

TABLE 14. Hydrogenations: electron-accepting, formally hydrogen-consuming reactions of energy metabolism^a

Equation no.	Substrates ^b	Products ^b	ΔG°	
			kcal/reaction	kJ/reaction
Carboxylic acids				
1	Formate ⁻ + H ⁺ + H ₂	Formaldehyde + H ₂ O	+5.6	+23.4
2	Formate ⁻ + H ⁺ + 2H ₂	Methanol + H ₂ O	-5.2	-21.8
3	Formate ⁻ + H ⁺ + 3H ₂	Methane + 2H ₂ O	-32.1	-134.3
4	Acetate ⁻ + H ⁺ + 2H ₂	Ethanol + H ₂ O	-2.3	-9.6
5	2 Acetate ⁻ + H ⁺ + 2H ₂	Butyrate ⁻ + 2H ₂ O	-11.5	-48.1
6	Acetate ⁻ + propionate ⁻ + H ⁺ + 2H ₂	Valerate ⁻ + 2H ₂ O	-11.5	-48.1
7	Acetate ⁻ + butyrate ⁻ + H ⁺ + 2H ₂	Caproate ⁻ + 2H ₂ O	-11.5	-48.1
8	Butyrate ⁻ + H ⁺ + 2H ₂	Butanol + H ₂ O	-3.9	-16.3
9	Propionate ⁻ + H ⁺ + 2H ₂	Propanol + H ₂ O	-3.0	-12.1
10	2 Acetate ⁻ + 2H ⁺ + 2H ₂	Acetoin + 2H ₂ O (129)	+12.5	+52.3
11	2 Acetate ⁻ + 2H ⁺ + 3H ₂	2,3-Butanediol + 2H ₂ O (129)	+4.0	+16.7
12	2 Acetate ⁻ + H ⁺	Acetone + HCO ₃ ⁻	+7.4	+31.0
13	2 Acetate ⁻ + H ⁺ + H ₂	Isopropanol + HCO ₃ ⁻	+1.4	+5.9
α-Keto acids				
14	Pyruvate ⁻ + H ₂	Lactate ⁻	-10.3	-43.1
15	Pyruvate ⁻ + H ₂ O + H ₂	Ethanol + HCO ₃ ⁻	-13.6	-56.9
16	Pyruvate ⁻ + H ₂	Acrylate ⁻ + H ₂ O	-11.6	-48.7
17	Pyruvate ⁻ + 2H ₂	Propionate + H ₂ O	-29.4	-123.0
18	2 Pyruvate ⁻ + 2H ₂ O + H ₂	2,3-Butanediol + 2HCO ₃ ⁻ (129)	-20.2	-84.5
19	2 Pyruvate ⁻ + H ₂ O + 2H ₂	2,3-Butanediol + HCO ₃ ⁻ + formate ⁻ (129)	-20.4	-85.4
20	2 Pyruvate ⁻ + H ₂ O + 2H ₂	Butanol + 2HCO ₃ ⁻	-38.0	-159.0
21	Pyruvate ⁻ + acetate ⁻ + H ₂	Butyrate ⁻ + HCO ₃ ⁻	-22.8	-95.4
22	Pyruvate ⁻ + HCO ₃ ⁻ + H ₂	Malate ²⁻ + H ₂ O	-5.0	-20.9
23	Pyruvate ⁻ + HCO ₃ ⁻ + H ₂	Fumarate ²⁻ + 2H ₂ O	-4.1	-17.2
24	Pyruvate ⁻ + HCO ₃ ⁻ + 2H ₂	Succinate ²⁻ + 2H ₂ O	-24.6	-102.9
25	Acetoacetate ⁻ + 2H ₂	Butyrate ⁻ + H ₂ O	-23.0	-96.2
26	Oxalacetate ⁻ + 2H ₂	Succinate ²⁻ + H ₂ O	-31.1	-130.1
27	Acetoacetate ⁻ + H ₂	β -Hydroxybutyrate ^{-c}	-7.0	-29.3
α,β-Unsaturated acids, hydroxy acids				
28	Acrylate ⁻ + H ₂	Propionate ⁻	-17.8	-74.5
29	Crotonate ⁻ + H ₂	Butyrate ⁻	-18.0	-75.2
30	Fumarate ²⁻ + H ₂	Succinate ²⁻	-20.6	-86.2
31	Lactate ⁻ + H ₂	Propionate ⁻ + H ₂ O	-19.1	-79.9
32	β -Hydroxybutyrate ⁻ + H ₂	Butyrate ⁻ + H ₂ O	-20.0	-83.7
33	Malate ²⁻ + H ₂	Succinate ²⁻ + H ₂ O	-19.7	-82.4
34	Glycollate ⁻ + H ₂	Acetate ⁻ + H ₂ O	-18.1	-75.7
35	Propiothetine + H ₂	Propionate ⁻ + H ⁺ + (CH ₃) ₂ S (618)	-27.9	-116.7
Aldehydes				
36	Formaldehyde + H ₂	Methanol	-10.7	-44.8
37	Acetaldehyde + H ₂	Ethanol	-10.0	-41.8
38	Acetone + H ₂	Isopropanol	-5.9	-24.7
39	Glyceraldehyde + H ₂	Glycerol	-12.2	-51.0
Alcohols				
40	Methanol + H ₂	Methane + H ₂ O	-26.9	-112.5
41	Ethanol + H ₂	Ethane + H ₂ O	-21.1	-88.3
42	Ethylene glycol + H ₂	Ethanol + H ₂ O	-21.1	-88.3
Amino acids				
43	Glycine + H ₂	Acetate ⁻ + NH ₄ ⁺	-18.6	-77.8
Inorganic electron acceptors				
44	HCO ₃ ⁻ + H ₂	Formate ⁻ + H ₂ O	-0.3	-1.3
45	HCO ₃ ⁻ + 2H ₂ + H ⁺	Formaldehyde + 2H ₂ O	+5.2	+21.8
46	HCO ₃ ⁻ + 3H ₂ + H ⁺	Methanol + 2H ₂ O	-5.5	-23.0
47	HCO ₃ ⁻ + 4H ₂ + H ⁺	Methane + 3H ₂ O	-32.4	-135.6
48	2 HCO ₃ ⁻ + 4H ₂ + H ⁺	Acetate ⁻ + 4H ₂ O	-25	+104.6

TABLE 14—Continued

Equation no.	Substrates ^b	Products ^b	ΔG°	
			kcal/reaction	kJ/reaction
49	S + H ₂	HS ⁻ + H ⁺	-6.7	-28.0
50	SO ₃ ²⁻ + 2H ⁺ + 2H ₂	S + 3H ₂ O	-34.7	-145.2
51	SO ₃ ²⁻ + 2H ⁺ + 3H ₂	H ₂ S + 3H ₂ O	-41.3	-172.8
52	SO ₄ ²⁻ + H ₂	SO ₃ ²⁻ + H ₂ O	+5.0	+20.9
53	SO ₄ ²⁻ + 2H ⁺ + 3H ₂	S + 4H ₂ O	-29.7	-124.3
54	SO ₄ ²⁻ + H ⁺ + 4H ₂	HS ⁻ + 4H ₂ O	-36.3	-151.9
55	S ₂ O ₃ ²⁻ + 4H ₂	2 HS ⁻ + 3H ₂ O	-41.6	-174.1
56	S ₂ O ₃ ²⁻ + 2H ⁺ + 2H ₂	2 S + 3H ₂ O	-28.3	-118.4
57	3SO ₃ ²⁻ + H ₂ + 4H ⁺	S ₃ O ₆ ²⁻ + 3H ₂ O	-12.0	-50.2
58	S ₃ O ₆ ²⁻ + H ₂	S ₂ O ₃ ²⁻ + SO ₃ ²⁻ + 2H ⁺	-29.1	-121.8
59	S ₂ O ₃ ²⁻ + H ₂	HS ⁻ + SO ₃ ²⁻ + H ⁺	-0.3	-1.1
60	S ₂ O ₆ ²⁻ + H ₂	2 S ₂ O ₃ ²⁻ + 2H ⁺	-20.2	-84.5
61	N ₂ + 2H ⁺ + 3H ₂	2 NH ₄ ⁺	-18.8	-80.0
62	2 NO ₂ ⁻ + 2H ⁺ + 3H ₂	N ₂ + 4H ₂ O	-189.8	-794.1
63	NO ₂ ⁻ + 2H ⁺ + 3H ₂	NH ₄ ⁺ + 2H ₂ O	-104.3	-436.4
64	NO ₃ ⁻ + H ₂	NO ₂ ⁻ + H ₂ O	-39.0	-163.2
65	NO ₃ ⁻ + 2H ⁺ + 4H ₂	NH ₄ ⁺ + 3H ₂ O	-143.3	-599.6
66	2 NO ₃ ⁻ + 2H ⁺ + 5H ₂	N ₂ + 6H ₂ O	-267.8	-1120.5
67	NO ₂ ⁻ + 1/2 H ₂ + H ⁺	NO + H ₂ O	-17.5	-73.2
68	2 NO + H ₂	N ₂ O + H ₂ O	-73.2	-306.3
69	N ₂ O + H ₂	N ₂ + H ₂ O	-81.6	-341.4
70	2 O ₂ + H ₂	2 O ₂ ⁻ + 2 H ⁺	-5.2	-21.9
71	O ₂ + H ₂	H ₂ O ₂	-32.1	-134.3
72	H ₂ O ₂ + H ₂	2H ₂ O	-81.3	-340.2
73	O ₂ + 2H ₂	2H ₂ O	-113.4	-474.5

^a According to Decker et al. (129). The free energy data have been recalculated using the free energies of formation from the elements listed in Table 15, and are given to the first decimal place, which is, however, not significant in most of the values. The data do not include the formation or consumption of ATP.

^b H₂, O₂, CH₄, C₂H₆, N₂, NO, and N₂O are in the gaseous state; all other substances at 1 mol/kg activity.

^c See footnote o, Table 15.

