Blue bottle reaction

CH102 General Chemistry, Spring 2009

Metabolism is powered by food “burning” in O₂

Metabolic pathways harness the spontaneous flow of electrons to power the life processes. Metabolic pathways are analogous to electrochemical external circuits.

Dextrose “burns” in oxygen

A step in oxidation of dextrose is

\[ 2 \text{RCHO} + \text{O}_2 \rightarrow 2 \text{RCOO}^- + 2 \text{H}^+ \ , \Delta G^\circ < 0 \]

Evaluate \( E^\circ \) and \( \Delta G^\circ \) for this oxidation step,

\[ \text{O}_2 + 4 \text{H}^+ + 4 e^- \rightarrow 2 \text{H}_2\text{O}, \ E^\circ = +0.816 \text{ V} \]

\[ \text{RCOO}^- + 3 \text{H}^+ + 2 e^- \rightarrow \text{RCHO} + \text{H}_2\text{O}, \ E^\circ = –0.44 \text{ V} \]

\[ 2 \text{RCHO} + \text{O}_2 \rightarrow 2 \text{RCOO}^- + 2 \text{H}^+ \]

\[ E^\circ = E^\circ_{\text{cathode}} – E^\circ_{\text{anode}} \]

\[ = +0.816 \text{ V} – (–0.44 \text{ V}) = +1.26 \text{ V} \]

\[ \Delta G^\circ = –nFE^\circ \]

\[ = –(4 \times 96,500 \text{ C/mol} \times 1.26 \text{ J/C}) = –486 \text{ kJ/mol} \]

How to harness the burning?

Metabolic pathways!
Couple dextrose oxidation to O₂

Methylene blue redox, $E^o = +0.011 \, V$,

(link) MB$^+$ + H$^+$ + 2 e$^- \leftrightarrow$ MBH

links the oxidation of dextrose, $E^o = –0.44 \, V$,

(ox) 2 RCHO + 2 H$_2$O $\rightarrow$ 2 RCOO$^-$ + 6 H$^+$ + 4 e$^-$

to reduction of oxygen, $E^o = +0.816 \, V$,

(reducing) O$_2$ + 4 H$^+$ + 4 e$^- \rightarrow$ 2 H$_2$O

The MB$^+$ | MBH process plays the role of an external circuit for the combustion of dextrose,

2 RCHO + O$_2$ $\rightarrow$ 2 RCOO$^-$ + 2 H$_2$O, $E^o = +1.26 \, V$

Coupling dextrose oxidation to O₂

Breathe in: (red) – (link): O$_2$ oxidizes MBH,

O$_2$ + 2 H$_2$O + 2 MBH $\rightarrow$ 2 MB$^+$ + 2 H$_2$O

Breathe out: (link) – (ox): MB$^+$ oxidizes dextrose (RCHO),

MB$^+$ + RCHO + H$_2$O $\rightarrow$ MBH + RCOO$^-$ + 2 H$^+$

Breathe in: (red) – (link): O$_2$ oxidizes MBH,

O$_2$ + 2 H$_2$O + 2 MBH $\rightarrow$ 2 MB$^+$ + 2 H$_2$O

Breathe out: (link) – (ox): MB$^+$ oxidizes dextrose (RCHO),

MB$^+$ + RCHO + H$_2$O $\rightarrow$ MBH + RCOO$^-$ + 2 H$^+$

e etc., ...

until the food runs out (time to eat!)

Metabolism couples oxidation of “food” to reduction of O₂

Metabolic pathways harness the spontaneous flow of electrons to power the life processes.

Metabolic pathways are analogous to electrochemical external circuits.