\cdot\text{G}_{\text{H}_2\text{gas}}+1/2\cdot\text{G}_{\text{O}_2\text{gas}})=\underline{75.2864} \text{ kJ/mol} ;$$

$$\Delta\text{G}^{\circ}_{\text{CRC}}=\text{G}_{\text{CH}_3\text{CH}_2\text{OH}}-(2\text{G}_{\text{Cgraph}}+3\cdot\text{G}_{\text{H}_2\text{gas}}+1/2\cdot\text{G}_{\text{O}_2\text{gas}})=-181 \text{ kJ/mol} ;$$

$$\Delta\text{G}^{\circ}_{\text{Alberty}}+(2\text{G}_{\text{Cgraph}}+3\cdot\text{G}_{\text{H}_2\text{gas}}+1/2\cdot\text{G}_{\text{O}_2\text{gas}})=\underline{75.2864}+(2\cdot91.26+3\cdot85.6+1/2\cdot303)=\text{G}_{\text{CH}_3\text{CH}_2\text{OH}}=\underline{666.106} \text{ kJ/mol} ;$$

$$\Delta\text{G}^{\circ}_{\text{CRC}}+(2\text{G}_{\text{Cgraph}}+3\cdot\text{G}_{\text{H}_2\text{gas}}+1/2\cdot\text{G}_{\text{O}_2\text{gas}})=-181+(2\cdot91.26+3\cdot85.6+1/2\cdot303)=\text{G}_{\text{CH}_3\text{CH}_2\text{OH}}=\underline{409.82} \text{ kJ/mol} ;$$

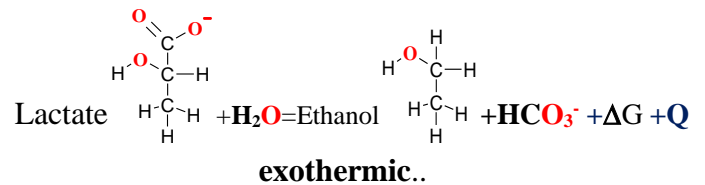
Substance	$\Delta\text{H}^{\circ}_{\text{H}}/\text{kJ/mol}$	$\Delta\text{S}^{\circ}_{\text{H}}/\text{J/mol/K}$	$\Delta\text{G}^{\circ}_{\text{H}}/\text{kJ/mol}$
$\text{H}_3\text{CCH}(\text{OH})\text{COO}^-$	-688.29	-1290.852	-303.4256
$\text{H}_3\text{CCH}(\text{OH})\text{COO}$	-686.2	-557.71	-313.70
$\text{H}_3\text{CCH}_2\text{OH}_{\text{aq}}$	-290.77	-1227.764	75.2864
$\text{H}_3\text{CCH}_2\text{OH}_l$	-277.6	160.7	62.96
H_2O	-285.85	69.9565	-237.191
H_2O	-286.65	-453.188	-151.549
HCO_3^-	-689.93	98.324	-586.94
HCO_3^-	-692.4948	-494.768	-544.9688

BioThermodynamics06; $\text{G}_{\text{H}_2\text{O_Biochem}}=\underline{85.64} \text{ kJ/mol}$;

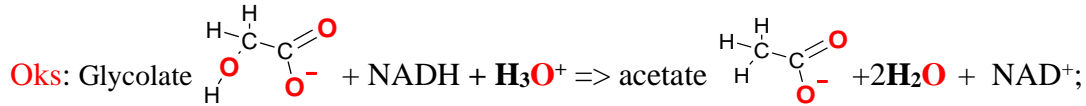
$$(\text{G}_{\text{H}_3\text{O}^+}+\text{G}_{\text{HCO}_3^-})=\underline{22.44+46.08} \text{ kJ/mol} ;$$

CRC 2010;

$$\Delta\text{S}_{\text{Hess}}=\Sigma\Delta\text{S}^{\circ}_{\text{products}}-\Sigma\Delta\text{S}^{\circ}_{\text{reactants}};\Delta\text{G}_{\text{Hess}}=\Delta\text{H}_{\text{Hess}}-\text{T}\cdot\Delta\text{S}_{\text{Hess}}$$

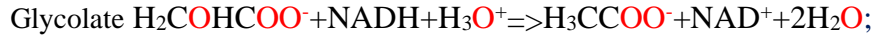


Oks: $\text{H}_2\text{COHCOO}^- + \text{H}^+(\text{H}^+ + 2\text{e}^-) + \text{H}_3\text{O}^+ \Rightarrow \text{H}_3\text{CCOO}^- + 2\text{H}_2\text{O}$; $E^\circ_{\text{OxH}_2\text{COHCOO}} = -0.033$ V absolute; [23]



$$\Delta G_{\text{Hess}} = \Delta G^\circ_{\text{H}_3\text{CCOO}^-} + \Delta G^\circ_{\text{NAD}^+} + 2\Delta G^\circ_{\text{H}_2\text{O}} - \Delta G^\circ_{\text{H}_2\text{COHCOO}^-} - \Delta G^\circ_{\text{NADH}} - \Delta G^\circ_{\text{H}_3\text{O}^+} = -161.8 \text{ kJ/mol};$$

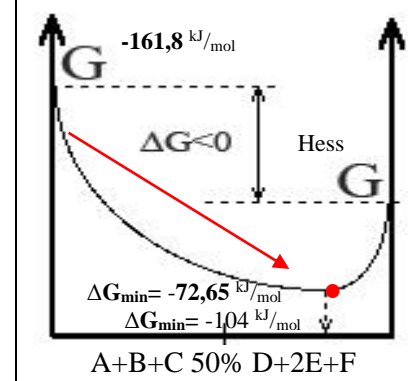
$$= -240.963 + 1112.534 - 2 \cdot 237.191 - (-403.2968 + 1175.5732 - 213.2746) = -161.8 \text{ kJ/mol exoergic} \dots \dots \dots$$



$$\Delta G_{\text{eq}} = (E^\circ_{\text{Red}} - E^\circ_{\text{OxH}_2\text{COHCOO}}) \cdot F \cdot n = (-0.4095 - (-0.033)) \cdot 96485 \cdot 2 = (-0.38) \cdot 96485 \cdot 2 = -72.65 \text{ kJ/mol};$$

Substance	$\Delta H^\circ_{\text{Hess}}$ kJ/mol	$\Delta S^\circ_{\text{Hess}}$ J/mol/K	$\Delta G^\circ_{\text{Hess}}$ kJ/mol
Glyoxylate			
OHCCOOH	-	-	-
OHCCOO^-	-	-	-426.588
$\text{H}_2\text{COHCOO}^-$	-	-	-403.2968
$\text{H}_2\text{COHCOOH}$	- 651	318.6	-
$\text{NADH}(aq)$	-1036.66	-140.5	-
$\text{NAD}^+(aq)$	-1041.41	-4081.784	1175.5732
$\text{H}_3\text{O}^+(aq)$	-285.81	-3.854	-213.2746
$\text{NAD}^+(aq)$	-1007.48	-183	-
$\text{NAD}^+(aq)$	-1010.3	-3766.008	1112.534
H_3CCOOH	-484.09	159.83	-531.743
H_3CCOO^-	-486.84	82.23	-247.83
H_3CCOO^-	-486	85.3	-240.963
H_2O	-285.85	69.9565	-237.191
H_2O	.65	-453.188	-151.549

$\text{H}_2\text{COHCOO}^- + \text{NADH} + \text{H}_3\text{O}^+ \Rightarrow \text{H}_3\text{CCOO}^- + \text{NAD}^+ + \text{H}_2\text{O}$;
 $G_{\text{OHCCOOH}} = -426.588 + (2 \cdot 91.26 + 85.6 + 1.5 \cdot 303) = 296.032 \text{ kJ/mol}$
 $G_{\text{OHCCOO}^-} = \Delta G_{\text{eqOHCCOOH}} - G_{\text{H}_3\text{O}^+} + (G_{\text{OHCCOOH}} + G_{\text{H}_2\text{O}}) = 305.6 \text{ kJ/mol}$
 $G_{\text{H}_2\text{COHCOO}^-} = \Delta G_{\text{eqH}_2\text{COHCOO}^-} - G_{\text{H}_3\text{O}^+} + (G_{\text{H}_2\text{COHCOOH}} + G_{\text{H}_2\text{O}}) = 414.3 \text{ kJ/mol}$
 $G_{\text{H}_2\text{COHCOOH}} = -403.2968 + (2 \cdot 91.26 + 2 \cdot 85.6 + 1.5 \cdot 303) = 404.9232 \text{ kJ/mol}$
 Exothermic, exoergic reduction
 Hess free energy change **-161.8**
 negative, but minimized
 reaching $\Delta G_{\text{min}} = \Delta G_{\text{eq}} = -72.65$
 or
-104 kJ/mol equilibrium mixture.
 Le Chatelier principle is
 Prigogine attractor free energy
 change minimum ΔG_{min}
 reaching.



Glyoxylic acid Formation 61st page $2\text{C} + \text{H}_2\text{gas} + 1.5\text{O}_2\text{gas} \Rightarrow \text{OHCCOOH}$; $\Delta G_{\text{OHCCOOH}} = -426.588 \text{ kJ/mol}$ [8];

$$\Delta G_{\text{OHCCOOH}} = G_{\text{OHCCOOH}} - (2G_{\text{Cgraph}} + G_{\text{H}_2\text{gas}} + 1.5 \cdot G_{\text{O}_2\text{gas}}) = -426.588 \text{ kJ/mol};$$

$$G_{\text{OHCCOOH}} = -426.588 + (2 \cdot 91.26 + 85.6 + 1.5 \cdot 303) = 296.032 \text{ kJ/mol};$$

Glyoxylic acid $\text{OHCCOOH} + \text{H}_2\text{O} \rightleftharpoons \text{OHCCOO}^- + \text{H}_3\text{O}^+$; $pK_{a1} = 3.32$; Wikipedia

$$K_{\text{eq}} = \frac{[\text{OHCCOO}^-][\text{H}_3\text{O}^+]}{[\text{OHCCOOH}][\text{H}_2\text{O}]} = K_a / [\text{H}_2\text{O}] = 10^{-(3.32)} / 55.3 = 8.655 \cdot 10^{-6} = 10^{-(5.063)};$$

$$\Delta G_{\text{eqOHCCOOH}} = -R \cdot T \cdot \ln(K_{\text{aeq}}) = -8.3144 \cdot 298.15 \cdot \ln(10^{-(5.063)}) / 1000 = 31.98 \text{ kJ/mol}.$$

$$\Delta G_{\text{eqOHCCOOH}} = G_{\text{OHCCOO}^-} + G_{\text{H}_3\text{O}^+} - (G_{\text{OHCCOOH}} + G_{\text{H}_2\text{O}}) = G_{\text{OHCCOO}^-} + 22.44 - (296.032 + 0) = 31.98 \text{ kJ/mol};$$

$$G_{\text{OHCCOO}^-} = \Delta G_{\text{eqOHCCOOH}} - G_{\text{H}_3\text{O}^+} + (G_{\text{OHCCOOH}} + G_{\text{H}_2\text{O}}) = 31.98 - 22.44 + (296.032 + 0) = 305.6 \text{ kJ/mol};$$

Glycolic acid Formation 61st page $2\text{C} + 2 \cdot \text{H}_2\text{gas} + 1.5\text{O}_2\text{gas} \Rightarrow \text{H}_2\text{COHCOOH}$; $\Delta G_{\text{H}_2\text{COHCOOH}} = -403.2968 \text{ kJ/mol}$ [8];

$$\Delta G_{\text{H}_2\text{COHCOOH}} = G_{\text{H}_2\text{COHCOOH}} - (2G_{\text{Cgraph}} + 2G_{\text{H}_2\text{gas}} + 1.5 \cdot G_{\text{O}_2\text{gas}}) = -403.2968 \text{ kJ/mol};$$

$$G_{\text{H}_2\text{COHCOOH}} = -403.2968 + (2 \cdot 91.26 + 2 \cdot 85.6 + 1.5 \cdot 303) = 404.9232 \text{ kJ/mol};$$

Glycolic acid $\text{H}_2\text{COHCOOH} + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{COHCOO}^- + \text{H}_3\text{O}^+$; $pK_{a1} = 3.83$; Wikipedia

$$K_{\text{eq}} = \frac{[\text{H}_2\text{COHCOO}^-][\text{H}_3\text{O}^+]}{[\text{H}_2\text{COHCOOH}][\text{H}_2\text{O}]} = K_a / [\text{H}_2\text{O}] = 10^{-(3.83)} / 55.3 = 2.675 \cdot 10^{-6} = 10^{-(5.573)};$$

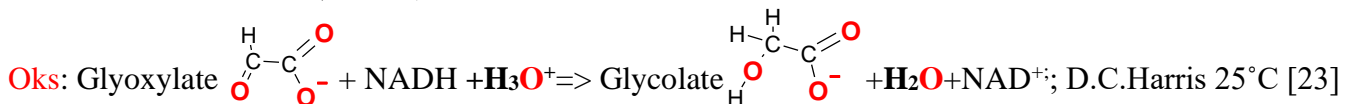
$$\Delta G_{\text{eqOHCCOOH}} = -R \cdot T \cdot \ln(K_{\text{aeq}}) = -8.3144 \cdot 298.15 \cdot \ln(10^{-(5.573)}) / 1000 = 31.81 \text{ kJ/mol}.$$

$$\Delta G_{\text{eqOHCCOOH}} = G_{\text{OHCCOO}^-} + G_{\text{H}_3\text{O}^+} - (G_{\text{OHCCOOH}} + G_{\text{H}_2\text{O}}) = G_{\text{OHCCOO}^-} + 22.44 - (404.9232 + 0) = 31.81 \text{ kJ/mol};$$

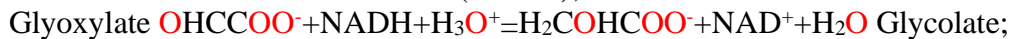
$$G_{\text{OHCCOO}^-} = \Delta G_{\text{eqOHCCOOH}} - G_{\text{H}_3\text{O}^+} + (G_{\text{OHCCOOH}} + G_{\text{H}_2\text{O}}) = 31.81 - 22.44 + (404.9232 + 0) = 414.3 \text{ kJ/mol};$$

Nernst's half reaction **glycolate** + $\text{H}_2\text{O} =$ **Glyoxylate** + $\text{H}^+(\text{H}^+ + 2\text{e}^-) + \text{H}_3\text{O}^+$; D.C.Harris 25°C [23]

Oks: $\text{OHCCOO}^- + \text{H}^+(\text{H}^+ + 2\text{e}^-) + \text{H}_3\text{O}^+ \Rightarrow \text{H}_2\text{COHCOO}^- + \text{H}_2\text{O}$; $E^\circ_{\text{H}_2\text{COHCOO}} = 0.1305$ V absolute; [23]



Nernst's half reaction **Red**: $\text{NADH} = \text{NAD}^+ + \text{H}^+(\text{H}^+ + 2\text{e}^-)$; $E^\circ_{\text{Red}} = -0.4095$ V David Harris absolute [22]



$$\Delta G_{\text{Hess}} = \Delta G^\circ_{\text{H}_2\text{COHCOOH}} + \Delta G^\circ_{\text{NAD}^+} + \Delta G^\circ_{\text{H}_2\text{O}} - \Delta G^\circ_{\text{H}_2\text{COHCOO}^-} - \Delta G^\circ_{\text{NADH}} - \Delta G^\circ_{\text{H}_3\text{O}^+} = -63.66 \text{ kJ/mol};$$

$$= -403.2968 + 1112.534 - 237.191 - (-426.588 + 1175.5732 - 213.2746) = -63.66 \text{ kJ/mol exoergic} \dots \dots \dots;$$

$$\Delta G_{\text{min}} = \Delta G_{\text{eq}} = (E^\circ_{\text{eqNernst_NADH}} - E^\circ_{\text{H}_2\text{COHCOO}}) \cdot F \cdot n = (-0.4095 - 0.1305) \cdot 96485 \cdot 2 = (-0.54) \cdot 96485 \cdot 2 = -104.2 \text{ kJ/mol};$$

Protolytic solubility in water relates the absolute electrode potential to the zero of the absolute free energy scale $G_{H_2O}=G_{CO_2,gas}=0$ kJ/mol and depends on absolute temperature. The protolytic solubility reactions consume water molecules to form products with an absolute equilibrium constant in mol fractions without the usual units of molar concentration.

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Abstract

The solubility and protolysis process consumes water molecules for aqua dissolute product formation.

Solubility of gases: oxygen $O_{2,gas}+H_2O=O_{2,aq}$; hydrogen $H_{2,gas}+H_2O=H_{2,aq}$; nitrogen $N_{2,gas}+H_2O=N_{2,aq}$;

Electrodes of metals: hydrogen $H(Pt)+H_2O=H_3O^++e^-$; iron $Fe_{(s)}+H_2O=Fe^{2+}+2e^-$; zinc $Zn+H_2O=Zn^{2+}+2e^-$; copper amalgam $Cu(Hg)+H_2O=Cu^{2+}+(Hg)+2e^-$; silver $Ag_{(s)}+H_2O=Ag^++e^-$; chromium $Cr+H_2O=Cr^{3+}+3e^-$;

For solid solubility: silver chloride $AgCl_{(s)}+2H_2O=Ag^++Cl^-$; calomel $Hg_2Cl_{2(s)}+3H_2O=Hg_2^{2+}+2Cl^-$;

mercury(II) oxide $Hg+H_2O+2OH^-=HgO+2H_2O+2e^-$, mercury(I) sulfate $Hg_2SO_{4(s)}+2H_2O=Hg_2^{2+}+SO_4^{2-}$;

For protolysis: peroxide $H_2O_2+H_2O=H_3O^++HOO^-$ $pK_a=11,75$; water $2H_2O=H_3O^++OH^-$ $pK_w=14$.

The solubility of gaseous oxygen $O_{2,gas}+H_2O=O_{2,aq}$ in oxidation half-reaction compensates one water molecule

$6H_2O=O_{2,gas}+H_2O+4H_3O^++4e^-$ from six to five $5H_2O=O_{2,aq}+4H_3O^++4e^-$. Its decreases the calculate free energy content of metal

hydrogen from $G_{H(Pt)}=51.05$ kJ/mol to $G_{H(Pt)}=48.56$ kJ/mol. The absolute standard potential scale reference increases from $E^{\circ}_{H}=-0.29654$ V to $E^{\circ}_{H}=-0.27073$ V less negative. The absolute potential scale shift down of thermodynamic $E^{\circ}_{H}=0,10166$ V increasing to $\Delta E_{absolute}=-0.37239$ V from $\Delta E_{absolute}=-0.3982$ V.

Standard potential shift down to $E^{\circ}_{O_2}=1.0868$ V for oxygen and for glucose $E^{\circ}_{C_6H_{12}O_6}=-0.13858$ V.

The operations sequence of the absolute standard potential determination: $E^{\circ}_{O_2}=1.0868$ Volts for two water oxygen oxidation in Nernst's half-reaction $5H_2O=O_{2,aq}+4H_3O^++4e^-$.

From Nernst classical value [1] $E^{\circ}_{classic O_2}=1.2288$ V subtract $E^{\circ}_{H_2O}=-0.0591/4*\log(1/55.3^{A5})$ the counting value of five water molecules. The concentration of water is $[H_2O]=996$ g/L /18 g/mol=55.3 M in one liter. Then add the reference value of the

Thermodynamic metal hydrogen electrode $E^{\circ}_{H}=+0.10166$ Volts. The absolute scale reference value decreases from the 0.10166 V down by $\Delta E_{absolute}=-0.37239$ Volts. In sum, the absolute value $E^{\circ}_{O_2}=1.2288-0.0591/4*\log(1/55.3^{A5})+0.10166-0.37239=1.0868$ Volts of the standard potential for the Nernst half-reaction $5H_2O=O_{2,aq}+4H_3O^++4e^-$ is obtained absolute potential expression in equation:

$$E_{O_2}=E^{\circ}_{O_2}+0.0591/4*\log \frac{[O_2]_{aqua} \cdot [H_3O^+]^4}{[H_2O]^5} = 1.0868+0.0591/4*\log \frac{[O_2]_{aqua} \cdot [H_3O^+]^4}{55,3^{A5}} \text{ Volts.}$$

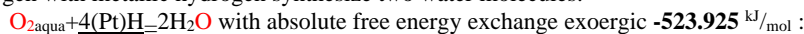
The inverse standard potential for the reduction of oxygen $O_{2,aq}+4H_3O^++4e^-=5H_2O$ has minus sign $-E^{\circ}_{O_2}$.

The oxygen reducing reaction is exoergic $\Delta G_{eq O_2}=E^{\circ}_{O_2} \cdot F \cdot n = -1.0868 * 96485 * 4 / 1000 = -419.44$ kJ/mol;

$\Delta G_{eq O_2}=5G_{H_2O}-(G_{O_{2,aq}}+4G_{H_3O^+})=5*0-(329.68+4*22.44)=-419.44$ kJ/mol; and coincides with the absolute potential scale. Oxygen energy $G_{O_{2,gas}}=303.1$ kJ/mol grows $G_{O_{2,aq}}=G_{O_{2,gas}}+G_{O_{2,sp}}=303.1+26.58=329.68$ kJ/mol at solubility.

Nernst's hydrogen oxidation $4(Pt)H+4H_2O=4H_3O^++4e^-$ standard absolute potential is $E^{\circ}_{H}=-0.27073$ Volts.

In sum reduction reaction of oxygen with metallic hydrogen synthesize two water molecules:



$$\Delta G_{eq}=(E^{\circ}_{H}-E^{\circ}_{O_2}) \cdot F \cdot 1 \cdot 4 = (-0.27073-1.0868) * 96485 * 4 = -1.3575 * 96485 * 4 / 1000 = 2 * 261.96 = -523.925 \text{ kJ/mol.}$$

Exchange $\Delta G_{eq 2H_2O}=2G_{H_2O}-4G_{(Pt)H}-G_{O_{2,aqua}}=2*0-(4*G_{(Pt)H}+329.68)=-523.925$ kJ/mol gives metal hydrogen free energy content $G_{H(Pt)}=(2G_{H_2O}-\Delta G_{eq 2H_2O}-G_{O_{2,aqua}})/4=(2*0+523.925-329.68)/4=194.245/4=48.56$ kJ/mol.

In the reaction, $H(Pt)+H_2O=H_3O^++e^-$, the standard potential $\Delta G_{eq}=E^{\circ}_{H} \cdot F \cdot 1 \cdot 1 = -0.27073 * 96485 * 1 = -26.12$ kJ/mol free energy is identical to the absolute free energy by Hess's law on a scale the zero $G_{H_2O}=0$ kJ/mol of water

$$\Delta G_{Hess, eq}=G_{H_3O^+}+G_{e^-}-(G_{H(Pt)}+G_{H_2O})=22.44+0-(48.56+0)=-26.12 \text{ kJ/mol.}$$

The absolute standard potential $E^{\circ}_{H}=-0.27073$ in Volts coincides with Alberty absolute free energy. [8]

Key Words: Physical Chemistry; Biochemistry; Thermodynamics; Attractors; Electrode potential.

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