

41. Heats of Formation and Heats of Combustion

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Tables 41-1, 41-2, and 41-3 list values of the enthalpy of formation, ΔH_f° , and enthalpy of combustion, ΔH_c° , of pure elements and compounds in their standard states at one atmosphere pressure and 25°C in units of kilocalories per mole. Data on "key" substances, which play important roles in evaluating the data on other compounds, are collected in Table 41-1. Enthalpies of formation of elements and inorganic compounds are given in Table 41-2. They are arranged in a standard order, based on the order of elements in the periodic table. The organic compounds in Table 41-3 are arranged first by standard order of the elements of which they are composed and then by classes which have certain common molecular structural features or functional groups.

41-1. Sources of Data. All reported values were derived from published experimental measurements, and most of the data were selected from the following compilations: (1) Selected Values of Chemical Thermodynamic Properties: part 1, *NBS Tech. Note 270-1*, 1965; part 2, *NBS Tech. Note 270-2*, 1966; (2) Selected Values of Properties of Hydrocarbons and Related Compounds, *Am. Petroleum Inst. Research Proj. 44*, Thermodynamics Research Center, Texas A&M University, College Station, Texas (looseleaf data sheets, extant 1967); (3) Selected Values of Properties of Chemical Compounds, *Thermodyn. Research Center Data Proj.*, Texas A&M University, College Station, Texas (looseleaf data sheets, extant 1967).

These sources were supplemented by information in the files of the Thermodynamics Research Center at Texas A&M University. Data in all three tables are internally consistent, and, wherever necessary, original data have been converted to the units and conventions listed below.

41-2. Symbols and Units

calorie the thermochemical calorie defined as equal to 4.184 joules (exactly)
mole a unit of mass equal to the formula (molecular) weight in grams, calculated from the 1961 table of unified atomic weights based on carbon-12
standard state for condensed phases, the specified crystal or liquid form at one atmosphere pressure; for gases, the hypothetical ideal gas at one atmosphere pressure

| | |
|-----|---|
| g | gas |
| l | liquid |
| c | crystal |
| aq | aqueous (water) solution |
| H | enthalpy, $H = U + PV$, for a change from an initial to a final state, $\Delta H = H(\text{final}) - H(\text{initial})$, which is equal to the heat absorbed by the system at constant pressure |

ΔH_f° the heat of formation of one mole of compound or element in its standard state from the elements in their reference states. [For an organic oxygen compound this corresponds to the chemical reaction, $a\text{C}(\text{graphite}) + \frac{1}{2}b\text{H}_2(\text{gas}) + \frac{1}{2}c\text{O}_2(\text{gas}) \rightarrow \text{C}_a\text{H}_b\text{O}_c(\text{standard state})$. Reference states for elements are identified by a zero enthalpy of formation in the tables.]

ΔH_c° , gross the heat of combustion of a compound with excess oxygen gas to produce pure, thermodynamically stable products at 25°C and one atmosphere, with all components in their standard states. [The products of combustion are: $\text{CO}_2(\text{gas})$, $\text{H}_2\text{O}(\text{liquid})$, $\text{HF}(\text{gas})$, $\text{Cl}_2(\text{gas})$, $\text{Br}_2(\text{liquid})$, $\text{I}_2(\text{crystal})$, $\text{H}_2\text{SO}_4(\text{liquid})$, and $\text{N}_2(\text{gas})$, as appropriate for the stoichiometry of the combustion reaction.]

ΔH_c° , net the heat of combustion of a compound with excess oxygen to produce the following products: $\text{CO}_2(\text{gas})$, $\text{H}_2\text{O}(\text{gas})$, $\text{HF}(\text{gas})$, $\text{Cl}_2(\text{gas})$, $\text{Br}_2(\text{gas})$, $\text{I}_2(\text{gas})$, $\text{SO}_2(\text{gas})$, and $\text{N}_2(\text{gas})$. (These are the principal products formed when a compound is burned in an open flame in the air.)

41-3. Uncertainties. The number of significant figures used in reporting a value of ΔH_f° or ΔH_c° is related to the estimated uncertainty according to the following scheme.

| <i>Estimated uncertainty in ΔH_f° or ΔH_c°, kcal mole⁻¹</i> | <i>Value written to</i> |
|--|-------------------------|
| 0.005-0.05 | 0.001 |
| 0.05-0.5 | 0.01 |
| 0.5-2 | 0.1 |
| 2-10 | 1. |

TABLE 4I-1. HEATS OF FORMATION AND HEATS OF COMBUSTION OF KEY COMPOUNDS

| Substance name | Formula and state | Mol. weight | kcal mole ⁻¹ at 25°C | | |
|---|--|-------------|---------------------------------|---------------------|----------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Water..... | H ₂ O,g | 18.015 | -57.796 | | |
| | H ₂ O,l | ..... | -68.315 | | |
| Hydrogen fluoride..... | HF,g | 20.006 | -64.8 | | |
| | HF,l | ..... | 71.65 | | |
| in ∞ H ₂ O..... | HF,aq | ..... | -79.54 | | |
| Hydrogen chloride..... | HCl,g | 36.461 | -22.062 | 12.096 | 6.836 |
| in ∞ H ₂ O..... | HCl,aq | ..... | -39.952 | | |
| Hydrogen bromide..... | HBr,g | 80.917 | -8.70 | 25.46 | 16.50 |
| in ∞ H ₂ O..... | HBr,aq | ..... | -29.05 | | |
| Hydrogen Iodide..... | HI,g | 127.912 | 6.33 | 40.49 | 27.77 |
| Sulfur dioxide..... | SO ₂ ,g | 64.063 | -70.944 | | |
| | SO ₂ ,l | ..... | -76.6 | | |
| Sulfuric acid..... | H ₂ SO ₄ ,l | 98.078 | -194.548 | | |
| in ∞ H ₂ O..... | H ₂ SO ₄ ,aq | ..... | -217.32 | | |
| in 115 H ₂ O..... | H ₂ SO ₄ ,aq | ..... | -212.192 | | |
| Orthophosphoric acid..... | H ₃ PO ₄ ,c | 97.995 | -305.7 | | |
| | H ₃ PO ₄ ,l | ..... | -302.8 | | |
| in ∞ H ₂ O..... | H ₃ PO ₄ ,aq | ..... | -307.92 | | |
| Carbon dioxide..... | CO ₂ ,g | 44.010 | -94.051 | | |
| Butanedioic acid (succinic acid) | C ₄ H ₆ O ₄ ,g | 118.090 | -196.8 | 384.35 | 352.79 |
| | C ₄ H ₆ O ₄ ,c | ..... | -224.86 | 356.29 | 324.73 |
| Benzoic acid..... | C ₇ H ₆ O ₂ ,g | 122.125 | -70.19 | 793.11 | 761.55 |
| | C ₇ H ₆ O ₂ ,c | ..... | -92.04 | 771.26 | 739.70 |
| Carbon tetrafluoride (tetrafluoromethane)..... | CF ₄ ,g | 88.005 | -221 | | |
| <i>p</i> -Fluorobenzoic acid..... | C ₈ H ₅ O ₂ F,c | 140.115 | -139.56 | 720.22 | 699.19 |
| α,α,α -Trifluoro- <i>m</i> -toluic acid..... | C ₈ H ₅ O ₂ F ₃ ,c | 190.123 | -253.68 | 761.44 | 750.92 |
| Carbon disulfide..... | CS ₂ ,g | 76.139 | 21.44 | ..... | 263.99 |
| | CS ₂ ,l | ..... | 28.05 | ..... | 257.38 |
| Thianthrene (diphenylene disulfide)..... | C ₁₂ H ₈ S ₂ ,c | 216.326 | 43.12 | 1,697.46 | 1,544.80 |
| <i>N</i> -Benzoylaminoethanoic acid (hippuric acid)... | C ₉ H ₉ O ₃ N,c | 179.177 | -145.49 | 1,008.39 | 961.05 |
| Boric oxide..... | B ₂ O ₃ ,c | 69.620 | -304.20 | | |
| amorphous..... | B ₂ O ₃ ,c | ..... | -200.81 | | |
| Boron trifluoride | BF ₃ ,g | 67.806 | -271.03 | | |
| Silicon dioxide | | | | | |
| quartz..... | SiO ₂ ,c | 60.085 | -217.72 | | |
| cristobalite..... | SiO ₂ ,c | ..... | -217.37 | | |
| tridymite..... | SiO ₂ ,c | ..... | -217.27 | | |
| amorphous..... | SiO ₂ ,c | ..... | -215.95 | | |
| Silicon tetrafluoride..... | SiF ₄ ,g | 104.080 | -385.98 | | |

HEATS OF FORMATION AND HEATS OF COMBUSTION 4-319

TABLE 4I-2. HEATS OF FORMATION OF ELEMENTS AND INORGANIC COMPOUNDS

| Substance name | Formula | Mol. weight | ΔH_f° , kcal mole ⁻¹ at 25°C | | |
|----------------------------|---------------------------------|-------------|--|---------|---------|
| | | | Gas | Liquid | Solid |
| Oxygen and Hydrogen | | | | | |
| Oxygen..... | O ₂ | 31.999 | 0.0 | | |
| Ozone..... | O ₃ | 47.998 | 34.1 | | |
| Hydrogen..... | H ₂ | 2.016 | 0.0 | | |
| Hydrogen peroxide..... | H ₂ O ₂ | 34.015 | ..... | -44.88 | |
| Halogens | | | | | |
| Fluorine..... | F ₂ | 37.997 | 0.0 | | |
| Chlorine..... | Cl ₂ | 70.906 | 0.0 | | |
| Chlorine monoxide..... | ClO | 51.452 | 24.36 | | |
| Chlorine dioxide..... | ClO ₂ | 67.452 | 24.5 | | |
| Dichlorine monoxide..... | Cl ₂ O | 86.905 | 19.2 | | |
| Perchloric acid..... | HClO ₄ | 100.459 | ..... | -9.70 | |
| Chlorine monofluoride..... | ClF | 54.451 | -11.92 | | |
| Chlorine trifluoride..... | ClF ₃ | 92.448 | -38.0 | -44.3 | |
| Bromine..... | Br ₂ | 159.818 | 7.39 | 0.0 | |
| Bromine monoxide..... | BrO | 95.908 | 30.06 | | |
| Bromine dioxide..... | BrO ₂ | 111.008 | ..... |  | 11.6 |
| Bromine trifluoride..... | BrF ₃ | 136.904 | ..... | -71.9 | |
| Bromine pentafluoride..... | BrF ₅ | 174.901 | -102.5 | -109.6 | |
| Bromine chloride..... | BrCl | 115.362 | 3.50 | | |
| Iodine..... | I ₂ | 253.809 | 14.92 | | 0.0 |
| Iodic acid..... | HIO ₃ | 175.911 | ..... |  | -55.0 |
| Iodine monofluoride..... | IF | 145.903 | -2.10 | | |
| Iodine pentafluoride..... | IF ₅ | 221.896 | -196.58 | -206.7 | |
| Iodine heptafluoride..... | IF ₇ | 259.893 | -225.0 | | |
| Iodine monochloride..... | ICl | 162.357 | 4.25 | -5.71 | -8.4 |
| Iodine trichloride..... | ICl ₃ | 233.263 | ..... |  | -21.4 |
| Iodine monobromide..... | IBr | 206.813 | 9.76 | ..... | -2.5 |
| Sulfur | | | | | |
| Sulfur..... | S | 32.064 | 66.64 | | |
| rhombic..... | ..... | ..... | ..... |  | 0.0 |
| monoclinic..... | ..... | ..... | ..... |  | 0.08 |
| Sulfur..... | S ₂ | 64.128 | 30.68 | | |
| Sulfur..... | S ₃ | 96.192 | 31.7 | | |
| Sulfur trioxide..... | SO ₃ | 80.062 | -94.58 | -105.41 | -108.63 |
| Hydrogen sulfide..... | H ₂ S | 34.080 | -4.93 | | |
| Sulfur tetrafluoride..... | SF ₄ | 108.058 | -185.2 | | |
| Sulfur hexafluoride..... | SF ₆ | 146.054 | -289. | | |
| Disulfur dichloride..... | S ₂ Cl ₂ | 135.034 | -4.4 | -14.2 | |
| Thionyl chloride..... | SOCl ₂ | 118.969 | -50.8 | -58.7 | |
| Sulfuryl chloride..... | SO ₂ Cl ₂ | 134.969 | -87.0 | -94.2 | |
| Thionyl bromide..... | SOBr ₂ | 207.881 | -17.7 | | |
| Nitrogen | | | | | |
| Nitrogen..... | N ₂ | 28.013 | 0.0 | | |
| Nitric oxide..... | NO | 30.006 | 21.57 | | |
| Nitrogen dioxide..... | NO ₂ | 46.006 | 7.93 | | |

TABLE 4I-2. HEATS OF FORMATION OF ELEMENTS AND INORGANIC COMPOUNDS (*Continued*)

| Substance name | Formula | Mol. weight | ΔH_f° , kcal mole ⁻¹ at 25°C | | |
|--------------------------------|---|-------------|--|--------|---------|
| | | | Gas | Liquid | Solid |
| Nitrogen (Cont.) | | | | | |
| Nitrous oxide..... | N ₂ O | 44.013 | 19.61 | | |
| Nitrogen trioxide..... | N ₂ O ₃ | 76.012 | 20.01 | 12.02 | |
| Nitrogen tetroxide..... | N ₂ O ₄ | 29.011 | 2.19 | -4.66 | |
| Nitrogen pentoxide..... | N ₂ O ₅ | 108.010 | 2.7 | | -10.3 |
| Ammonia..... | NH ₃ | 17.031 | -11.02 | | |
| Hydrazine..... | N ₂ H ₄ | 32.045 | 22.80 | 12.10 | |
| Hydrogen azide..... | HN ₃ | 43.028 | 70.3 | 63.1 | |
| Nitrous acid..... | HNO ₂ | 47.014 | -19.0 | | |
| Nitric acid..... | HNO ₃ | 63.013 | -92.28 | -41.01 | |
| Hydroxylamine..... | NH ₂ OH | 33.030 | | | -27.3 |
| Ammonium hydroxide..... | NH ₄ OH | 35.046 | | -86.33 | |
| Ammonium nitrate..... | NH ₄ NO ₃ | 80.044 | | | -87.37 |
| Nitrogen trifluoride..... | NF ₃ | 71.002 | -29.8 | | |
| Nitrosyl fluoride..... | NOF | 49.005 | -15.9 | | |
| Ammonium fluoride..... | NH ₄ F | 37.037 | | | -110.89 |
| Nitrogen trichloride..... | NCl ₃ | 120.366 | | 55 | |
| Nitrosyl chloride..... | NOCl | 65.459 | 12.36 | | |
| Ammonium chloride..... | NH ₄ Cl | 53.492 | | | -75.15 |
| Hydrazine hydrochloride... | N ₂ H ₅ Cl | 68.506 | | | -47.0 |
| Ammonium perchlorate.... | NH ₄ ClO ₄ | 117.489 | | | -70.58 |
| Nitrosyl bromide..... | NOBr | 109.915 | 19.64 | | |
| Ammonium bromide..... | NH ₄ Br | 94.924 | | | -64.73 |
| Ammonium iodide..... | NH ₄ I | 144.943 | | | -48.14 |
| Ammonium hydrogen sulfide..... | NH ₄ HS | 51.111 | | | -37.5 |
| Sulfamic acid..... | H ₂ NSO ₃ H | 97.093 | | | -161.3 |
| Sulfamide..... | SO ₂ (NH ₂) ₂ | 96.108 | | | -129.3 |
| Ammonium hydrogen sulfate..... | NH ₄ HSO ₄ | 115.108 | | | -245.45 |
| Ammonium sulfate..... | (NH ₄) ₂ SO ₄ | 132.139 | | | -282.23 |
| Phosphorus | | | | | |
| Phosphorus | | | | | |
| α, white..... | P | 30.974 | | | 0.0 |
| triclinic, red..... | | | | | -4.2 |
| black..... | | | | | -9.4 |
| amorphous, red..... | | | | | -1.8 |
| Phosphorus..... | P ₂ | 61.948 | 34.5 | | |
| Phosphorus..... | P ₄ | 123.895 | 14.08 | | |
| Phosphorus trioxide..... | P ₄ O ₆ | 219.892 | | | -392.0 |
| Phosphorus pentoxide..... | P ₄ O ₁₀ | 283.889 | | | -713.2 |
| Phosphine..... | PH ₃ | 33.998 | 1.3 | | |
| Metaphosphoric acid..... | HPO ₃ | 79.980 | | | -226.7 |
| Pyrophosphoric acid..... | H ₄ P ₂ O ₇ | 177.975 | | | -535.6 |
| Phosphorus trifluoride.... | PF ₃ | 87.969 | -219.6 | | |
| Phosphorus pentafluoride... | PF ₅ | 125.966 | -381.4 | | |
| Phosphorus oxyfluoride.... | POF ₃ | 103.968 | -289.5 | | |
| Phosphorus trichloride.... | PCl ₃ | 137.333 | | -76.4 | |
| Phosphorus pentachloride... | PCl ₅ | 208.239 | -89.6 | | -106.0 |
| Phosphorus oxychloride.... | POCl ₃ | 153.332 | | -142.7 | |
| Phosphorus tribromide.... | PBr ₃ | 270.701 | -33.3 | -44.1 | |
| Phosphorus pentabromide... | PBr ₅ | 430.494 | | | -64.5 |
| Phosphorus oxybromide.... | POBr ₃ | 286.700 | | | -109.6 |

HEATS OF FORMATION AND HEATS OF COMBUSTION 4-321

 TABLE 4I-2. HEATS OF FORMATION OF ELEMENTS AND
 INORGANIC COMPOUNDS (Continued)

| Substance name | Formula | Mol. weight | ΔH_f° , kcal mole ⁻¹ at 25°C | | |
|------------------------------------|---|-------------|--|--------|---------|
| | | | Gas | Liquid | Solid |
| Phosphorus (Cont.) | | | | | |
| Phosphorus triiodide..... | PI ₃ | 411.687 | ..... | ..... | -10.0 |
| Ammonium dihydrogen phosphate..... | NH ₄ H ₂ PO ₄ | 115.026 | ..... | ..... | -345.94 |
| Ammonium hydrogen phosphate..... | (NH ₄) ₂ HPO ₄ | 132.057 | ..... | ..... | -347.50 |
| Ammonium phosphate..... | (NH ₄) ₃ PO ₄ | 149.087 | ..... | ..... | -399.6 |
| Boron | | | | | |
| Boron..... | B | 10.811 | ..... | ..... | 0.0 |
| amorphous..... | ..... | ..... | ..... | ..... | 0.9 |
| Diborane..... | B ₂ H ₆ | 27.670 | 8.5 | ..... | ..... |
| Boric acid..... | H ₃ BO ₃ | 61.833 | ..... | ..... | -261.55 |
| Boron trichloride..... | BCl ₃ | 117.170 | -96.50 | -102.1 | ..... |
| Silicon | | | | | |
| Silicon..... | Si | 28.086 | ..... | ..... | 0.0 |
| amorphous..... | ..... | ..... | ..... | ..... | 1.0 |
| Silicon..... | Si ₂ | 56.172 | 142 | ..... | ..... |
| Silicon monoxide..... | SiO | 44.085 | -23.8 | ..... | ..... |
| Silane..... | SiH ₄ | 32.118 | 8.2 | ..... | ..... |
| Disilane..... | Si ₂ H ₆ | 62.220 | 19.2 | ..... | ..... |
| Metasilic acid..... | H ₂ SiO ₃ | 78.100 | ..... | ..... | -284.1 |
| Orthosilic acid..... | H ₄ SiO ₄ | 96.116 | ..... | ..... | -354.0 |
| Silicon tetrachloride..... | SiCl ₄ | 169.898 | -157.03 | -164.2 | ..... |
| Silicon tetrabromide..... | SiBr ₄ | 347.722 | -99.3 | -109.3 | ..... |
| Silicon tetraiodide..... | SiI ₄ | 535.704 | ..... | ..... | -45.3 |
| Tetramethylsilane..... | Si(CH ₃) ₄ | 88.226 | -57.15 | -63 | ..... |
| Hexamethyldisiloxane..... | [(CH ₃) ₂ Si] ₂ O | 162.382 | -185.88 | -194.8 | ..... |
| Beryllium, Sodium, Potassium | | | | | |
| Beryllium..... | Be | 9.012 | 78.0 | ..... | 0.0 |
| Beryllium oxide..... | BeO | 25.012 | 30.2 | ..... | -145.0 |
| Beryllium fluoride..... | BeF ₂ | 47.009 | -186.1 | ..... | -245.3 |
| Beryllium chloride..... | BeCl ₂ | 79.918 | -85.7 | ..... | -117.2 |
| Sodium..... | Na | 22.990 | 25.9 | ..... | 0.0 |
| Sodium oxide..... | Na ₂ O | 61.979 | ..... | ..... | -99.4 |
| Sodium hydride..... | NaH | 23.998 | 29.88 | ..... | -13.7 |
| Sodium hydroxide..... | NaOH | 39.997 | ..... | ..... | -101.72 |
| Sodium fluoride..... | NaF | 41.988 | -70.1 | ..... | -136.6 |
| Sodium chloride..... | NaCl | 58.443 | -43.7 | ..... | -98.5 |
| Sodium carbonate..... | Na ₂ CO ₃ | 105.989 | ..... | ..... | -269.8 |
| Sodium formate..... | NaCHO ₂ | 68.008 | ..... | ..... | -155.03 |
| Sodium acetate..... | NaC ₂ H ₃ O ₂ | 82.035 | ..... | ..... | -169.8 |
| Potassium..... | K | 39.102 | 21.52 | ..... | 0.0 |
| Potassium oxide..... | K ₂ O | 94.203 | ..... | ..... | -86.4 |
| Potassium hydride..... | KH | 40.110 | 30.0 | ..... | -15.6 |
| Potassium hydroxide..... | KOH | 56.109 | ..... | ..... | -101.52 |
| Potassium fluoride..... | KF | 58.100 | -78.2 | ..... | -134.4 |
| Potassium chloride..... | KCl | 74.555 | -51.6 | ..... | -104.1 |

TABLE 4I-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|----------------------------------|-----------------------------------|-------------|---------------------------------|---------------------|----------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon and Carbon-Oxygen | | | | | |
| Carbon..... | C,g | 12.011 | 171.29 | 265.34 | 265.34 |
| graphite..... | C,c | ..... | 0.0 | 94.05 | 94.05 |
| diamond..... | C,c | ..... | 0.45 | 94.50 | 94.50 |
| Carbon..... | C ₂ ,g | 24.021 | 199.03 | 387.13 | 387.13 |
| Carbon monoxide..... | CO,g | 28.011 | -26.42 | 67.64 | 67.64 |
| Carbon suboxide..... | C ₃ O ₂ ,g | 68.032 | -22.20 | 259.95 | 259.95 |
| | C ₃ O ₂ ,l | ..... | -28.03 | 254.12 | 254.12 |
| Carbon-Hydrogen, Alkanes | | | | | |
| Methane..... | CH ₄ ,g | 16.043 | -17.88 | 212.80 | 191.76 |
| Ethane..... | C ₂ H ₆ ,g | 30.070 | -20.23 | 372.82 | 341.26 |
| Propane..... | C ₃ H ₈ ,g | 44.097 | -24.81 | 530.60 | 488.52 |
| | C ₃ H ₈ ,l | ..... | -28.69 | 526.72 | 484.64 |
| <i>n</i> -Butane..... | C ₄ H ₁₀ ,g | 58.124 | -30.14 | 687.64 | 635.04 |
| | C ₄ H ₁₀ ,l | ..... | -35.31 | 682.47 | 629.87 |
| 2-Methylpropane (isobutane) .. | C ₄ H ₁₀ ,g | 58.124 | -32.14 | 685.64 | 633.04 |
| | C ₄ H ₁₀ ,l | ..... | -36.88 | 680.89 | 628.30 |
| <i>n</i> -Pentane..... | C ₅ H ₁₂ ,g | 72.151 | -34.98 | 845.16 | 782.05 |
| | C ₅ H ₁₂ ,l | ..... | -41.37 | 838.78 | 775.66 |
| 2-Methylbutane (isopentane) .. | C ₅ H ₁₂ ,g | 72.151 | -36.90 | 843.24 | 780.13 |
| | C ₅ H ₁₂ ,l | ..... | -42.92 | 837.22 | 774.11 |
| 2,2-Dimethylpropane (neopentane) | C ₅ H ₁₂ ,g | 72.151 | -39.66 | 840.49 | 777.38 |
| | C ₅ H ₁₂ ,l | ..... | -45.00 | 835.14 | 772.03 |
| <i>n</i> -Hexane..... | C ₆ H ₁₄ ,g | 86.178 | -39.92 | 1,002.59 | 928.95 |
| | C ₆ H ₁₄ ,l | ..... | -47.50 | 995.01 | 921.38 |
| 2-Methylpentane..... | C ₆ H ₁₄ ,g | 86.178 | -41.62 | 1,000.89 | 927.26 |
| | C ₆ H ₁₄ ,l | ..... | -48.80 | 993.71 | 920.08 |
| 3-Methylpentane..... | C ₆ H ₁₄ ,g | 86.178 | -40.99 | 1,001.52 | 927.89 |
| | C ₆ H ₁₄ ,l | ..... | -48.26 | 994.25 | 920.62 |
| 2,2-Dimethylbutane..... | C ₆ H ₁₄ ,g | 86.178 | -44.32 | 998.19 | 924.56 |
| | C ₆ H ₁₄ ,l | ..... | -50.99 | 991.52 | 917.89 |
| 2,3-Dimethylbutane..... | C ₆ H ₁₄ ,g | 86.178 | -42.46 | 1,000.06 | 926.42 |
| | C ₆ H ₁₄ ,l | ..... | -49.46 | 993.05 | 919.42 |
| <i>n</i> -Heptane..... | C ₇ H ₁₆ ,g | 100.206 | -44.85 | 1,160.02 | 1,075.87 |
| | C ₇ H ₁₆ ,l | ..... | -53.61 | 1,151.27 | 1,067.12 |
| 2-Methylhexane..... | C ₇ H ₁₆ ,g | 100.206 | -46.57 | 1,158.31 | 1,074.16 |
| | C ₇ H ₁₆ ,l | ..... | -54.91 | 1,149.97 | 1,065.82 |
| 3-Methylhexane..... | C ₇ H ₁₆ ,g | 100.206 | -45.92 | 1,158.96 | 1,074.80 |
| | C ₇ H ₁₆ ,l | ..... | -54.32 | 1,150.55 | 1,066.40 |
| 3-Ethylpentane..... | C ₇ H ₁₆ ,g | 100.206 | -45.29 | 1,159.59 | 1,075.44 |
| | C ₇ H ₁₆ ,l | ..... | -53.75 | 1,151.13 | 1,066.98 |
| 2,2-Dimethylpentane..... | C ₇ H ₁₆ ,g | 100.206 | -49.25 | 1,155.63 | 1,071.48 |
| | C ₇ H ₁₆ ,l | ..... | -57.03 | 1,147.85 | 1,063.70 |
| 2,3-Dimethylpentane..... | C ₇ H ₁₆ ,g | 100.206 | -46.78 | 1,158.10 | 1,073.95 |
| | C ₇ H ₁₆ ,l | ..... | -55.79 | 1,149.09 | 1,064.94 |
| 2,4-Dimethylpentane..... | C ₇ H ₁₆ ,g | 100.206 | -48.26 | 1,156.62 | 1,072.47 |
| | C ₇ H ₁₆ ,l | ..... | -56.15 | 1,148.73 | 1,064.58 |

HEATS OF FORMATION AND HEATS OF COMBUSTION 4-323

TABLE 4I-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (Continued)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|----------------------------------|-----------------------------------|-------------|---------------------------------|---------------------|----------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Hydrogen, Alkanes (Cont.) | | | | | |
| 3,3-Dimethylpentane..... | C ₇ H ₁₆ ,g | 100.206 | -48.12 | 1,156.75 | 1,072.60 |
| | C ₇ H ₁₆ ,l | ..... | -56.05 | 1,148.83 | 1,064.68 |
| 2,2,3-Trimethylbutane..... | C ₇ H ₁₆ ,g | 100.206 | -48.92 | 1,155.96 | 1,071.81 |
| | C ₇ H ₁₆ ,l | ..... | -56.61 | 1,148.27 | 1,064.12 |
| n-Octane..... | C ₈ H ₁₈ ,g | 114.233 | -49.79 | 1,317.45 | 1,222.78 |
| | C ₈ H ₁₈ ,l | ..... | -59.71 | 1,307.53 | 1,212.86 |
| 2-Methylheptane..... | C ₈ H ₁₈ ,g | 114.233 | -51.47 | 1,315.77 | 1,221.10 |
| | C ₈ H ₁₈ ,l | ..... | -60.96 | 1,306.28 | 1,211.61 |
| 3-Methylheptane..... | C ₈ H ₁₈ ,g | 114.233 | -50.80 | 1,316.45 | 1,221.78 |
| | C ₈ H ₁₈ ,l | ..... | -60.32 | 1,306.92 | 1,212.25 |
| 4-Methylheptane..... | C ₈ H ₁₈ ,g | 114.233 | -50.66 | 1,316.58 | 1,221.91 |
| | C ₈ H ₁₈ ,l | ..... | -60.15 | 1,307.09 | 1,212.42 |
| 3-Ethylhexane..... | C ₈ H ₁₈ ,g | 114.233 | -50.37 | 1,316.87 | 1,222.20 |
| | C ₈ H ₁₈ ,l | ..... | -59.85 | 1,307.39 | 1,212.72 |
| 2,2-Dimethylhexane..... | C ₈ H ₁₈ ,g | 114.233 | -53.68 | 1,313.50 | 1,218.89 |
| | C ₈ H ₁₈ ,l | ..... | -62.60 | 1,304.64 | 1,209.97 |
| 2,3-Dimethylhexane..... | C ₈ H ₁₈ ,g | 114.233 | -51.10 | 1,316.14 | 1,221.47 |
| | C ₈ H ₁₈ ,l | ..... | -60.38 | 1,306.86 | 1,212.19 |
| 2,4-Dimethylhexane..... | C ₈ H ₁₈ ,g | 114.233 | -52.41 | 1,314.83 | 1,220.16 |
| | C ₈ H ₁₈ ,l | ..... | -61.44 | 1,305.80 | 1,211.13 |
| 2,5-Dimethylhexane..... | C ₈ H ₁₈ ,g | 114.233 | -53.19 | 1,314.06 | 1,219.38 |
| | C ₈ H ₁₈ ,l | ..... | -62.24 | 1,305.00 | 1,210.33 |
| 3,3-Dimethylhexane..... | C ₈ H ₁₈ ,g | 114.233 | -52.58 | 1,314.66 | 1,219.99 |
| | C ₈ H ₁₈ ,l | ..... | -61.56 | 1,305.68 | 1,211.01 |
| 3,4-Dimethylhexane..... | C ₈ H ₁₈ ,g | 114.233 | -50.88 | 1,316.36 | 1,221.69 |
| | C ₈ H ₁₈ ,l | ..... | -60.20 | 1,307.04 | 1,212.37 |
| 2-Methyl-3-ethylpentane..... | C ₈ H ₁₈ ,g | 114.233 | -50.45 | 1,316.79 | 1,222.12 |
| | C ₈ H ₁₈ ,l | ..... | -59.66 | 1,307.58 | 1,212.91 |
| 3-Methyl-3-ethylpentane..... | C ₈ H ₁₈ ,g | 114.233 | -51.36 | 1,315.88 | 1,221.21 |
| | C ₈ H ₁₈ ,l | ..... | -60.44 | 1,306.80 | 1,212.13 |
| 2,2,3-Trimethylpentane..... | C ₈ H ₁₈ ,g | 114.233 | -52.58 | 1,314.66 | 1,219.99 |
| | C ₈ H ₁₈ ,l | ..... | -61.41 | 1,305.83 | 1,211.16 |
| 2,2,4-Trimethylpentane..... | C ₈ H ₁₈ ,g | 114.233 | -53.55 | 1,313.69 | 1,219.02 |
| | C ₈ H ₁₈ ,l | ..... | -61.95 | 1,305.20 | 1,210.62 |
| 2,3,3-Trimethylpentane..... | C ₈ H ₁₈ ,g | 114.233 | -51.70 | 1,315.54 | 1,220.87 |
| | C ₈ H ₁₈ ,l | ..... | -60.60 | 1,306.64 | 1,211.97 |
| 2,3,4-Trimethylpentane..... | C ₈ H ₁₈ ,g | 114.233 | -51.94 | 1,315.30 | 1,220.63 |
| | C ₈ H ₁₈ ,l | ..... | -60.96 | 1,306.28 | 1,211.61 |
| 2,2,3,3-Tetramethylbutane.... | C ₈ H ₁₈ ,g | 114.233 | -53.97 | 1,313.28 | 1,218.61 |
| | C ₈ H ₁₈ ,l | ..... | -64.21 | 1,303.03 | 1,208.36 |
| n-Nonane..... | C ₉ H ₂₀ ,g | 128.260 | -54.56 | 1,475.05 | 1,369.86 |
| | C ₉ H ₂₀ ,l | ..... | -65.66 | 1,463.95 | 1,358.76 |
| 2,2-Dimethylheptane..... | C ₉ H ₂₀ ,g | 128.260 | -58.74 | 1,470.87 | 1,365.68 |
| | C ₉ H ₂₀ ,l | ..... | -68.85 | 1,460.76 | 1,355.57 |
| 2,2,3-Trimethylhexane..... | C ₉ H ₂₀ ,g | 128.260 | -57.59 | 1,472.02 | 1,366.83 |
| | C ₉ H ₂₀ ,l | ..... | -67.56 | 1,462.05 | 1,356.86 |
| 2,2,4-Trimethylhexane..... | C ₉ H ₂₀ ,g | 128.260 | -57.85 | 1,471.76 | 1,366.57 |
| | C ₉ H ₂₀ ,l | ..... | -67.58 | 1,462.03 | 1,356.84 |

TABLE 4I-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (Continued)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|---|-----------------------------------|-------------|---------------------------------|---------------------|----------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Hydrogen, Alkanes (Cont.) | | | | | |
| 2,2,5-Trimethylhexane..... | C ₉ H _{20,g} | 128.260 | -60.36 | 1,469.24 | 1,364.06 |
| | C ₉ H _{20,l} | ..... | -69.97 | 1,459.64 | 1,354.45 |
| 2,3,3-Trimethylhexane..... | C ₉ H _{20,g} | 128.260 | -57.13 | 1,472.48 | 1,367.29 |
| | C ₉ H _{20,l} | ..... | -67.18 | 1,462.43 | 1,357.24 |
| 2,3,5-Trimethylhexane..... | C ₉ H _{20,g} | 128.260 | -57.91 | 1,471.70 | 1,366.51 |
| | C ₉ H _{20,l} | ..... | -67.81 | 1,461.80 | 1,356.61 |
| 2,4,4-Trimethylhexane..... | C ₉ H _{20,g} | 128.260 | -57.06 | 1,472.55 | 1,367.36 |
| | C ₉ H _{20,l} | ..... | -66.87 | 1,462.74 | 1,357.55 |
| 3,3,4-Trimethylhexane..... | C ₉ H _{20,g} | 128.260 | -56.20 | 1,473.41 | 1,368.22 |
| | C ₉ H _{20,l} | ..... | -66.33 | 1,463.28 | 1,358.09 |
| 2,2-Dimethyl-3-ethylpentane.. | C ₉ H _{20,g} | 128.260 | -55.21 | 1,474.40 | 1,369.21 |
| | C ₉ H _{20,l} | ..... | -65.17 | 1,464.44 | 1,359.25 |
| 2,4-Dimethyl-3-ethylpentane.. | C ₉ H _{20,g} | 128.260 | -54.30 | 1,475.31 | 1,370.12 |
| | C ₉ H _{20,l} | ..... | -64.42 | 1,465.19 | 1,360.00 |
| <i>n</i> -Decane..... | C ₁₀ H _{22,g} | 142.287 | -59.64 | 1,632.34 | 1,516.63 |
| | C ₁₀ H _{22,l} | ..... | -71.92 | 1,620.06 | 1,504.35 |
| Carbon-Hydrogen, Cycloalkanes | | | | | |
| Cyclopropane..... | C ₃ H _{6,g} | 42.081 | 12.75 | 499.85 | 468.29 |
| Cyclobutane..... | C ₄ H _{8,g} | 56.108 | 6.32 | 655.78 | 613.70 |
| | C ₄ H _{8,l} | ..... | 0.76 | 650.22 | 608.14 |
| Cyclopentane..... | C ₅ H _{10,g} | 70.135 | -18.41 | 793.42 | 740.83 |
| | C ₅ H _{10,l} | ..... | -25.28 | 786.55 | 733.96 |
| Methylcyclopentane..... | C ₆ H _{12,g} | 84.163 | -25.34 | 948.80 | 885.75 |
| | C ₆ H _{12,l} | ..... | -32.92 | 941.28 | 878.17 |
| Ethylcyclopentane..... | C ₇ H _{14,g} | 98.190 | -30.33 | 1,106.23 | 1,032.60 |
| | C ₇ H _{14,l} | ..... | -39.06 | 1,097.50 | 1,023.87 |
| 1,1-Dimethylcyclopentane.... | C ₇ H _{14,g} | 98.190 | -33.02 | 1,103.54 | 1,029.91 |
| | C ₇ H _{14,l} | ..... | -41.12 | 1,095.44 | 1,021.81 |
| 1- <i>cis</i> -2-Dimethylcyclopentane.. | C ₇ H _{14,g} | 98.190 | -30.94 | 1,105.62 | 1,031.99 |
| | C ₇ H _{14,l} | ..... | -39.50 | 1,097.06 | 1,023.43 |
| 1- <i>trans</i> -2-Dimethylcyclopentane | C ₇ H _{14,g} | 98.190 | -32.64 | 1,103.92 | 1,030.29 |
| | C ₇ H _{14,l} | ..... | -40.92 | 1,095.64 | 1,022.01 |
| 1- <i>cis</i> -3-Dimethylcyclopentane.. | C ₇ H _{14,g} | 98.190 | -32.44 | 1,104.12 | 1,030.49 |
| | C ₇ H _{14,l} | ..... | -40.66 | 1,095.90 | 1,022.27 |
| 1- <i>trans</i> -3-Dimethylcyclopentane | C ₇ H _{14,g} | 98.190 | -31.90 | 1,104.66 | 1,031.03 |
| | C ₇ H _{14,l} | ..... | -40.17 | 1,096.39 | 1,022.76 |
| <i>n</i> -Propylcyclopentane..... | C ₈ H _{16,g} | 112.217 | -35.37 | 1,263.56 | 1,179.41 |
| | C ₈ H _{16,l} | ..... | -45.19 | 1,253.74 | 1,169.59 |
| <i>n</i> -Butylcyclopentane..... | C ₉ H _{18,g} | 126.244 | -40.19 | 1,421.10 | 1,326.43 |
| | C ₉ H _{18,l} | ..... | -51.19 | 1,410.10 | 1,315.43 |
| <i>n</i> -Pentylcyclopentane..... | C ₁₀ H _{20,g} | 140.271 | -45.12 | 1,578.54 | 1,473.35 |
| | C ₁₀ H _{20,l} | ..... | -57.30 | 1,566.36 | 1,461.17 |
| <i>n</i> -Hexylcyclopentane..... | C ₁₁ H _{22,g} | 154.298 | -50.04 | 1,735.99 | 1,620.28 |
| | C ₁₁ H _{22,l} | ..... | -63.40 | 1,722.63 | 1,606.92 |
| <i>n</i> -Heptylcyclopentane..... | C ₁₂ H _{24,g} | 168.325 | -54.96 | 1,893.43 | 1,767.20 |
| | C ₁₂ H _{24,l} | ..... | -69.50 | 1,878.89 | 1,752.66 |

TABLE 4I-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (Continued)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|--|------------------------------------|-------------|---------------------------------|---------------------|----------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Hydrogen, Cycloalkanes (Cont.) | | | | | |
| <i>n</i> -Octylcyclopentane..... | C ₁₃ H ₂₆ ,g | 182.352 | -59.89 | 2,050.87 | 1,914.12 |
| | C ₁₃ H ₂₆ ,l | ..... | -75.61 | 2,035.15 | 1,898.40 |
| <i>n</i> -Nonylcyclopentane..... | C ₁₄ H ₂₈ ,g | 196.379 | 64.80 | 2,208.32 | 2,061.05 |
| | C ₁₄ H ₂₈ ,l | ..... | -81.70 | 2,191.42 | 2,044.15 |
| <i>n</i> -Decylcyclopentane..... | C ₁₅ H ₃₀ ,g | 210.406 | -69.73 | 2,365.76 | 2,207.98 |
| | C ₁₅ H ₃₀ ,l | ..... | -87.81 | 2,347.68 | 2,189.90 |
| Cyclohexane..... | C ₆ H ₁₂ ,g | 84.163 | -29.42 | 944.78 | 881.67 |
| | C ₆ H ₁₂ ,l | ..... | -37.33 | 936.87 | 873.76 |
| Methylcyclohexane..... | C ₇ H ₁₄ ,g | 98.190 | -36.98 | 1,099.58 | 1,025.95 |
| | C ₇ H ₁₄ ,l | ..... | -45.43 | 1,091.13 | 1,017.50 |
| Ethylcyclohexane..... | C ₈ H ₁₆ ,g | 112.217 | -41.03 | 1,257.90 | 1,173.75 |
| | C ₈ H ₁₆ ,l | ..... | -50.70 | 1,248.23 | 1,164.08 |
| 1,1-Dimethylcyclohexane..... | C ₈ H ₁₆ ,g | 112.217 | -43.24 | 1,255.69 | 1,171.54 |
| | C ₈ H ₁₆ ,l | ..... | -52.28 | 1,246.65 | 1,255.69 |
| 1- <i>cis</i> -2-Dimethylcyclohexane.. | C ₈ H ₁₆ ,g | 112.217 | -41.12 | 1,257.81 | 1,173.66 |
| | C ₈ H ₁₆ ,l | ..... | -50.62 | 1,248.31 | 1,164.16 |
| 1- <i>trans</i> -2-Dimethylcyclohexane | C ₈ H ₁₆ ,g | 112.217 | -42.98 | 1,255.95 | 1,171.80 |
| | C ₈ H ₁₆ ,l | ..... | -52.16 | 1,246.77 | 1,162.62 |
| 1- <i>cis</i> -3-Dimethylcyclohexane.. | C ₈ H ₁₆ ,g | 112.217 | -44.12 | 1,254.81 | 1,170.66 |
| | C ₈ H ₁₆ ,l | ..... | -53.28 | 1,245.65 | 1,161.50 |
| 1- <i>trans</i> -3-Dimethylcyclohexane | C ₈ H ₁₆ ,g | 112.217 | -42.17 | 1,256.76 | 1,172.61 |
| | C ₈ H ₁₆ ,l | ..... | -51.55 | 1,247.38 | 1,163.23 |
| 1- <i>cis</i> -4-Dimethylcyclohexane.. | C ₈ H ₁₆ ,g | 112.217 | -42.19 | 1,256.74 | 1,172.59 |
| | C ₈ H ₁₆ ,l | ..... | -51.53 | 1,247.40 | 1,163.25 |
| 1- <i>trans</i> -4-Dimethylcyclohexane | C ₈ H ₁₆ ,g | 112.217 | -44.08 | 1,254.85 | 1,170.70 |
| | C ₈ H ₁₆ ,l | ..... | -53.15 | 1,245.78 | 1,161.63 |
| Cycloheptane..... | C ₇ H ₁₄ ,g | 98.190 | -28.26 | 1,108.30 | 1,034.67 |
| | C ₇ H ₁₄ ,l | ..... | -37.47 | 1,099.09 | 1,025.46 |
| Cyclooctane..... | C ₈ H ₁₆ ,g | 112.217 | -30.22 | 1,268.71 | 1,184.56 |
| | C ₈ H ₁₆ ,l | ..... | -40.58 | 1,258.35 | 1,174.20 |
| Cyclotetradecane..... | C ₁₄ H ₂₈ ,g | 196.379 | -54.36 | 2,218.76 | 2,071.49 |
| | C ₁₄ H ₂₈ ,l | ..... | -86.57 | 2,186.55 | 2,039.28 |
| Carbon-Hydrogen, Alkenes | | | | | |
| Ethene (ethylene)..... | C ₂ H ₄ ,g | 28.054 | 12.50 | 337.23 | 316.19 |
| Propene (propylene)..... | C ₃ H ₆ ,g | 42.081 | 4.89 | 491.99 | 460.43 |
| 1-Butene..... | C ₄ H ₈ ,g | 56.108 | -0.01 | 649.45 | 607.37 |
| | C ₄ H ₈ ,l | ..... | -4.98 | 644.49 | 602.41 |
| <i>cis</i> -2-Butene..... | C ₄ H ₈ ,g | 56.108 | -1.65 | 647.81 | 605.73 |
| | C ₄ H ₈ ,l | ..... | -7.06 | 642.41 | 600.33 |
| <i>trans</i> -2-Butene..... | C ₄ H ₈ ,g | 56.108 | -2.65 | 646.81 | 604.73 |
| | C ₄ H ₈ ,l | ..... | -7.88 | 641.58 | 599.50 |
| 2-Methylpropene (isobutene).. | C ₄ H ₈ ,g | 56.108 | -4.03 | 645.43 | 603.35 |
| | C ₄ H ₈ ,l | ..... | -9.11 | 640.36 | 598.28 |
| 1-Pentene..... | C ₅ H ₁₀ ,g | 70.135 | -4.98 | 806.85 | 754.26 |
| | C ₅ H ₁₀ ,l | ..... | -11.14 | 800.68 | 748.09 |

TABLE 41-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (Continued)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|--|----------------------------------|-------------|---------------------------------|---------------------|----------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Hydrogen, Alkenes (Cont.) | | | | | |
| <i>cis</i> -2-Pentene..... | C ₅ H _{10,g} | 70.135 | -6.49 | 805.34 | 752.74 |
| | C ₅ H _{10,l} | ..... | -12.96 | 798.87 | 746.27 |
| <i>trans</i> -2-Pentene..... | C ₅ H _{10,g} | 70.135 | -7.57 | 804.26 | 751.66 |
| | C ₅ H _{10,l} | ..... | -14.02 | 797.81 | 745.22 |
| 2-Methyl-1-butene..... | C ₅ H _{10,g} | 70.135 | -8.66 | 803.17 | 750.58 |
| | C ₅ H _{10,l} | ..... | -14.92 | 796.92 | 744.32 |
| 3-Methyl-1-butene..... | C ₅ H _{10,g} | 70.135 | -6.90 | 804.93 | 752.34 |
| | C ₅ H _{10,l} | ..... | -12.76 | 799.07 | 746.47 |
| 2-Methyl-2-butene..... | C ₅ H _{10,g} | 70.135 | -10.15 | 801.68 | 749.08 |
| | C ₅ H _{10,l} | ..... | -16.68 | 795.15 | 742.55 |
| 1-Hexene..... | C ₆ H _{12,g} | 84.163 | -9.92 | 904.28 | 901.10 |
| | C ₆ H _{12,l} | ..... | -17.28 | 956.92 | 893.81 |
| <i>cis</i> -2-Hexene..... | C ₆ H _{12,g} | 84.163 | -12.49 | 961.71 | 898.60 |
| | C ₆ H _{12,l} | ..... | -20.04 | 954.16 | 891.05 |
| <i>trans</i> -2-Hexene..... | C ₆ H _{12,g} | 84.163 | -12.86 | 961.34 | 898.23 |
| | C ₆ H _{12,l} | ..... | -20.43 | 953.77 | 890.66 |
| <i>cis</i> -3-Hexene..... | C ₆ H _{12,g} | 84.163 | -11.35 | 962.85 | 899.74 |
| | C ₆ H _{12,l} | ..... | -18.85 | 955.35 | 892.24 |
| <i>trans</i> -3-Hexene..... | C ₆ H _{12,g} | 84.163 | -12.98 | 961.22 | 898.11 |
| | C ₆ H _{12,l} | ..... | -20.55 | 953.65 | 890.54 |
| 2-Methyl-1-pentene..... | C ₆ H _{12,g} | 84.163 | -14.16 | 960.04 | 896.93 |
| | C ₆ H _{12,l} | ..... | -21.48 | 952.72 | 889.61 |
| 3-Methyl-1-pentene..... | C ₆ H _{12,g} | 84.163 | -11.80 | 962.40 | 899.29 |
| | C ₆ H _{12,l} | ..... | -18.66 | 955.54 | 892.43 |
| 4-Methyl-1-pentene..... | C ₆ H _{12,g} | 84.163 | -12.22 | 961.98 | 898.87 |
| | C ₆ H _{12,l} | ..... | -19.11 | 955.09 | 891.08 |
| 2-Methyl-2-pentene..... | C ₆ H _{12,g} | 84.163 | -15.96 | 958.24 | 895.13 |
| | C ₆ H _{12,l} | ..... | -23.54 | 950.66 | 887.55 |
| 3-Methyl- <i>cis</i> -2-pentene..... | C ₆ H _{12,g} | 84.163 | -15.03 | 959.17 | 896.06 |
| | C ₆ H _{12,l} | ..... | -22.55 | 951.65 | 888.54 |
| 3-Methyl- <i>trans</i> -2-pentene..... | C ₆ H _{12,g} | 84.163 | -14.89 | 959.31 | 896.20 |
| | C ₆ H _{12,l} | ..... | -22.59 | 951.61 | 888.50 |
| 4-Methyl- <i>cis</i> -2-pentene..... | C ₆ H _{12,g} | 84.163 | -13.70 | 960.50 | 897.39 |
| | C ₆ H _{12,l} | ..... | -20.78 | 953.42 | 890.31 |
| 4-Methyl- <i>trans</i> -2-pentene..... | C ₆ H _{12,g} | 84.163 | -14.66 | 959.54 | 896.43 |
| | C ₆ H _{12,l} | ..... | -21.86 | 952.34 | 889.23 |
| 2-Ethyl-1-butene..... | C ₆ H _{12,g} | 84.163 | -13.36 | 960.84 | 897.73 |
| | C ₆ H _{12,l} | ..... | -20.80 | 953.40 | 890.29 |
| 2,3-Dimethyl-1-butene..... | C ₆ H _{12,g} | 84.163 | -15.48 | 958.72 | 895.61 |
| | C ₆ H _{12,l} | ..... | -22.49 | 951.71 | 888.60 |
| 3,3-Dimethyl-1-butene..... | C ₆ H _{12,g} | 84.163 | -14.48 | 959.72 | 896.61 |
| | C ₆ H _{12,l} | ..... | -20.89 | 953.31 | 890.20 |
| 2,3-Dimethyl-2-butene..... | C ₆ H _{12,g} | 84.163 | -16.41 | 957.79 | 894.67 |
| | C ₆ H _{12,l} | ..... | -24.22 | 949.98 | 886.87 |
| 1-Heptene..... | C ₇ H _{14,g} | 98.190 | -14.66 | 1,121.90 | 1,048.27 |
| | C ₇ H _{14,l} | ..... | -23.19 | 1,113.37 | 1,039.74 |
| <i>cis</i> -2-Heptene..... | C ₇ H _{14,g} | 98.190 | -16.47 | 1,120.09 | 1,046.46 |
| | C ₇ H _{14,l} | ..... | -25.09 | 1,111.47 | 1,037.84 |

HEATS OF FORMATION AND HEATS OF COMBUSTION 4-327

TABLE 4I-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (Continued)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|---------------------------------------|----------------------------------|-------------|---------------------------------|---------------------|----------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Hydrogen, Alkenes (Cont.) | | | | | |
| <i>trans</i> -2-Heptene..... | C ₇ H _{14,g} | 98.190 | -17.47 | 1,119.09 | 1,045.46 |
| | C ₇ H _{14,l} | ..... | -26.09 | 1,110.47 | 1,036.84 |
| <i>cis</i> -3-Heptene..... | C ₇ H _{14,g} | 98.190 | -16.47 | 1,120.09 | 1,046.46 |
| | C ₇ H _{14,l} | ..... | -24.99 | 1,111.57 | 1,037.94 |
| <i>trans</i> -3-Heptene..... | C ₇ H _{14,g} | 98.190 | -17.47 | 1,119.09 | 1,045.46 |
| | C ₇ H _{14,l} | ..... | -25.99 | 1,110.57 | 1,036.94 |
| 2-Methyl-1-hexene..... | C ₇ H _{14,g} | 98.190 | -18.48 | 1,118.08 | 1,044.45 |
| | C ₇ H _{14,l} | ..... | -26.90 | 1,109.66 | 1,036.03 |
| 3-Methyl-1-hexene..... | C ₇ H _{14,g} | 98.190 | -15.94 | 1,120.62 | 1,046.99 |
| | C ₇ H _{14,l} | ..... | -24.16 | 1,112.40 | 1,038.77 |
| 4-Methyl-1-hexene..... | C ₇ H _{14,g} | 98.190 | -15.94 | 1,120.62 | 1,046.99 |
| | C ₇ H _{14,l} | ..... | -24.26 | 1,112.30 | 1,038.67 |
| 5-Methyl-1-hexene..... | C ₇ H _{14,g} | 98.190 | -16.58 | 1,119.98 | 1,046.35 |
| | C ₇ H _{14,l} | ..... | -24.80 | 1,111.76 | 1,038.13 |
| 2-Methyl-2-hexene..... | C ₇ H _{14,g} | 98.190 | -19.88 | 1,116.68 | 1,043.05 |
| | C ₇ H _{14,l} | ..... | -28.40 | 1,108.16 | 1,034.53 |
| 3-Methyl- <i>cis</i> -2-hexene..... | C ₇ H _{14,g} | 98.100 | -19.24 | 1,117.32 | 1,043.69 |
| | C ₇ H _{14,l} | ..... | -27.76 | 1,108.80 | 1,035.17 |
| 3-Methyl- <i>trans</i> -2-hexene..... | C ₇ H _{14,g} | 98.190 | -19.24 | 1,117.32 | 1,043.69 |
| | C ₇ H _{14,l} | ..... | -27.76 | 1,108.80 | 1,035.17 |
| 4-Methyl- <i>cis</i> -2-hexene..... | C ₇ H _{14,g} | 98.190 | -17.54 | 1,119.02 | 1,045.39 |
| | C ₇ H _{14,l} | ..... | -25.86 | 1,110.70 | 1,037.07 |
| 4-Methyl- <i>trans</i> -2-hexene..... | C ₇ H _{14,g} | 98.190 | -18.54 | 1,118.02 | 1,044.39 |
| | C ₇ H _{14,l} | ..... | -26.96 | 1,109.60 | 1,035.97 |
| 5-Methyl- <i>cis</i> -2-hexene..... | C ₇ H _{14,g} | 98.190 | -18.18 | 1,118.38 | 1,044.75 |
| | C ₇ H _{14,l} | ..... | -26.50 | 1,110.06 | 1,036.43 |
| 5-Methyl- <i>trans</i> -2-hexene..... | C ₇ H _{14,g} | 98.190 | -19.18 | 1,117.38 | 1,043.75 |
| | C ₇ H _{14,l} | ..... | -27.50 | 1,109.06 | 1,035.43 |
| 2-Methyl- <i>cis</i> -3-hexene..... | C ₇ H _{14,g} | 98.190 | -18.18 | 1,118.38 | 1,044.75 |
| | C ₇ H _{14,l} | ..... | -26.40 | 1,110.16 | 1,036.53 |
| 2-Methyl- <i>trans</i> -3-hexene..... | C ₇ H _{14,g} | 98.190 | -19.18 | 1,117.38 | 1,043.75 |
| | C ₇ H _{14,l} | ..... | -27.40 | 1,109.16 | 1,035.53 |
| 3-Methyl- <i>cis</i> -3-hexene..... | C ₇ H _{14,g} | 98.190 | -18.99 | 1,117.57 | 1,043.94 |
| | C ₇ H _{14,l} | ..... | -27.72 | 1,108.84 | 1,035.21 |
| 3-Methyl- <i>trans</i> -3-hexene..... | C ₇ H _{14,g} | 98.190 | -18.37 | 1,118.19 | 1,044.56 |
| | C ₇ H _{14,l} | ..... | -26.95 | 1,109.61 | 1,035.98 |
| 2-Ethyl-1-pentene..... | C ₇ H _{14,g} | 98.190 | -17.84 | 1,118.72 | 1,045.09 |
| | C ₇ H _{14,l} | ..... | -26.26 | 1,110.30 | 1,036.67 |
| 3-Ethyl-1-pentene..... | C ₇ H _{14,g} | 98.190 | -15.32 | 1,121.24 | 1,047.61 |
| | C ₇ H _{14,l} | ..... | -23.54 | 1,113.02 | 1,039.39 |
| 2,3-Dimethyl-1-pentene..... | C ₇ H _{14,g} | 98.190 | -19.50 | 1,117.06 | 1,043.43 |
| | C ₇ H _{14,l} | ..... | -27.72 | 1,108.84 | 1,035.21 |
| 2,4-Dimethyl-1-pentene..... | C ₇ H _{14,g} | 98.190 | -20.04 | 1,116.52 | 1,042.89 |
| | C ₇ H _{14,l} | ..... | -27.97 | 1,108.59 | 1,034.96 |
| 3,3-Dimethyl-1-pentene..... | C ₇ H _{14,g} | 98.190 | -18.15 | 1,118.41 | 1,044.78 |
| | C ₇ H _{14,l} | ..... | -26.17 | 1,110.39 | 1,036.76 |
| 3,4-Dimethyl-1-pentene..... | C ₇ H _{14,g} | 98.190 | -17.60 | 1,118.96 | 1,045.33 |
| | C ₇ H _{14,l} | ..... | -25.72 | 1,110.84 | 1,037.21 |
| 4,4-Dimethyl-1-pentene..... | C ₇ H _{14,g} | 98.190 | -18.96 | 1,117.60 | 1,043.97 |
| | C ₇ H _{14,l} | ..... | -26.43 | 1,110.13 | 1,036.50 |

TABLE 4I-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (Continued)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|---|------------------------------------|-------------|---------------------------------|---------------------|----------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Hydrogen, Alkenes (Cont.) | | | | | |
| 3-Ethyl-2-pentene. | C ₇ H ₁₄ ,g | 98.190 | -18.62 | 1,117.94 | 1,044.31 |
| | C ₇ H ₁₄ ,l | ..... | -27.14 | 1,109.42 | 1,035.79 |
| 2,3-Dimethyl-2-pentene. | C ₇ H ₁₄ ,g | 98.190 | -21.10 | 1,115.46 | 1,041.83 |
| | C ₇ H ₁₄ ,l | ..... | -29.62 | 1,106.94 | 1,033.31 |
| 2,4-Dimethyl-2-pentene. | C ₇ H ₁₄ ,g | 98.190 | -21.20 | 1,115.36 | 1,041.73 |
| | C ₇ H ₁₄ ,l | ..... | -29.42 | 1,107.14 | 1,033.51 |
| 3,4-Dimethyl- <i>cis</i> -2-pentene. | C ₇ H ₁₄ ,g | 98.100 | -20.00 | 1,115.66 | 1,042.03 |
| | C ₇ H ₁₄ ,l | ..... | -29.22 | 1,107.34 | 1,033.71 |
| 3,4-Dimethyl- <i>trans</i> -2-pentene. . | C ₇ H ₁₄ ,g | 98.190 | -20.90 | 1,115.66 | 1,042.03 |
| | C ₇ H ₁₄ ,l | ..... | -29.32 | 1,107.24 | 1,033.61 |
| 4,4-Dimethyl- <i>cis</i> -2-pentene. | C ₇ H ₁₄ ,g | 98.190 | -17.36 | 1,119.20 | 1,045.57 |
| | C ₇ H ₁₄ ,l | ..... | -25.17 | 1,111.39 | 1,037.76 |
| 4,4-Dimethyl- <i>trans</i> -2-pentene. . | C ₇ H ₁₄ ,g | 98.190 | -21.24 | 1,115.32 | 1,041.69 |
| | C ₇ H ₁₄ ,l | ..... | -29.11 | 1,107.45 | 1,033.82 |
| 3-Methyl-2-ethyl-1-butene. | C ₇ H ₁₄ ,g | 98.190 | -19.04 | 1,117.52 | 1,043.89 |
| | C ₇ H ₁₄ ,l | ..... | -27.26 | 1,109.30 | 1,035.67 |
| 2,3,3-Trimethyl-1-butene. | C ₇ H ₁₄ ,g | 98.190 | -20.43 | 1,116.13 | 1,042.50 |
| | C ₇ H ₁₄ ,l | ..... | -28.13 | 1,108.43 | 1,034.80 |
| 1-Octene. | C ₈ H ₁₆ ,g | 112.217 | -19.41 | 1,279.52 | 1,195.37 |
| | C ₈ H ₁₆ ,l | ..... | -29.11 | 1,269.82 | 1,185.67 |
| 2,2-Dimethyl- <i>cis</i> -3-hexene. | C ₈ H ₁₆ ,l | 112.217 | -30.21 | 1,268.72 | 1,184.56 |
| 2,2-Dimethyl- <i>trans</i> -3-hexene. . | C ₈ H ₁₆ ,l | 112.217 | -34.65 | 1,264.98 | 1,180.13 |
| 2-Methyl-3-ethyl-1-pentene. . | C ₈ H ₁₆ ,l | 112.217 | -32.92 | 1,266.01 | 1,181.86 |
| 2,2,4-Trimethyl-1-pentene. | C ₈ H ₁₆ ,l | 112.217 | -34.81 | 1,264.12 | 1,179.97 |
| 2,4,4-Trimethyl-2-pentene. | C ₈ H ₁₆ ,l | 112.217 | -34.04 | 1,264.89 | 1,180.74 |
| 1-Nonene. | C ₉ H ₁₈ ,g | 126.244 | -24.70 | 1,436.50 | 1,341.92 |
| | C ₉ H ₁₈ ,l | ..... | -35.58 | 1,425.71 | 1,331.04 |
| 1-Decene. | C ₁₀ H ₂₀ ,g | 140.271 | -29.48 | 1,594.18 | 1,488.99 |
| | C ₁₀ H ₂₀ ,l | ..... | -41.54 | 1,582.12 | 1,476.93 |
| 2,2,5,5-Tetramethyl- <i>cis</i> -3-hexene. | C ₁₀ H ₂₀ ,l | 140.271 | -39.09 | 1,584.57 | 1,479.38 |
| 2,2,5,5-Tetramethyl- <i>trans</i> -3-hexene. | C ₁₀ H ₂₀ ,l | 140.271 | -49.62 | 1,574.04 | 1,468.83 |
| Carbon-Hydrogen, Alkadienes | | | | | |
| Propadiene (allene) | C ₃ H ₄ ,g | 40.065 | 45.93 | 464.71 | 443.67 |
| 1,2-Butadiene | C ₄ H ₆ ,g | 54.092 | 38.78 | 619.93 | 588.37 |
| | C ₄ H ₆ ,l | ..... | 32.98 | 614.13 | 582.58 |
| 1,3-Butadiene | C ₄ H ₆ ,g | 54.092 | 26.34 | 607.49 | 575.93 |
| | C ₄ H ₆ ,l | ..... | 21.17 | 602.32 | 570.76 |
| 1,2-Pentadiene. | C ₅ H ₈ ,g | 68.120 | 33.62 | 777.14 | 735.06 |
| | C ₅ H ₈ ,l | ..... | 26.74 | 770.26 | 728.18 |
| 1- <i>cis</i> -3-Pentadiene. | C ₅ H ₈ ,g | 68.120 | 19.78 | 763.30 | 721.22 |
| | C ₅ H ₈ ,l | ..... | 12.97 | 756.48 | 714.41 |
| 1- <i>trans</i> -3-Pentadiene. | C ₅ H ₈ ,g | 68.120 | 18.12 | 761.64 | 719.56 |
| | C ₅ H ₈ ,l | ..... | 11.44 | 754.95 | 712.88 |

HEATS OF FORMATION AND HEATS OF COMBUSTION 4-329

TABLE 4I-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (Continued)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|-------------------------------------|------------------------------------|-------------|---------------------------------|---------------------|----------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Hydrogen, Alkadienes (Cont.) | | | | | |
| 1,4-Pentadiene..... | C ₅ H ₈ ,g | 68.120 | 25.42 | 768.94 | 726.86 |
| | C ₅ H ₈ ,l | ..... | 19.33 | 762.84 | 720.76 |
| 2,3-Pentadiene..... | C ₅ H ₈ ,g | 68.120 | 31.80 | 775.32 | 733.24 |
| | C ₅ H ₈ ,l | ..... | 24.72 | 768.23 | 726.16 |
| 3-Methyl-1,2-butadiene..... | C ₅ H ₈ ,g | 68.120 | 31.00 | 774.51 | 732.43 |
| | C ₅ H ₈ ,l | ..... | 23.26 | 766.78 | 724.70 |
| 2-Methyl-1,3-butadiene (isoprene) | C ₅ H ₈ ,g | 68.120 | 18.10 | 761.62 | 719.54 |
| | C ₅ H ₈ ,l | ..... | 11.72 | 755.24 | 713.16 |
| Carbon-Hydrogen, Cycloalkenes | | | | | |
| Cyclopropene..... | C ₃ H ₄ ,g | 40.065 | 66. | 485. | 464. |
| | C ₃ H ₄ ,l | 68.120 | 7.75 | 751.27 | 709.19 |
| Cyclopentene..... | C ₅ H ₈ ,g | ..... | 1.04 | 744.55 | 702.47 |
| | C ₅ H ₈ ,l | ..... | -0.96 | 904.92 | 852.32 |
| 1-Methylcyclopentene..... | C ₆ H ₁₀ ,g | 82.147 | -8.71 | 897.17 | 844.58 |
| | C ₆ H ₁₀ ,l | ..... | -5.66 | 900.22 | 847.62 |
| 3-Methylcyclopentene..... | C ₆ H ₁₀ ,l | 82.147 | -4.20 | 901.68 | 849.08 |
| 4-Methylcyclopentene..... | C ₆ H ₁₀ ,l | 82.147 | -4.89 | 1,063.36 | 1,000.25 |
| 1-Ethylcyclopentene..... | C ₇ H ₁₂ ,g | 96.174 | -13.93 | 1,054.32 | 991.21 |
| | C ₇ H ₁₂ ,l | ..... | -11.77 | 1,056.48 | 993.37 |
| 3-Ethylcyclopentene..... | C ₇ H ₁₂ ,l | 96.174 | -10.31 | 1,057.94 | 994.83 |
| 4-Ethylcyclopentene..... | C ₇ H ₁₂ ,l | 96.174 | -9.81 | 1,220.80 | 1,147.17 |
| 1-n-Propylcyclopentene..... | C ₈ H ₁₄ ,g | 110.201 | -20.03 | 1,210.58 | 1,136.95 |
| | C ₈ H ₁₄ ,l | ..... | -17.87 | 1,112.74 | 1,039.11 |
| 3-n-Propylcyclopentene..... | C ₈ H ₁₄ ,l | 110.201 | -16.41 | 1,214.20 | 1,140.57 |
| 3-n-Propylcyclopentene..... | C ₈ H ₁₄ ,l | 110.201 | -14.73 | 1,378.25 | 1,294.10 |
| 1-n-Butylcyclopentene..... | C ₉ H ₁₆ ,g | 124.228 | -26.13 | 1,366.85 | 1,282.70 |
| | C ₉ H ₁₆ ,l | ..... | -23.97 | 1,369.01 | 1,284.86 |
| 3-n-Butylcyclopentene..... | C ₉ H ₁₆ ,l | 124.228 | -22.51 | 1,370.47 | 1,286.32 |
| 4-n-Butylcyclopentene..... | C ₉ H ₁₆ ,l | 124.228 | -19.66 | 1,535.69 | 1,441.02 |
| 1-n-Pentylcyclopentene..... | C ₁₀ H ₁₈ ,g | 138.255 | -32.24 | 1,523.11 | 1,428.44 |
| | C ₁₀ H ₁₈ ,l | ..... | -30.08 | 1,525.27 | 1,430.60 |
| 3-n-Pentylcyclopentene..... | C ₁₀ H ₁₈ ,l | 138.255 | -28.62 | 1,526.73 | 1,432.06 |
| 4-n-Pentylcyclopentene..... | C ₁₀ H ₁₈ ,l | 138.255 | -1.08 | 904.80 | 852.21 |
| Cyclohexene..... | C ₆ H ₁₀ ,g | 82.147 | -9.13 | 896.75 | 844.16 |
| | C ₆ H ₁₀ ,l | ..... | -10.36 | 1,057.89 | 994.78 |
| 1-Methylcyclohexene..... | C ₇ H ₁₂ ,g | 96.174 | -19.40 | 1,048.85 | 985.74 |
| | C ₇ H ₁₂ ,l | ..... | -15.17 | 1,215.44 | 1,141.81 |
| 1-Ethylcyclohexene..... | C ₈ H ₁₄ ,g | 110.201 | -25.50 | 1,205.11 | 1,131.48 |
| | C ₈ H ₁₄ ,l | ..... | -20.10 | 1,372.88 | 1,288.73 |
| 1-n-Propylcyclohexene..... | C ₉ H ₁₆ ,g | 124.228 | -31.61 | 1,361.37 | 1,277.22 |
| | C ₉ H ₁₆ ,l | ..... | -25.02 | 1,530.33 | 1,435.66 |
| 1-n-Butylcyclohexene..... | C ₁₀ H ₁₈ ,g | 138.255 | -37.71 | 1,517.64 | 1,422.97 |
| | C ₁₀ H ₁₈ ,l | ..... | -29.94 | 1,687.77 | 1,582.58 |
| 1-n-Pentylcyclohexene..... | C ₁₁ H ₂₀ ,g | 152.282 | -43.71 | 1,674.00 | 1,568.81 |
| | C ₁₁ H ₂₀ ,l | ..... |  |  |  |

TABLE 4I-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (Continued)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|--|-----------------------------------|-------------|---------------------------------|---------------------|----------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Hydrogen, Alkynes | | | | | |
| Ethyne (acetylene)..... | C ₂ H _{2,g} | 26.038 | 54.20 | 310.62 | 300.10 |
| Propyne (methylacetylene).... | C ₃ H _{4,g} | 40.065 | 44.33 | 463.11 | 442.07 |
| 1-Butyne (ethylacetylene)..... | C ₄ H _{6,g} | 54.092 | 39.49 | 620.64 | 589.08 |
| | C ₄ H _{6,l} | ..... | 33.70 | 614.85 | 583.30 |
| 2-Butyne (dimethylacetylene).... | C ₄ H _{6,g} | 54.092 | 34.98 | 616.13 | 584.57 |
| | C ₄ H _{6,l} | ..... | 28.54 | 609.69 | 578.13 |
| 1-Pentyne..... | C ₅ H _{8,g} | 68.120 | 34.52 | 778.03 | 735.95 |
| | C ₅ H _{8,l} | ..... | 27.67 | 771.18 | 729.10 |
| 2-Pentyne..... | C ₅ H _{8,g} | 68.120 | 30.81 | 774.33 | 732.25 |
| | C ₅ H _{8,l} | ..... | 23.43 | 766.95 | 724.87 |
| 3-Methyl-1-butyne..... | C ₅ H _{8,g} | 68.120 | 32.62 | 776.13 | 734.05 |
| | C ₅ H _{8,l} | ..... | 26.35 | 769.86 | 727.79 |
| 1-Hexyne..... | C ₆ H _{10,g} | 82.147 | 29.5 | 935.45 | 882.86 |
| 1-Heptyne..... | C ₇ H _{12,g} | 96.174 | 24.64 | 1,092.89 | 1,029.78 |
| 1-Octyne..... | C ₈ H _{14,g} | 110.201 | 19.73 | 1,250.34 | 1,176.71 |
| 1-Nonyne..... | C ₉ H _{16,g} | 124.228 | 14.80 | 1,407.78 | 1,323.63 |
| 1-Decyne..... | C ₁₀ H _{18,g} | 138.255 | 9.88 | 1,565.22 | 1,470.55 |
| 1,8-Cyclotetradecadiyne..... | C ₁₄ H _{20,g} | 188.315 | 76.97 | 2,076.83 | 1,971.64 |
| | C ₁₄ H _{20,c} | ..... | 37.29 | 2,037.15 | 1,931.96 |
| Carbon-Hydrogen-Miscellaneous Ring Compounds | | | | | |
| Spiropentane..... | C ₅ H _{8,g} | 68.120 | 44.26 | 787.77 | 745.69 |
| | C ₅ H _{8,l} | ..... | 37.66 | 781.17 | 730.09 |
| <i>cis</i> -Decahydronaphthalene.... | C ₁₀ H _{18,g} | 138.255 | -40.36 | 1,514.99 | 1,420.32 |
| | C ₁₀ H _{18,l} | ..... | -52.42 | 1,502.92 | 1,408.25 |
| <i>trans</i> -Decahydronaphthalene.. | C ₁₀ H _{18,g} | 138.255 | -43.54 | 1,511.80 | 1,417.13 |
| | C ₁₀ H _{18,l} | ..... | -55.12 | 1,500.23 | 1,405.50 |
| 9-Methyl- <i>trans</i> -decalin..... | C ₁₁ H _{20,l} | 152.282 | -59.67 | 1,658.04 | 1,552.85 |
| 9-Methyl- <i>cis</i> -decalin..... | C ₁₁ H _{20,l} | 152.282 | -58.28 | 1,659.43 | 1,554.24 |
| 1,3,5,7-Cyclooctatetraene..... | C ₈ H _{8,l} | 104.153 | 60.83 | 1,086.50 | 1,044.42 |
| Carbon-Hydrogen, Benzenes and Naphthalenes | | | | | |
| Benzene..... | C ₆ H _{6,g} | 78.115 | 19.80 | 789.05 | 757.49 |
| | C ₆ H _{6,l} | ..... | 11.71 | 780.96 | 749.40 |
| Methylbenzene (toluene)..... | C ₇ H _{8,g} | 92.142 | 11.95 | 943.57 | 901.49 |
| | C ₇ H _{8,l} | ..... | 2.87 | 934.49 | 892.41 |
| Ethylbenzene..... | C ₈ H _{10,g} | 106.169 | 7.14 | 1,101.13 | 1,048.53 |
| | C ₈ H _{10,l} | ..... | -2.95 | 1,091.03 | 1,038.44 |
| 1,2-Dimethylbenzene (<i>o</i> -xylene) | C ₈ H _{10,g} | 106.169 | 4.56 | 1,098.54 | 1,045.95 |
| | C ₈ H _{10,l} | ..... | -5.82 | 1,088.16 | 1,035.56 |
| 1,3-Dimethylbenzene (<i>m</i> -xylene) | C ₈ H _{10,g} | 106.169 | 4.13 | 1,098.12 | 1,045.52 |
| | C ₈ H _{10,l} | ..... | -6.06 | 1,087.92 | 1,035.33 |
| 1,4-Dimethylbenzene (<i>p</i> -xylene) | C ₈ H _{10,g} | 106.169 | 4.30 | 1,098.29 | 1,045.69 |
| | C ₈ H _{10,l} | ..... | -5.82 | 1,088.16 | 1,035.56 |

HEATS OF FORMATION AND HEATS OF COMBUSTION 4-331

TABLE 4-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (Continued)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|--|------------------------------------|-------------|---------------------------------|---------------------|----------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Hydrogen, Benzenes and Naphthalenes (Cont.) | | | | | |
| <i>n</i> -Popylbenzene..... | C ₉ H ₁₂ ,g | 120.196 | 1.89 | 1,258.24 | 1,195.12 |
| | C ₉ H ₁₂ ,l | ..... | -9.16 | 1,247.19 | 1,184.08 |
| Isopropylbenzene (cumene)... | C ₉ H ₁₂ ,g | 120.196 | 0.90 | 1,257.91 | 1,194.20 |
| | C ₉ H ₁₂ ,l | ..... | -9.83 | 1,246.52 | 1,183.41 |
| 1-Methyl-2-ethylbenzene..... | C ₉ H ₁₂ ,g | 120.196 | 0.31 | 1,256.66 | 1,193.55 |
| | C ₉ H ₁₂ ,l | ..... | -11.09 | 1,245.26 | 1,182.15 |
| 1-Methyl-3-ethylbenzene..... | C ₉ H ₁₂ ,g | 120.196 | -0.43 | 1,255.92 | 1,192.81 |
| | C ₉ H ₁₂ ,l | ..... | -11.64 | 1,244.71 | 1,181.60 |
| 1-Methyl-4-ethylbenzene..... | C ₉ H ₁₂ ,g | 120.196 | -0.49 | 1,255.86 | 1,192.75 |
| | C ₉ H ₁₂ ,l | ..... | -11.90 | 1,244.45 | 1,181.34 |
| 1,2,3-Trimethylbenzene (hemimellitene) | C ₉ H ₁₂ ,g | 120.196 | -2.26 | 1,254.08 | 1,190.97 |
| | C ₉ H ₁₂ ,l | ..... | -13.99 | 1,242.36 | 1,179.25 |
| 1,2,4-Trimethylbenzene (pseudocumene) | C ₉ H ₁₂ ,g | 120.196 | -3.31 | 1,253.04 | 1,189.92 |
| | C ₉ H ₁₂ ,l | ..... | -14.77 | 1,241.58 | 1,178.47 |
| 1,3,5-Trimethylbenzene (mesitylene) | C ₉ H ₁₂ ,g | 120.196 | -3.81 | 1,252.54 | 1,189.42 |
| | C ₉ H ₁₂ ,l | ..... | -15.16 | 1,241.19 | 1,178.08 |
| <i>n</i> -Butylbenzene..... | C ₁₀ H ₁₄ ,g | 134.223 | -3.30 | 1,415.42 | 1,341.78 |
| | C ₁₀ H ₁₄ ,l | ..... | -15.28 | 1,403.44 | 1,329.80 |
| <i>n</i> -Pentylbenzene..... | C ₁₁ H ₁₆ ,g | 148.250 | -8.23 | 1,572.85 | 1,488.70 |
| | C ₁₁ H ₁₆ ,l | ..... | -21.39 | 1,559.69 | 1,475.54 |
| <i>n</i> -Hexylbenzene..... | C ₁₂ H ₁₈ ,g | 162.277 | -13.15 | 1,730.30 | 1,635.63 |
| | C ₁₂ H ₁₈ ,l | ..... | -27.49 | 1,715.06 | 1,621.29 |
| <i>n</i> -Heptylbenzene..... | C ₁₃ H ₂₀ ,g | 176.304 | -18.08 | 1,887.73 | 1,782.54 |
| | C ₁₃ H ₂₀ ,l | ..... | -33.60 | 1,872.21 | 1,767.02 |
| <i>n</i> -Octylbenzene..... | C ₁₄ H ₂₂ ,g | 190.331 | -23.00 | 2,045.18 | 1,929.47 |
| | C ₁₄ H ₂₂ ,l | ..... | -39.70 | 2,028.48 | 1,912.77 |
| <i>n</i> -Nonylbenzene..... | C ₁₅ H ₂₄ ,g | 204.358 | -27.93 | 2,202.92 | 2,076.69 |
| | C ₁₅ H ₂₄ ,l | ..... | -45.51 | 2,185.03 | 2,058.81 |
| <i>n</i> -Decylbenzene..... | C ₁₆ H ₂₆ ,g | 218.385 | -32.86 | 2,360.05 | 2,223.30 |
| | C ₁₆ H ₂₆ ,l | ..... | -51.92 | 2,340.99 | 2,204.24 |
| Ethenylbenzene (styrene)..... | C ₈ H ₈ ,g | 104.153 | 35.23 | 1,060.90 | 1,018.82 |
| | C ₈ H ₈ ,l | ..... | 24.84 | 1,050.51 | 1,008.43 |
| Biphenyl..... | C ₁₂ H ₁₀ ,g | 154.214 | 43.52 | 1,513.71 | 1,461.11 |
| | C ₁₂ H ₁₀ ,c | ..... | 24.02 | 1,494.21 | 1,441.61 |
| Naphthalene..... | C ₁₀ H ₈ ,g | 128.175 | 36.14 | 1,249.91 | 1,207.83 |
| | C ₁₀ H ₈ ,c | ..... | 18.77 | 1,232.54 | 1,190.46 |
| 1-Methylnaphthalene..... | C ₁₁ H ₁₀ ,l | 142.202 | 13.54 | 1,389.59 | 1,337.00 |
| 2-Methylnaphthalene..... | C ₁₁ H ₁₀ ,l | 142.202 | 10.74 | 1,386.88 | 1,334.29 |
| Carbon-Oxygen-Hydrogen, Alkanols | | | | | |
| Methanol (methyl alcohol).... | CH ₄ O,g | 32.042 | -48.06 | 182.62 | 161.58 |
| | CH ₄ O,l | ..... | -57.13 | 173.55 | 152.51 |
| Ethanol (ethyl alcohol)..... | C ₂ H ₆ O,g | 46.070 | -56.03 | 337.02 | 305.46 |
| | C ₂ H ₆ O,l | ..... | -66.20 | 326.85 | 295.29 |
| 1-Propanol (<i>n</i> -propyl alcohol)... | C ₃ H ₈ O,g | 60.097 | -61.28 | 494.13 | 452.06 |
| | C ₃ H ₈ O,l | ..... | -72.66 | 484.75 | 440.68 |

TABLE 4I-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (Continued)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|---|--|-------------|---------------------------------|---------------------|---------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Oxygen-Hydrogen, Alkanols (Cont.) | | | | | |
| 2-Propanol (isopropyl alcohol) | C ₃ H ₈ O,g | 60.097 | -65.11 | 490.30 | 448.23 |
| | C ₃ H ₈ O,l | ..... | -75.97 | 479.44 | 437.37 |
| 1-Butanol..... | C ₄ H ₁₀ O,g | 74.124 | -65.65 | 652.13 | 599.53 |
| | C ₄ H ₁₀ O,l | ..... | -78.18 | 639.00 | 587.00 |
| 2-Butanol..... | C ₄ H ₁₀ O,g | 74.124 | -69.94 | 647.84 | 595.24 |
| | C ₄ H ₁₀ O,l | ..... | -81.88 | 635.90 | 583.30 |
| 2-Methyl-1-propanol..... | C ₄ H ₁₀ O,g | 74.124 | -67.69 | 650.09 | 597.49 |
| | C ₄ H ₁₀ O,l | ..... | -79.85 | 637.93 | 585.33 |
| 2-Methyl-2-propanol..... | C ₄ H ₁₀ O,g | 74.124 | -74.67 | 643.11 | 590.51 |
| | C ₄ H ₁₀ O,l | ..... | -85.86 | 631.92 | 579.32 |
| 1-Pentanol..... | C ₅ H ₁₂ O,g | 88.151 | -71.94 | 808.20 | 745.09 |
| | C ₅ H ₁₂ O,l | ..... | -85.55 | 794.60 | 731.48 |
| 2-Pentanol..... | C ₅ H ₁₂ O,g | 88.151 | -75.0 | 805.1 | 742.0 |
| | C ₅ H ₁₂ O,l | ..... | -87.70 | 792.44 | 729.33 |
| 3-Pentanol..... | C ₅ H ₁₂ O,g | 88.151 | -75.8 | 804.3 | 741.2 |
| | C ₅ H ₁₂ O,l | ..... | -88.46 | 791.68 | 728.57 |
| 2-Methyl-1-butanol..... | C ₅ H ₁₂ O,g | 88.151 | -72.2 | 807.9 | 744.8 |
| | C ₅ H ₁₂ O,l | ..... | -85.19 | 794.96 | 731.84 |
| 3-Methyl-1-butanol..... | C ₅ H ₁₂ O,g | 88.151 | -71.8 | 808.3 | 745.2 |
| | C ₅ H ₁₂ O,l | ..... | -85.13 | 795.01 | 731.90 |
| 2-Methyl-2-butanol..... | C ₅ H ₁₂ O,g | 88.151 | -78.7 | 801.3 | 738.2 |
| | C ₅ H ₁₂ O,l | ..... | -90.66 | 789.48 | 726.37 |
| 3-Methyl-2-butanol..... | C ₅ H ₁₂ O,g | 88.151 | -75.18 | 804.90 | 741.85 |
| | C ₅ H ₁₂ O,l | ..... | -87.58 | 792.57 | 729.45 |
| 1-Hexanol..... | C ₆ H ₁₄ O,g | 102.178 | -75.9 | 966.6 | 893.0 |
| | C ₆ H ₁₄ O,l | ..... | -90.7 | 951.8 | 878.2 |
| 1-Heptanol..... | C ₇ H ₁₆ O,g | 110.205 | -79.4 | 1,125.4 | 1,041.3 |
| | C ₇ H ₁₆ O,l | ..... | -95.3 | 1,109.6 | 1,025.4 |
| 1-Octanol..... | C ₈ H ₁₈ O,g | 130.232 | -84.4 | 1,282.8 | 1,188.2 |
| | C ₈ H ₁₈ O,l | ..... | -101.6 | 1,265.6 | 1,171.0 |
| 1-Nonanol..... | C ₉ H ₂₀ O,g | 144.259 | -91.2 | 1,438.4 | 1,333.2 |
| | C ₉ H ₂₀ O,l | ..... | -109.7 | 1,419.9 | 1,314.7 |
| 1-Decanol..... | C ₁₀ H ₂₂ O,g | 158.286 | -94.2 | 1,597.8 | 1,482.1 |
| | C ₁₀ H ₂₂ O,l | ..... | -114.3 | 1,577.7 | 1,462.0 |
| Carbon-Oxygen-Hydrogen, Polyhydroxy Alkanols | | | | | |
| 1,2-Ethanediol (ethylene glycol)..... | C ₂ H ₆ O ₂ ,l | 62.069 | -108.72 | 284.33 | 252.77 |
| 1,2-Propanediol..... | C ₃ H ₈ O ₂ ,l | 76.096 | -118.10 | 437.3 | 345.2 |
| 1,2-Butanediol..... | C ₄ H ₁₀ O ₂ ,l | 90.123 | -123.17 | 594.61 | 542.01 |
| 1,2,3-Propanetriol (glycerol)... | C ₃ H ₈ O ₃ ,g | 92.095 | -139.8 | 415.6 | 373.5 |
| | C ₃ H ₈ O ₃ ,l | ..... | -160.3 | 395.1 | 353.0 |
| <i>anti</i> -1,2,3,4-Butanetetrol (erythritol)..... | C ₄ H ₁₀ O ₄ ,c | 122.122 | -217.6 | 500.2 | 447.6 |
| 1,2,3,4,5,6-Hexanehexol (dulcitol)..... | C ₆ H ₁₄ O ₆ ,c | 182.175 | -321.87 | 720.64 | 646.74 |
| 1,2,3,4,5,6-Hexanehexol (mannitol)..... | C ₆ H ₁₄ O ₆ ,c | 182.175 | -319.58 | 722.93 | 649.03 |

HEATS OF FORMATION AND HEATS OF COMBUSTION 4-333

TABLE 41-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (Continued)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|--|---|-------------|---------------------------------|---------------------|---------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Oxygen-Hydrogen, Cycloalkanols | | | | | |
| Cyclopentanol..... | C ₅ H ₁₀ O,g | 86.135 | -57.62 | 754.21 | 701.62 |
| | C ₅ H ₁₀ O,l | ..... | -71.36 | 740.47 | 687.88 |
| Cyclohexanol..... | C ₆ H ₁₂ O,g | 100.162 | -68.39 | 905.81 | 842.70 |
| | C ₆ H ₁₂ O,l | ..... | -83.21 | 890.99 | 827.88 |
| <i>cis</i> -2-Methylcyclohexanol..... | C ₇ H ₁₄ O,l | 114.189 | -90.9 | 1,045.7 | 927.0 |
| <i>trans</i> -2-Methylcyclohexanol.... | C ₇ H ₁₄ O,l | 114.189 | -97.0 | 1,039.6 | 965.9 |
| <i>cis</i> -3-Methylcyclohexanol..... | C ₇ H ₁₄ O,l | 114.189 | -91.0 | 1,044.7 | 971.0 |
| <i>trans</i> -3-Methylcyclohexanol.... | C ₇ H ₁₄ O,l | 114.189 | -97.1 | 1,039.5 | 965.8 |
| Carbon-Oxygen Hydrogen, Ethers | | | | | |
| Dimethyl ether..... | C ₂ H ₆ O,g | 46.070 | -43.99 | 349.06 | 317.50 |
| | C ₂ H ₆ O,l | ..... | -48.6 | 344.4 | 312.9 |
| Methyl ethyl ether..... | C ₃ H ₈ O,g | 60.097 | -51.73 | 503.68 | 461.01 |
| | C ₃ H ₈ O,l | ..... | -57.4 | 498.0 | 455.9 |
| Diethyl ether..... | C ₄ H ₁₀ O,g | 74.124 | -60.26 | 657.52 | 604.92 |
| | C ₄ H ₁₀ O,l | ..... | -66.83 | 650.95 | 598.35 |
| Methyl- <i>n</i> -propyl ether..... | C ₄ H ₁₀ O,g | 74.124 | -56.82 | 660.96 | 608.36 |
| | C ₄ H ₁₀ O,l | ..... | -63.61 | 654.17 | 601.57 |
| Methyl isopropyl ether..... | C ₄ H ₁₀ O,g | 74.124 | -60.24 | 657.54 | 604.94 |
| Methyl <i>tert</i> -butyl ether..... | C ₅ H ₁₂ O,g | 88.151 | -69.1 | 811.0 | 747.9 |
| | C ₅ H ₁₂ O,l | ..... | -76.6 | 803.5 | 740.4 |
| Di- <i>n</i> -Propyl ether..... | C ₆ H ₁₄ O,g | 102.178 | -70.07 | 972.44 | 898.81 |
| | C ₆ H ₁₄ O,l | ..... | -78.58 | 963.93 | 890.30 |
| Diisopropyl ether..... | C ₆ H ₁₄ O,g | 102.178 | -76.24 | 966.27 | 892.64 |
| | C ₆ H ₁₄ O,l | ..... | -84.00 | 958.51 | 884.88 |
| Ethyl <i>tert</i> -butyl ether..... | C ₆ H ₁₄ O,l | 102.178 | -88.5 | 954.0 | 880.4 |
| Di- <i>n</i> -butyl ether..... | C ₈ H ₁₈ O,g | 130.232 | -79.8 | 1,287.4 | 1,192.8 |
| | C ₈ H ₁₈ O,l | ..... | -90.2 | 1,277.0 | 1,182.4 |
| Ethylene oxide..... | C ₂ H ₄ O,g | 44.054 | -12.58 | 312.15 | 291.11 |
| Propylene oxide..... | C ₃ H ₆ O,g | 58.081 | -22.17 | 464.93 | 433.37 |
| | C ₃ H ₆ O,l | ..... | -28.84 | 458.26 | 426.70 |
| Furan..... | C ₄ H ₄ O,g | 68.076 | -8.29 | 504.54 | 483.50 |
| | C ₄ H ₄ O,l | ..... | -14.77 | 498.07 | 477.03 |
| 1,3-Dioxane..... | C ₄ H ₈ O ₂ ,g | 88.107 | -81.5 | 568.0 | 525.9 |
| | C ₄ H ₈ O ₂ ,l | ..... | -89.99 | 559.47 | 517.39 |
| 1,4-Dioxane..... | C ₄ H ₈ O ₂ ,g | 88.107 | -75.30 | 574.16 | 532.09 |
| | C ₄ H ₈ O ₂ ,l | ..... | -84.50 | 564.96 | 522.89 |
| Carbon-Oxygen-Hydrogen, Alkanals and Alkanones | | | | | |
| Methanal (formaldehyde)..... | CH ₂ O,g | 30.027 | -27.70 | 134.67 | 124.15 |
| Ethanal (acetaldehyde)..... | C ₂ H ₄ O,g | 44.054 | -39.68 | 285.05 | 264.01 |
| <i>n</i> -Propanal..... | C ₃ H ₆ O,g | 58.081 | -45.56 | 441.54 | 409.98 |
| | C ₃ H ₆ O,l | ..... | -52.65 | 434.45 | 402.89 |
| <i>n</i> -Butanal..... | C ₄ H ₈ O,g | 72.108 | -48.80 | 600.66 | 558.59 |
| | C ₄ H ₈ O,l | ..... | -56.85 | 592.61 | 550.54 |

TABLE 4I-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (Continued)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|---|--|-------------|---------------------------------|---------------------|---------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Oxygen-Hydrogen. Alkanals and Alkanones (Cont.) | | | | | |
| Ketene..... | C ₂ H ₂ O,g | 42.038 | -14.6 | 241.8 | 231.3 |
| 2-Propanone (acetone)..... | C ₃ H ₆ O,g | 58.081 | -51.80 | 435.30 | 403.74 |
| | C ₃ H ₆ O,l | ..... | -58.99 | 428.11 | 396.55 |
| 2-Butanone..... | C ₄ H ₈ O,l | 72.108 | -66.85 | 582.61 | 540.54 |
| Cyclopentanone..... | C ₅ H ₈ O,g | 84.119 | -46.40 | 697.12 | 655.04 |
| | C ₅ H ₈ O,l | ..... | -56.61 | 686.91 | 644.83 |
| Cyclohexanone..... | C ₆ H ₁₀ O,g | 98.146 | -54.07 | 851.81 | 799.22 |
| | C ₆ H ₁₀ O,l | ..... | -64.84 | 841.04 | 788.44 |
| Carbon-Oxygen-Hydrogen, Sugars | | | | | |
| D-Ribose..... | C ₅ H ₁₀ O ₅ ,c | 150.121 | -251.16 | 560.67 | 508.08 |
| n-Arabinose..... | C ₅ H ₁₀ O ₅ ,c | 150.132 | -252.84 | 558.99 | 506.40 |
| D-Xylose..... | C ₅ H ₁₀ O ₅ ,c | 150.132 | -251.4 | 560.4 | 507.8 |
| α -D-Galactose..... | C ₆ H ₁₂ O ₆ ,c | 180.159 | -307.4 | 666.8 | 603.7 |
| α -D-Galactose monohydrate... | C ₆ H ₁₄ O ₇ ,c | 198.174 | -373.3 | 669.2 | 595.6 |
| α -D-Glucose..... | C ₆ H ₁₂ O ₆ ,c | 180.159 | -304.60 | 669.60 | 606.48 |
| β -D-Glucose..... | C ₆ H ₁₂ O ₆ ,c | 180.159 | -303.07 | 671.13 | 608.01 |
| α -D-Glucose monohydrate..... | C ₆ H ₁₄ O ₇ ,c | 198.174 | -375.50 | 667.01 | 593.38 |
| β -D-Fructose..... | C ₆ H ₁₂ O ₆ ,c | 180.159 | -302.5 | 671.7 | 608.6 |
| L-Sorbose..... | C ₆ H ₁₂ O ₆ ,c | 180.159 | -303.8 | 670.4 | 607.3 |
| α -Lactose..... | C ₁₂ H ₂₂ O ₁₁ ,c | 342.303 | -531.0 | 1,349.1 | 1,233.4 |
| β -Lactose..... | C ₁₂ H ₂₂ O ₁₁ ,c | 342.303 | -534.6 | 1,345.5 | 1,229.8 |
| α -Lactose monohydrate..... | C ₁₂ H ₂₄ O ₁₂ ,c | 360.318 | -606.2 | 1,342.2 | 1,216.0 |
| Maltose..... | C ₁₂ H ₂₂ O ₁₁ ,c | 342.303 | -592.2 | 1,350.9 | 1,235.2 |
| β -Maltose monohydrate..... | C ₁₂ H ₂₄ O ₁₂ ,c | 360.318 | -606.9 | 1,341.5 | 1,215.3 |
| Sucrose..... | C ₁₂ H ₂₂ O ₁₁ ,c | 342.303 | -531.0 | 1,349.1 | 1,233.4 |
| Carbon-Oxygen-Hydrogen, Alkanoic and Alkanedioic Acids, Anhydrides and Esters | | | | | |
| Methanoic acid (formic acid) | CH ₂ O ₂ ,g | 46.026 | -90.48 | 71.89 | 61.57 |
| | CH ₂ O ₂ ,l | ..... | -101.51 | 60.86 | 50.54 |
| Ethanoic acid (acetic acid).... | C ₂ H ₄ O ₂ ,g | 60.053 | -103.83 | 220.96 | 199.86 |
| | C ₂ H ₄ O ₂ ,l | ..... | -115.73 | 209.00 | 187.96 |
| n-Propanoic acid (propionic acid)..... | C ₃ H ₆ O ₂ ,l | 74.080 | -122.12 | 364.98 | 333.42 |
| n-Butanoic acid (butyric acid) | C ₄ H ₈ O ₂ ,l | 88.107 | -127.9 | 521.6 | 479.5 |
| n-Pentanoic acid..... | C ₅ H ₁₀ O ₂ ,l | 102.134 | -133.88 | 677.95 | 625.36 |
| Hexadecanoic acid (palmitic acid) | C ₁₆ H ₃₂ O ₂ ,g | 240.433 | -176.0 | 2,421.9 | 2,253.6 |
| | C ₁₆ H ₃₂ O ₂ ,c | ..... | -212.9 | 2,385.0 | 2,216.7 |
| Octadecanoic acid (stearic acid) | C ₁₈ H ₃₆ O ₂ ,g | 268.487 | -118.5 | 2,804.1 | 2,614.7 |
| | C ₁₈ H ₃₆ O ₂ ,c | ..... | -158.3 | 2,764.3 | 2,574.9 |
| Ethanoic (acetic) anhydride... | C ₄ H ₆ O ₃ ,g | 102.091 | -137.62 | 433.53 | 411.97 |
| | C ₄ H ₆ O ₃ ,l | ..... | -149.16 | 431.99 | 400.43 |
| Methyl methanoate (methyl formate) | C ₂ H ₄ O ₂ ,g | 60.053 | -83.6 | 241.1 | 220.1 |
| | C ₂ H ₄ O ₂ ,l | ..... | -90.4 | 234.4 | 213.3 |
| Ethyl ethanoate (ethyl acetate) | C ₄ H ₈ O ₂ ,g | 88.107 | -108.0 | 541.5 | 499.4 |
| | C ₄ H ₈ O ₂ ,l | ..... | -116.3 | 533.2 | 491.1 |
| Ethanedioic acid..... | C ₂ H ₂ O ₄ ,g | 90.036 | -174.5 | 81.9 | 71.4 |
| α -Oxalic acid..... | C ₂ H ₂ O ₄ ,c | ..... | -197.9 | 58.5 | 48.0 |

HEATS OF FORMATION AND HEATS OF COMBUSTION 4-335

TABLE 4I-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (Continued)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|--|---|-------------|---------------------------------|---------------------|--------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Oxygen-Hydrogen, Alkanoic and Alkanedioic Acid, Anhydrides and Esters (Cont.) | | | | | |
| β -Oxalic acid..... | C ₂ H ₂ O _{4,c} | ..... | -196.7 | 59.7 | 49.2 |
| Ethanedioic acid dihydrate.... | C ₂ H ₆ O _{6,c} | 126.067 | -339.7 | 53.3 | 21.8 |
| Propanedioic acid (malonic acid)..... | C ₃ H ₄ O _{4,c} | 104.063 | -212.93 | 205.85 | 184.82 |
| Pentanedioic acid (glutaric acid)..... | C ₅ H ₈ O _{4,c} | 132.117 | -229.3 | 514.2 | 472.1 |
| Carbon-Oxygen-Hydrogen, Hydroxy Acids and Esters | | | | | |
| L(+)-2-Hydroxypropanoic acid (L(+)-lactic acid) | C ₃ H ₆ O _{3,l} | 90.079 | -161.9 | 325.2 | 293.6 |
| L-2-Hydroxybutanedioic acid (L-malic acid)..... | C ₃ H ₆ O _{3,c} | ..... | -165.88 | 321.21 | 289.66 |
| DL-2-Hydroxybutanedioic acid (DL-malic acid)..... | C ₄ H ₆ O _{5,c} | 134.089 | -263.7 | 317.4 | 285.9 |
| D-1,2-Dihydroxybutanedioic acid (D-tartaric acid)..... | C ₄ H ₆ O _{5,c} | 134.089 | -264.2 | 319.9 | 285.4 |
| DL-1,2-Dihydroxybutanedioic acid (DL-tartaric acid)..... | C ₄ H ₆ O _{5,c} | 150.089 | -306.1 | 275.0 | 243.5 |
| DL-1,2-Dihydroxybutanedioic acid monohydrate (DL-tartaric acid monohydrate)... | C ₄ H ₈ O _{6,c} | 150.089 | -308.2 | 272.9 | 241.4 |
| meso-1,2-Dihydroxybutanedioic acid (meso-tartaric acid)..... | C ₄ H ₈ O _{7,c} | 168.104 | -377.9 | 203.2 | 171.7 |
| D-Dimethyltartrate..... | C ₄ H ₆ O _{6,c} | 150.089 | -306.7 | 274.4 | 242.9 |
| DL-Dimethyltartrate..... | C ₆ H ₁₀ O _{6,c} | 178.143 | -286.2 | 619.7 | 567.1 |
| meso-Dimethyltartrate..... | C ₆ H ₁₀ O _{6,g} | 178.143 | -260.4 | 645.5 | 592.9 |
| | C ₆ H ₁₀ O _{6,c} | ..... | -287.6 | 618.3 | 565.7 |
| | C ₆ H ₁₀ O _{6,c} | 178.143 | -258 | 648 | 595 |
| | C ₆ H ₁₀ O _{6,c} | ..... | -286.1 | 619.8 | 567.2 |
| 2-Hydroxy-1,2,3-propanetricarboxylic acid (citric acid)..... | C ₆ H ₈ O _{7,c} | 192.126 | -396.0 | 468.6 | 426.5 |
| 2-Hydroxy-1,2,3-propanetricarboxylic acid monohydrate (citric acid monohydrate)..... | C ₆ H ₁₀ O _{8,c} | 210.142 | -439.4 | 466.5 | 413.9 |
| Carbon-Oxygen-Hydrogen, Unsaturated Compounds | | | | | |
| 2-Propen-1-ol (allyl alcohol)... | C ₃ H ₆ O,l | 58.081 | -41.60 | 445.50 | 413.94 |
| Propenoic acid (acrylic acid)... | C ₃ H ₄ O _{2,g} | 72.064 | -80.56 | 338.22 | 317.19 |
| | C ₃ H ₄ O _{2,l} | ..... | -91.77 | 327.01 | 305.98 |
| cis-Butenedioic acid (maleic acid) | C ₄ H ₄ O _{4,g} | 116.074 | -161.6 | 351.2 | 330.2 |
| | C ₄ H ₄ O _{4,c} | ..... | -188.65 | 324.18 | 303.15 |
| Maleic anhydride..... | C ₄ H ₂ O _{3,g} | 74.036 | -99.6 | 344.9 | 334.4 |
| | C ₄ H ₂ O _{3,c} | ..... | -112.43 | 332.09 | 321.57 |
| trans-Butenedioic acid (fumaric acid) | C ₄ H ₄ O _{4,g} | 116.074 | -160.6 | 352.2 | 331.2 |
| | C ₄ H ₄ O _{4,c} | ..... | -193.75 | 319.08 | 298.05 |

TABLE 4I-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (*Continued*)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|---|---|-------------|---------------------------------|---------------------|----------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Oxygen-Hydrogen, Hydroxy Benzenes | | | | | |
| Phenol..... | C ₆ H ₆ O,g | 94.114 | -22.98 | 746.27 | 714.71 |
| | C ₆ H ₆ O,c | ..... | -39.44 | 729.81 | 698.25 |
| 2-Methylphenol (<i>o</i> -cresol)..... | C ₇ H ₈ O,g | 108.141 | -30.70 | 900.92 | 858.84 |
| | C ₇ H ₈ O,c | ..... | -48.87 | 882.75 | 840.67 |
| 3-Methylphenol (<i>m</i> -cresol)..... | C ₇ H ₈ O,g | 108.141 | -31.53 | 900.09 | 858.01 |
| | C ₇ H ₈ O,l | ..... | -46.28 | 885.34 | 843.26 |
| 4-Methylphenol (<i>p</i> -cresol)..... | C ₇ H ₈ O,g | 108.141 | -29.9 | 901.7 | 859.64 |
| | C ₇ H ₈ O,c | ..... | -47.61 | 884.01 | 841.93 |
| 2-Ethylphenol..... | C ₈ H ₁₀ O,g | 122.168 | -34.7 | 1,059.3 | 1,006.7 |
| | C ₈ H ₁₀ O,l | ..... | -49.91 | 1,044.07 | 991.48 |
| 3-Ethylphenol..... | C ₈ H ₁₀ O,g | 122.168 | -35.9 | 1,058.1 | 1,005.5 |
| | C ₈ H ₁₀ O,l | ..... | -51.21 | 1,042.77 | 990.18 |
| 4-Ethylphenol..... | C ₈ H ₁₀ O,g | 122.168 | -34.4 | 1,059.6 | 1,007.0 |
| | C ₈ H ₁₀ O,c | ..... | -54.63 | 1,040.35 | 987.76 |
| 2,3-Dimethylphenol (2,3-xylene) | C ₈ H ₁₀ O,g | 122.168 | -37.6 | 1,056.4 | 1,003.8 |
| | C ₈ H ₁₀ O,c | ..... | -57.65 | 1,036.33 | 983.74 |
| 2,4-Dimethylphenol (2,4-xylene) | C ₈ H ₁₀ O,g | 122.168 | -38.9 | 1,055.1 | 1,002.5 |
| | C ₈ H ₁₀ O,l | ..... | -54.67 | 1,039.31 | 986.72 |
| 2,5-Dimethylphenol (2,5-xylene) | C ₈ H ₁₀ O,g | 122.168 | -38.6 | 1,055.4 | 1,002.8 |
| | C ₈ H ₁₀ O,c | ..... | -58.94 | 1,035.04 | 982.45 |
| 2,6-Dimethylphenol (2,6-xylene) | C ₈ H ₁₀ O,g | 122.168 | -38.7 | 1,055.3 | 1,002.7 |
| | C ₈ H ₁₀ O,c | ..... | -56.73 | 1,037.25 | 984.66 |
| 3,4-Dimethylphenol (3,4-xylene) | C ₈ H ₁₀ O,g | 122.168 | -37.4 | 1,056.6 | 1,004.0 |
| | C ₈ H ₁₀ O,c | ..... | -57.91 | 1,036.07 | 983.48 |
| 3,5-Dimethylphenol (3,5-xylene) | C ₈ H ₁₀ O,g | 122.168 | -38.6 | 1,055.4 | 1,002.8 |
| | C ₈ H ₁₀ O,c | ..... | -58.41 | 1,035.57 | 982.08 |
| 1,2-Dihydroxybenzene (pyro- catechol) | C ₆ H ₆ O ₂ ,g | 110.114 | -65.0 | 704.3 | 672.7 |
| | C ₆ H ₆ O ₂ ,c | ..... | -84.4 | 684.9 | 653.3 |
| 1,3-Dihydroxybenzene (resorcinol) | C ₆ H ₆ O ₂ ,g | 110.114 | -65.7 | 703.6 | 672.0 |
| | C ₆ H ₆ O ₂ ,c | ..... | -87.95 | 681.30 | 649.74 |
| 1,4-Dihydroxybenzene (hydro- quinone) | C ₆ H ₆ O ₂ ,g | 110.114 | -65.9 | 703.4 | 671.8 |
| | C ₆ H ₆ O ₂ ,c | ..... | -87.35 | 681.90 | 650.34 |
| Benzyl alcohol..... | C ₇ H ₈ O,l | 108.141 | -38.41 | 893.21 | 851.13 |
| α -Hydroxy- α -phenylaceto- phenone (benzoin)..... | C ₁₄ H ₁₂ O ₂ ,c | 212.251 | -59.21 | 1,667.39 | 1,604.28 |
| Carbon-Fluorine and Oxygen | | | | | |
| Tetrafluoroethene..... | C ₂ F ₄ ,g | 100.016 | -155.0 | | |
| Hexafluoroethane..... | C ₂ F ₆ ,g | 138.013 | -316.8 | | |
| Carbonyl fluoride..... | COF ₂ ,g | 66.007 | -151.7 | | |
| Carbon-Hydrogen-Fluorine | | | | | |
| Difluoromethane..... | CH ₂ F ₂ ,g | 52.024 | -106.8 | 86.2 | 80.9 |
| Trifluoromethane..... | CHF ₃ ,g | 70.014 | -164.5 | | |
| 1-Fluoropropane..... | C ₃ H ₇ F,g | 62.088 | -66.8 | 585.1 | 453.5 |

HEATS OF FORMATION AND HEATS OF COMBUSTION 4-337

TABLE 4I-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (Continued)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|---|--|-------------|---------------------------------|---------------------|--------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Hydrogen-Fluorine (Cont.) | | | | | |
| 2-Fluoropropane..... | C ₃ H ₇ F,g | 62.088 | -68.6 | 483.3 | 451.7 |
| Perfluoro- <i>n</i> -heptane..... | C ₇ F ₁₆ ,l | 388.052 | -808.2 | | |
| Perfluoroethylcyclohexane..... | C ₈ F ₁₆ ,l | 388.052 | -789.5 | | |
| Perfluoromethylcyclohexane.... | C ₇ F ₁₄ ,l | 350.056 | -692.8 | | |
| Fluorobenzene..... | C ₆ H ₅ F,g | 96.105 | -27.09 | 738.64 | 717.61 |
| | C ₆ H ₅ F,l | ..... | -35.36 | 730.37 | 709.34 |
| 1,2-Difluorobenzene..... | C ₆ H ₄ F ₂ ,g | 114.006 | -68.95 | 693.27 | 682.75 |
| | C ₆ H ₄ F ₂ ,l | ..... | -77.60 | 684.62 | 674.10 |
| 1,3-Difluorobenzene..... | C ₆ H ₄ F ₂ ,g | 114.096 | -72.00 | 690.22 | 679.70 |
| | C ₆ H ₄ F ₂ ,l | ..... | -80.94 | 681.93 | 671.41 |
| 1,4-Difluorobenzene..... | C ₆ H ₄ F ₂ ,g | 114.096 | 72.03 | 690.19 | 679.67 |
| | C ₆ H ₄ F ₂ ,l | ..... | -80.54 | 681.68 | 671.16 |
| 4-Fluorotoluene..... | C ₇ H ₇ F,g | 110.132 | -34.65 | 893.45 | 861.89 |
| | C ₇ H ₇ F,l | ..... | -44.07 | 884.03 | 852.47 |
| <i>m</i> -Fluorobenzotrifluoride..... | C ₇ H ₄ F ₄ ,g | 164.104 | -180.77 | 730.78 | 730.78 |
| | C ₇ H ₄ F ₄ ,l | ..... | -195.84 | 721.71 | 721.71 |
| Benzotrifluoride..... | C ₇ H ₃ F ₃ ,g | 146.113 | -141.08 | 779.99 | 769.47 |
| | C ₇ H ₃ F ₃ ,l | ..... | -150.06 | 771.00 | 760.49 |
| Carbon-Oxygen-Hydrogen-Fluorine | | | | | |
| <i>m</i> -Fluorobenzoic acid..... | C ₇ H ₅ O ₂ F,c | 140.115 | -138.46 | 721.32 | 700.29 |
| <i>o</i> -Fluorobenzoic acid..... | C ₇ H ₅ O ₂ F,c | 140.115 | -135.00 | 724.78 | 703.75 |
| Carbon-Chlorine and Oxygen | | | | | |
| Tetrachloromethane (carbon tetrachloride) | CCl ₄ ,g | 153.823 | -24.6 | 69.5 | 69.5 |
| | CCl ₄ ,l | ..... | -32.37 | 61.68 | 61.68 |
| Tetrachloroethene..... | C ₂ Cl ₄ ,g | 165.834 | -3.6 | 184.5 | 184.5 |
| Hexachloroethane, triclinic.... | C ₂ Cl ₆ ,g | 236.740 | -35.3 | 152.8 | 152.8 |
| | C ₂ Cl ₆ ,c | ..... | -49.4 | 138.7 | 138.7 |
| Carbonyl chloride (phosgene).. | COCl ₂ ,g | 98.917 | 52.3 | 41.8 | 41.8 |
| Carbon-Hydrogen-Chlorine | | | | | |
| Chloromethane..... | CH ₃ Cl,g | 50.488 | -19.32 | 177.20 | 161.42 |
| Dichloromethane..... | CH ₂ Cl ₂ ,g | 84.933 | -22.10 | 140.27 | 129.75 |
| | CH ₂ Cl ₂ ,l | ..... | -29.02 | 133.34 | 122.82 |
| Trichloromethane..... | CHCl ₃ ,g | 119.378 | -24.65 | 103.56 | 98.30 |
| | CHCl ₃ ,l | ..... | -32.14 | 96.07 | 90.81 |
| Chloroethane..... | C ₂ H ₅ Cl,g | 64.515 | -25.5 | 333.4 | 307.1 |
| 1,2-Dichloroethane..... | C ₂ H ₄ Cl ₂ ,g | 98.960 | -31.1 | 293.6 | 272.6 |
| | C ₂ H ₄ Cl ₂ ,l | ..... | -39.6 | 285.1 | 264.1 |
| 1-Chloropropane..... | C ₃ H ₇ Cl,g | 78.542 | -31.2 | 490.1 | 453.2 |
| | C ₃ H ₇ Cl,l | ..... | -38.2 | 483.0 | 446.2 |

TABLE 4I-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (Continued)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|--|--|-------------|---------------------------------|---------------------|-------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Hydrogen-Chlorine (Cont.) | | | | | |
| 2-Chloropropane..... | C ₃ H ₇ Cl,g | 78.542 | -32.9 | 488.4 | 451.5 |
| | C ₃ H ₇ Cl,l | ..... | -39.2 | 482.0 | 445.2 |
| 2-Chloro-2-methylpropane.... | C ₄ H ₉ Cl,g | 92.569 | -43.0 | 640.6 | 593.3 |
| Chloroethene..... | C ₂ H ₃ Cl,g | 62.499 | 8.1 | 298.7 | 282.9 |
| 1,1-Dichloroethene..... | C ₂ H ₂ Cl ₂ ,g | 96.944 | 0.3 | 256.7 | 246.2 |
| | C ₂ H ₂ Cl ₂ ,l | ..... | -6.0 | 250.4 | 239.9 |
| Chlorobenzene..... | C ₆ H ₅ Cl,g | 112.560 | 12.5 | 747.6 | 721.3 |
| | C ₆ H ₅ Cl,l | ..... | 2.5 | 737.6 | 711.3 |
| <i>o</i> -Dichlorobenzene..... | C ₆ H ₄ Cl ₂ ,l | 147.005 | -4.4 | 696.5 | 675.5 |
| <i>p</i> -Dichlorobenzene..... | C ₆ H ₄ Cl ₂ ,l | 147.005 | -10.1 | 690.8 | 669.8 |
| <i>m</i> -Dichlorobenzene..... | C ₆ H ₄ Cl ₂ ,l | 147.005 | -4.8 | 696.1 | 675.1 |
| Carbon-Fluorine-Chlorine | | | | | |
| Fluorotrichloromethane..... | CFCl ₃ ,g | 137.369 | -66. | | |
| | CFCl ₃ ,l | ..... | -72.02 | | |
| Difluorodichloromethane..... | CF ₂ Cl ₂ ,g | 120.914 | -114 | | |
| Trifluorochloromethane..... | CF ₃ Cl,g | 104.459 | -166 | | |
| Carbon-Bromine, and Oxygen, Hydrogen, Fluorine, and Chlorine | | | | | |
| Tetrabromomethane (carbon tetrabromide)..... | CBr ₄ ,g | 331.647 | 19 | 113 | 98 |
| Carbonyl bromide..... | COBr ₂ ,g | 187.829 | -23.0 | 71.1 | 63.7 |
| | COBr ₂ ,l | ..... | -30.4 | 63.7 | 56.3 |
| Bromomethane..... | CH ₃ Br,g | 94.944 | -8.4 | 188.1 | 168.6 |
| | CH ₃ Br,l | ..... | -14.1 | 182.5 | 163.0 |
| Tribromomethane..... | CHBr ₃ ,g | 252.746 | 4 | 132 | 116 |
| | CHBr ₃ ,l | ..... | -6.8 | 121.4 | 105.1 |
| Bromoethane..... | C ₂ H ₅ Br,g | 108.971 | -14.8 | 344.1 | 314.1 |
| | C ₂ H ₅ Br,l | ..... | -21.5 | 337.3 | 307.4 |
| 1-Bromopropane..... | C ₃ H ₇ Br,g | 122.998 | -19.9 | 501.4 | 460.8 |
| | C ₃ H ₇ Br,l | ..... | -27.5 | 493.7 | 453.2 |
| 2-Bromopropane..... | C ₃ H ₇ Br,g | 122.998 | -22.7 | 498.6 | 458.0 |
| | C ₃ H ₇ Br,l | ..... | -29.9 | 491.3 | 450.8 |
| Bromoethene..... | C ₂ H ₃ Br,g | 106.955 | 18.7 | 309.3 | 289.8 |
| | C ₂ H ₃ Br,l | ..... | 13.3 | 303.9 | 284.4 |
| Bromobenzene..... | C ₆ H ₅ Br,g | 157.016 | 27.2 | 762.3 | 732.3 |
| | C ₆ H ₅ Br,l | ..... | 16.5 | 751.6 | 721.6 |
| Trifluorobromomethane..... | CF ₃ Br,g | 148.915 | -153.6 | | |
| Trichlorobromomethane..... | CCl ₃ Br,g | 198.279 | -11.0 | 83.0 | 79.4 |
| Carbon-Hydrogen-Iodine | | | | | |
| Iodomethane..... | CH ₃ I,g | 191.940 | 3.1 | 199.6 | 176.4 |
| | CH ₃ I,l | ..... | -3.7 | 192.8 | 169.6 |
| Diiodomethane..... | CH ₂ I ₂ ,g | 267.836 | 27.0 | 189.4 | 163.9 |
| | CH ₂ I ₂ ,l | ..... | 16.0 | 178.4 | 152.9 |

HEATS OF FORMATION AND HEATS OF COMBUSTION 4-339

TABLE 4I-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (Continued)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|--|--|-------------|---------------------------------|---------------------|--------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Hydrogen-Iodine (Cont.) | | | | | |
| Triiodomethane..... | CHI _{3,c} | 393.732 | 33.7 | 161.9 | 134.3 |
| 2-Iodo-2-methylpropane..... | C ₄ H ₉ I,g | 184.021 | -17.2 | 666.4 | 611.6 |
| 1,2-Diiodoethane..... | C ₂ H ₄ I _{2,g} | 281.863 | 15.9 | 340.6 | 304.7 |
| | C ₂ H ₄ I _{2,c} | ..... | 0.8 | 325.5 | 289.6 |
| Iodobenzene..... | C ₆ H ₅ I,g | 204.011 | 40.5 | 775.6 | 741.8 |
| | C ₆ H ₅ I,l | ..... | 29.0 | 764.1 | 730.3 |
| Carbon-Oxygen-Sulfur | | | | | |
| Carbon oxysulfide..... | COS,g | 60.075 | -33.96 | ..... | 131.04 |
| Carbon-Hydrogen-Sulfur, Alkanethiols and Cycloalkanethiols | | | | | |
| Methanethiol (methyl mercaptan) | CH ₃ S,g | 48.107 | -5.34 | 351.57 | 275.25 |
| | CH ₃ S,l | ..... | -11.08 | 345.83 | 269.51 |
| Ethanethiol..... | C ₂ H ₅ S,g | 62.134 | -11.01 | 508.27 | 421.42 |
| | C ₂ H ₅ S,l | ..... | -17.59 | 501.69 | 414.84 |
| 1-Propanethiol..... | C ₃ H ₇ S,g | 76.161 | -16.21 | 665.44 | 568.07 |
| | C ₃ H ₇ S,l | ..... | -23.86 | 657.79 | 560.43 |
| 2-Propanethiol..... | C ₃ H ₇ S,g | 76.161 | -18.21 | 663.44 | 566.07 |
| | C ₃ H ₇ S,l | ..... | -25.29 | 656.36 | 558.99 |
| 1-Butanethiol..... | C ₄ H ₁₀ S,g | 90.188 | -21.05 | 822.96 | 715.08 |
| | C ₄ H ₁₀ S,l | ..... | -29.78 | 814.23 | 706.35 |
| 2-Butanethiol..... | C ₄ H ₁₀ S,g | 90.188 | -23.15 | 820.86 | 712.98 |
| | C ₄ H ₁₀ S,l | ..... | -31.29 | 812.72 | 704.84 |
| 2-Methyl-1-propanethiol..... | C ₄ H ₁₀ S,g | 90.188 | -23.24 | 820.77 | 712.59 |
| | C ₄ H ₁₀ S,l | ..... | -31.54 | 812.47 | 704.29 |
| 2-Methyl-2-propanethiol..... | C ₄ H ₁₀ S,g | 90.188 | -26.17 | 817.84 | 709.96 |
| | C ₄ H ₁₀ S,l | ..... | -33.56 | 810.45 | 702.57 |
| 1-Pentanethiol..... | C ₅ H ₁₂ S,g | 104.215 | -25.92 | 980.46 | 862.06 |
| | C ₅ H ₁₂ S,l | ..... | -35.74 | 970.63 | 852.23 |
| 3-Methyl-1-butanethiol..... | C ₅ H ₁₂ S,g | 104.215 | -27.45 | 978.93 | 860.52 |
| 2-Methyl-2-butanethiol..... | C ₅ H ₁₂ S,g | 104.215 | -30.31 | 976.07 | 857.67 |
| | C ₅ H ₁₂ S,l | ..... | -38.85 | 967.53 | 849.13 |
| Cyclopentanethiol..... | C ₅ H ₁₀ S,g | 102.199 | -11.46 | 926.60 | 818.72 |
| | C ₅ H ₁₀ S,l | ..... | -21.39 | 916.67 | 808.79 |
| Cyclohexanethiol..... | C ₆ H ₁₂ S,g | 116.227 | -22.95 | 1,077.48 | 959.08 |
| Carbon-Hydrogen-Sulfur, Thiaalkanes, Dithiaalkanes, and Thiacycloalkanes | | | | | |
| 2-Thiapropane (dimethyl sulfide) | C ₂ H ₆ S,g | 62.134 | -8.96 | 510.32 | 423.47 |
| | C ₂ H ₆ S,l | ..... | -15.62 | 503.66 | 416.82 |
| 2-Thiabutane..... | C ₃ H ₈ S,g | 76.161 | -14.24 | 667.41 | 570.04 |
| | C ₃ H ₈ S,l | ..... | -21.88 | 659.77 | 562.40 |
| 2-Thiapentane..... | C ₄ H ₁₀ S,g | 90.188 | -19.54 | 824.47 | 716.59 |
| | C ₄ H ₁₀ S,l | ..... | -28.19 | 815.82 | 707.94 |
| 3-Thiapentane..... | C ₄ H ₁₀ S,g | 90.188 | -19.95 | 824.06 | 716.18 |
| | C ₄ H ₁₀ S,l | ..... | -28.50 | 815.51 | 707.63 |

TABLE 4I-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (Continued)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|--|--|-------------|---------------------------------|---------------------|----------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Hydrogen-Sulfur, Thiaalkanes, Dithiaalkanes, and Thiacycloalkanes (Cont.) | | | | | |
| 3-Methyl-2-thiabutane..... | C ₄ H ₁₀ S,g | 90.188 | -21.66 | 822.35 | 643.52 |
| | C ₄ H ₁₀ S,l | ..... | -29.81 | 814.20 | 635.37 |
| 2-Thiahexane..... | C ₅ H ₁₂ S,g | 104.215 | -24.43 | 981.93 | 863.54 |
| | C ₅ H ₁₂ S,l | ..... | -34.16 | 972.22 | 853.81 |
| 3-Thiahexane..... | C ₅ H ₁₂ S,g | 104.215 | -25.01 | 981.37 | 862.96 |
| | C ₅ H ₁₂ S,l | ..... | -34.59 | 971.79 | 853.38 |
| 3,2-Dimethyl-2-thiabutane.... | C ₅ H ₁₂ S,g | 104.215 | -28.88 | 977.50 | 859.09 |
| | C ₅ H ₁₂ S,l | ..... | -37.44 | 968.94 | 850.53 |
| 4-Thiaheptane..... | C ₆ H ₁₄ S,g | 118.242 | -29.98 | 1,138.86 | 1,009.94 |
| | C ₆ H ₁₄ S,l | ..... | -40.76 | 1,127.98 | 999.06 |
| 2,4-Dimethyl-3-thiapentane.... | C ₆ H ₁₄ S,g | 118.242 | -33.89 | 1,134.85 | 1,005.93 |
| | C ₆ H ₁₄ S,l | ..... | -43.33 | 1,125.41 | 996.49 |
| 5-Thianonane..... | C ₆ H ₁₄ S,g | 146.297 | -40.02 | 1,453.46 | 1,303.50 |
| 2,3-Dithiabutane..... | C ₂ H ₆ S ₂ ,g | 94.198 | -5.74 | 639.77 | 497.64 |
| | C ₂ H ₆ S ₂ ,l | ..... | -14.91 | 630.60 | 488.47 |
| 3,4-Dithiahexane..... | C ₄ H ₁₀ S ₂ ,g | 122.252 | -17.82 | 952.42 | 789.25 |
| | C ₄ H ₁₀ S ₂ ,l | ..... | -28.71 | 941.54 | 778.36 |
| 4,5-Dithiaoctane..... | C ₆ H ₁₄ S ₂ ,g | 150.306 | -28.01 | 1,266.97 | 1,082.76 |
| | C ₆ H ₁₄ S ₂ ,l | ..... | -40.56 | 1,254.42 | 1,070.21 |
| Thiacyclobutane..... | C ₃ H ₆ S,g | 74.145 | 14.59 | 627.92 | 541.08 |
| | C ₃ H ₆ S,l | ..... | 6.01 | 619.34 | 532.50 |
| Thiacyclopentane..... | C ₄ H ₈ S,g | 88.172 | -8.20 | 707.50 | 670.13 |
| | C ₄ H ₈ S,l | ..... | -17.48 | 758.22 | 660.85 |
| 2-Methylthiacyclopentane..... | C ₅ H ₁₀ S,g | 102.199 | -15.16 | 922.90 | 815.02 |
| Thiacyclohexane..... | C ₅ H ₁₀ S,g | 102.199 | -15.16 | 922.90 | 815.02 |
| | C ₅ H ₁₀ S,l | ..... | -25.38 | 912.68 | 804.80 |
| Carbon-Hydrogen-Sulfur, Miscellaneous | | | | | |
| Cyclopentyl-1-thiaethane..... | C ₆ H ₁₂ S,g | 116.227 | -15.46 | 1,084.96 | 966.57 |
| Benzenethiol (thiophene)..... | C ₆ H ₆ S,g | 110.179 | 26.94 | 922.42 | 835.58 |
| | C ₆ H ₆ S,l | ..... | 15.30 | 910.78 | 823.94 |
| Thiophene (thiofuran)..... | C ₄ H ₄ S,g | 84.140 | 27.78 | 666.85 | 590.52 |
| | C ₄ H ₄ S,l | ..... | 19.49 | 658.56 | 582.23 |
| Carbon-Hydrogen-Nitrogen, Amines | | | | | |
| Aminomethane (methylamine) | CH ₅ N,g | 31.058 | -5.49 | 259.35 | 233.05 |
| | CH ₅ N,l | ..... | -11.3 | 253.5 | 227.2 |
| Aminoethane (ethylamine).... | C ₂ H ₇ N,g | 45.085 | -11.0 | 416.20 | 379.39 |
| | C ₂ H ₇ N,l | ..... | -17.71 | 409.49 | 372.68 |
| 1-Aminopropane (<i>n</i> -propyl-amine) | C ₃ H ₉ N,g | 59.112 | -17.3 | 572.3 | 524.9 |
| | C ₃ H ₉ N,l | ..... | -24.8 | 564.8 | 517.4 |
| 1-Aminobutane (<i>n</i> -butyl-amine) | C ₄ H ₁₁ N,g | 73.139 | -22.10 | 729.84 | 671.98 |
| | C ₄ H ₁₁ N,l | ..... | -30.53 | 721.41 | 663.55 |
| 2-Aminobutane (<i>sec</i> -butyl-amine) | C ₄ H ₁₁ N,g | 73.139 | -24.9 | 727.0 | 669.2 |
| | C ₄ H ₁₁ N,l | ..... | -32.88 | 719.06 | 661.20 |

HEATS OF FORMATION AND HEATS OF COMBUSTION 4-341

TABLE 4I-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (Continued)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|---|---|-------------|---------------------------------|---------------------|--------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbod-Oxygen-Hydrogen-Nitrogen (Cont.) | | | | | |
| 2-Amino-2-methylpropane (<i>tert</i> -butylamine) | C ₄ H ₁₁ N,g | 73.139 | -28.65 | 723.29 | 665.43 |
| | C ₄ H ₁₁ N,l | ..... | -35.95 | 715.99 | 658.13 |
| Dimethylamine..... | C ₂ H ₇ N,g | 45.085 | -4.5 | 492.70 | 385.89 |
| | C ₂ H ₇ N,l | ..... | -10.50 | 416.70 | 379.89 |
| Diethylamine..... | C ₄ H ₁₁ N,g | 73.139 | -17.3 | 734.64 | 676.78 |
| | C ₄ H ₁₁ N,l | ..... | -24.79 | 727.15 | 669.29 |
| Trimethylamine..... | C ₃ H ₉ N,g | 59.112 | -5.70 | 583.87 | 536.54 |
| | C ₃ H ₉ N,l | ..... | -10.94 | 578.63 | 531.30 |
| Triethylamine..... | C ₆ H ₁₅ N,g | 101.193 | -23.8 | 1,052.9 | 974.0 |
| | C ₆ H ₁₅ N,l | ..... | -32.07 | 1,044.60 | 965.71 |
| Aminobenzene (aniline)..... | C ₆ H ₇ N,g | 93.129 | 20.76 | 824.17 | 787.35 |
| | C ₆ H ₇ N,l | ..... | 7.43 | 810.84 | 774.02 |
| Carbon-Hydrogen-Nitrogen, Cyanides | | | | | |
| Hydrogen cyanide..... | HCN,g | 27.026 | 32.3 | 160.5 | 155.2 |
| | HCN,l | ..... | 26.02 | 154.23 | 148.97 |
| Cyanamide..... | CH ₂ N ₂ ,c | 42.041 | 14.1 | 176.5 | 165.9 |
| Ammonium cyanide..... | NH ₄ CN,c | 44.056 | 0.10 | 230.78 | 209.74 |
| Acetonitrile..... | C ₂ H ₃ N,g | 41.053 | 21.0 | 311.6 | 295.8 |
| | C ₂ H ₃ N,l | ..... | 12.3 | 302.9 | 287.1 |
| Acrylonitrile..... | C ₃ H ₃ N,g | 53.064 | 44.2 | 428.8 | 404.7 |
| | C ₃ H ₃ N,l | ..... | 35.9 | 420.5 | 413.0 |
| Carbon-Hydrogen-Nitrogen, Cyclic Compounds | | | | | |
| Pyrrolidine..... | C ₄ H ₉ N,g | 71.123 | -0.86 | 682.76 | 635.43 |
| | C ₄ H ₉ N,l | ..... | -9.84 | 678.78 | 626.45 |
| Pyridine..... | C ₅ H ₅ N,g | 79.102 | 33.50 | 674.54 | 648.24 |
| | C ₅ H ₅ N,l | ..... | 23.89 | 664.93 | 638.64 |
| 6-Aminopurine (adenine)..... | C ₅ H ₅ N ₅ ,g | 135.129 | 48. | 689. | 663. |
| | C ₅ H ₅ N ₅ ,c | ..... | 23.2 | 664.2 | 637.9 |
| 2-Picoline..... | C ₆ H ₇ N,g | 93.129 | 23.65 | 827.06 | 790.24 |
| | C ₆ H ₇ N,l | ..... | 13.50 | 816.91 | 780.09 |
| 3-Picoline..... | C ₆ H ₇ N,g | 93.129 | 25.37 | 828.78 | 791.96 |
| | C ₆ H ₇ N,l | ..... | 14.75 | 818.16 | 781.34 |
| Carbon-Oxygen-Hydrogen-Nitrogen | | | | | |
| Ammonium formate..... | CH ₃ O ₂ N,c | 63.057 | -135.63 | 129.2 | 102.9 |
| Ammonium bicarbonate..... | CH ₃ O ₂ N,c | 79.056 | -203.0 | 61.8 | 35.5 |
| Ammonium cyanate..... | CH ₃ ON ₂ ,c | 60.056 | -72.75 | 157.9 | 136.9 |
| Methyl nitrate..... | CH ₃ O ₂ N,g | 77.040 | -29.8 | 166.7 | 150.9 |
| | CH ₃ O ₂ N,l | ..... | -38.0 | 158.5 | 142.7 |
| Methyl nitrite..... | CH ₃ O ₂ N,g | 61.041 | -16.5 | 180.0 | 164.2 |

TABLE 4I-3. HEATS OF FORMATION AND HEATS OF COMBUSTION OF COMPOUNDS OF CARBON (*Continued*)

| Substance name | Formula and state | Mol. weight | Kcal mole ⁻¹ at 25°C | | |
|--|--|-------------|---------------------------------|---------------------|--------|
| | | | ΔH_f° | $-\Delta H_c^\circ$ | |
| | | | | Gross | Net |
| Carbon-Oxygen-Hydrogen-Nitrogen (Cont.) | | | | | |
| Nitromethane..... | CH ₃ O ₂ N,g | 61.041 | -17.86 | 178.66 | 162.89 |
| | CH ₃ O ₂ N,l | ..... | -27.03 | 169.49 | 153.72 |
| Nitroethane..... | C ₂ H ₅ O ₂ N,g | 75.068 | -24.2 | 334.7 | 308.4 |
| | C ₂ H ₅ O ₂ N,l | ..... | -33.9 | 325.0 | 298.7 |
| 1-Nitropropane..... | C ₃ H ₇ O ₂ N,g | 89.095 | -29.8 | 491.5 | 454.6 |
| | C ₃ H ₇ O ₂ N,l | ..... | -40.15 | 481.11 | 444.29 |
| 2-Nitropropane..... | C ₃ H ₇ O ₂ N,g | 89.095 | -33.5 | 487.8 | 450.9 |
| | C ₃ H ₇ O ₂ N,l | ..... | -43.3 | 478.0 | 441.1 |
| 1-Nitrobutane..... | C ₄ H ₉ O ₂ N,g | 103.122 | -34.4 | 649.2 | 601.9 |
| | C ₄ H ₉ O ₂ N,l | ..... | -46.03 | 637.59 | 590.26 |
| 2-Nitrobutane..... | C ₄ H ₉ O ₂ N,g | 103.122 | -30.1 | 644.5 | 597.2 |
| | C ₄ H ₉ O ₂ N,l | ..... | -49.61 | 634.01 | 586.68 |
| Trinitromethane..... | CHO ₃ N ₃ ,l | 151.036 | -5.1 | 123.1 | 117.5 |
| Formamide..... | CH ₃ ON,l | 45.041 | -60.7 | 135.8 | 120.0 |
| Urea..... | CH ₄ ON ₂ ,c | 60.056 | -79.58 | 151.10 | 130.00 |
| Aminoethanoic acid (glycine)... | C ₂ H ₃ O ₂ N,g | 75.068 | -94.4 | 264.5 | 238.2 |
| | C ₂ H ₃ O ₂ N,c | ..... | -128.4 | 230.5 | 204.2 |
| DL-2-Aminopropanoic acid (DL-alanine)..... | C ₃ H ₇ O ₂ N,c | 89.095 | -134.7 | 386.6 | 349.7 |
| L-2-Aminopropanoic acid (L-alanine)..... | C ₃ H ₇ O ₂ N,g | 89.095 | -101.0 | 420.3 | 383.4 |
| | C ₃ H ₇ O ₂ N,c | ..... | -134.5 | 386.8 | 349.9 |
| Carbon-Nitrogen, and Hydrogen, Chlorine, Bromine, Iodine, and Sulfur | | | | | |
| Methylamine hydrochloride.... | CH ₅ ClN,c | 67.519 | -71.20 | 227.8 | 196.2 |
| Trinitrochloromethane..... | CO ₃ ClN ₃ ,l | 185.481 | -5.6 | 88.5 | 88.5 |
| Cyanogen bromide..... | CBrN,g | 105.927 | 44.5 | 138.6 | 134.9 |
| | CBrN,c | ..... | 33.58 | 127.63 | 123.93 |
| Cyanogen iodide..... | CIN,g | 152.922 | 53.9 | 148.0 | 140.5 |
| | CIN,c | ..... | 39.71 | 133.8 | 126.3 |
| Thiourea..... | CH ₄ SN ₂ ,c | 76.120 | -21.1 | 335.8 | 259.5 |
| Ammonium thiocyanate..... | CH ₄ SN ₂ ,c | 76.120 | -18.8 | 338.1 | 261.8 |