1. On the basis of your experience, predict which of the following reactions are spontaneous.

   (a) $NaCl(s) \rightarrow NaCl(l)$ at 25 °C
   (b) $2\ NaCl(s) \rightarrow 2\ Na(s) + Cl_2(g)$
   (c) $CO_2(s) \rightarrow CO_2(g)$ at 25 °C
   (d) $CO_2(g) \rightarrow C(s) + O_2(g)$
   (e) $H_2O\ (l) \rightarrow H_2O(s)$ at 25 °C

2. Without doing a calculation, predict which of the following shows a ***decrease*** in entropy?

   (a) $CO_2(s) \longrightarrow CO_2(g)$
   (b) $FeCl_2(s) + H_2(g) \longrightarrow Fe(s) + 2HCl(g)$
   (c) $CO(g) + 2\ H_2\ (g) \longrightarrow CH_3OH(l)$
   (d) $2H_2O(g) + \longrightarrow 2H_2(g) + O_2(g)$
   (e) $CH_3OH(l) + 3/2\ O_2(g) \longrightarrow 2H_2O(g) + CO_2(g)$

3. The sign of ΔH_{rxn} and ΔS_{rxn} for several reactions are given. In which case is the reaction spontaneous at all temperatures?

   (a) $\Delta H_{rxn} < 0$; $\Delta S_{rxn} < 0$
   (b) $\Delta H_{rxn} < 0$; $\Delta S_{rxn} > 0$
   (c) $\Delta H_{rxn} > 0$; $\Delta S_{rxn} < 0$
   (d) $\Delta H_{rxn} > 0$; $\Delta S_{rxn} > 0$
   (e) $\Delta H_{rxn} = \Delta S_{rxn}$

4. Select the correct statement that corresponds to the third law of thermodynamics.

   (a) The standard Gibbs free energy change, ΔG^o, can be calculated from Gibbs free energies of formation, ΔG_f^o
   (b) The entropy of a perfect crystal of any pure substance approaches zero, as the temperature approaches absolute zero (0 K)
   (c) The entropy change for a reaction, ΔS^o, can be calculated from the standard molar entropies of the reactants and products
   (d) $\Delta E_{universe} = \Delta E_{system} + \Delta E_{surroundings} = 0$
   (e) In any spontaneous process, $\Delta S_{universe} = \Delta S_{system} + \Delta S_{surroundings} > 0$

5. Confirm that the reaction below would be spontaneous, or nonspontaneous at 25°C, by calculating the standard free energy change, ΔG^o, using values for ΔH^o and ΔS^o.

$$CO(g) + \frac{1}{2} O_2(g) \rightarrow CO_2(g)$$
$$\Delta H_{rxn}^o = -283.0 \text{ kJ}; \ \Delta S_{rxn}^o = -86.6 \text{ J/K}$$

(a) -257 kJ; the reaction is spontaneous at 25°C.
(b) +389 kJ; the reaction is spontaneous at 25°C.
(c) -389 kJ; the reaction is spontaneous at 25°C.
(d) +196 kJ; the reaction is not spontaneous at 25°C.
(e) -196 kJ; the reaction is spontaneous at 25°C.

6. For which of the following substances is $\Delta H_f^\circ = 0$; $\Delta G_f^\circ = 0$?

(a) $Al_2O_3(s)$
(b) C(*s*, diamond)
(c) $CO_2(g)$
(d) $Cl_2(g)$
(e) $MgCO_3$(aq)

7. When magnesium sulfite decomposes, the solid transforms into magnesium oxide and sulfur dioxide.

$$MgSO_3(s) \rightarrow MgO(s) + SO_2(g)$$

At what temperature will this reaction be spontaneous according to Gibb's Energy?

ΔH_f^o in kJ/mol for: $MgSO_3(s) = -1068$, $MgO(s) = -601.8$, $SO_2(g) = -296.8$
S^o in J/mol K for: $MgSO_3(s) = 121$, $MgO(s) = 27$, $SO_2(g) = 248.1$

(a) temps below −63.1 K
(b) temps below 179.5 K
(c) temps below 415.8 K
(d) temps above 415.8 K
(e) temps above 1100 K

8. Confirm that the reaction below would be spontaneous, or nonspontaneous at 25°C, by calculating the standard free energy change, ΔG^o, using values for ΔG_f^o.

$$2\ C_4H_{10}(g) + 13\ O_2(g) \rightarrow 8\ CO_2(g) + 10\ H_2O(l)$$

ΔG_f^o(kJ/mol)	-15.71	0	-394.4	-237.2

(a) -615.89 kJ; the reaction is spontaneous.
(b) +615.89 kJ; the reaction is not spontaneous.
(c) 0 kJ; the reaction is spontaneous.
(d) +5496 kJ; the reaction is not spontaneous.
(e) -5496 kJ; the reaction is spontaneous.

9. If a 5.0 L flask holds 0.125 moles of nitrogen at STP, what happens to the entropy of the system upon cooling the gas to -75 °C?

(a) The entropy is zero.
(b) The entropy increases.
(c) The entropy remains the same.
(d) The entropy decreases.
(e) There is too little information to assess the change.

10. In the first 10.0 s of the reaction, the concentration of B decreased from 0.50 M to 0.37 M. What is the rate of the reaction in this time interval?

$$2A + 3B \rightarrow 2C + D$$

(a) 2.3 M/s
(b) 0.50 M/s
(c) 0.13 M/s
(d) 1.3×10^{-2} M/s
(e) 4.3×10^{-3} M/s

11. If ammonia, $NH_3(g)$, is being produced at a rate of 6.29×10^{-5} mol L^{-1} s^{-1}, at what rate is nitrogen gas being consumed?

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

(a) 9.44×10^{-5} mol L^{-1} s^{-1}.
(b) 6.29×10^{-5} mol L^{-1} s^{-1}.
(c) 4.17×10^{-5} mol L^{-1} s^{-1}.

(d) 3.15×10^{-5} mol L^{-1} s^{-1}
(e) 1.26×10^{-4} M/s

12. Based on the generic rate law, which of the following is not really correct?

$$\text{Rate of reaction} = k[A]^m [B]^n$$

(a) The experimentally determined exponents (m, n) are referred to as the order of the reaction with respect to A and B, respectively.
(b) If $m = 1$, the reaction is first order with respect to A.
(c) If $m = 0$, the reaction is independent of the concentration of A.
(d) If $n = 2$, the reaction is second order with respect to B.
(e) The overall order of the reaction = m × n

13. Consider the reaction: A + B → C, and a kinetics study on this reaction yielded:

[A] mol·L^{-1}	[B] mol·L^{-1}	Rate = mol·L^{-1}·s^{-1}
0.100	0.200	4.45×10^{-3}
0.050	0.200	1.12×10^{-3}
0.050	0.100	1.11×10^{-3}

What is the value of the rate constant?

(a) 3.20 L·mol^{-1}·s^{-1}
(b) 19.8 L·mol^{-1}·s^{-1}
(c) 0.445 L·mol^{-1}·s^{-1}
(d) 4.60 L·mol^{-1}·s^{-1}
(e) 4.60 s^{-1}

14. The decomposition of N_2O_5 in solution of carbon tetrachloride is a first-order reaction:

$$2\,N_2O_5 \rightarrow 4\,NO_2 + O_2$$

The rate constant at a given temperature is found to be 4.50×10^{-4} s^{-1}. If the initial concentration of N_2O_5 is 0.250 M, what is its concentration after exactly 15 minutes have passed?

(a) 0.000 M
(b) 0.073 M
(c) 0.167 M
(d) 0.195 M
(e) 0.199 M

15. Consider the production of oxygen from ozone. The mechanism includes two elementary steps:

$$O_3 + Cl\cdot \rightarrow ClO\cdot + O_2$$
$$ClO\cdot + O_3 \rightarrow Cl\cdot + 2\ O_2$$

Which species is a reactive intermediate?

(a) O_3
(b) $ClO\cdot$
(c) $Cl\cdot$
(d) O_2
(e) both $ClO\cdot$ and $Cl\cdot$

16. If a reaction is second order with respect to [B], doubling the concentration of [B] will result in:

(a) a doubling of the rate
(b) a tripling of the rate
(c) a four-fold increase in rate
(d) an eight-fold increase in rate
(e) no change in the rate of reaction

17. If the initial concentration of the reactant in a first-order reaction A → products is 0.64 mol/L and the half-life is 30.0 s, how long would it take for the concentration of the reactant to drop to 0.040 mol/L?

(a) 30.0 s
(b) 60.0 s
(c) 90.0 s
(d) 120.0 s
(e) 150.0 s

18. Consider the elementary step: 2A + B → C. What type of elementary step is this?

(a) unimolecular
(b) bimolecular
(c) termolecular
(d) all of the above
(e) none of the above

19. Raising the temperature of a reaction elevates the rate of reaction by:

(a) increasing the energy of activation
(b) creating more molecules in the reaction.
(c) providing a new reaction mechanism
(d) increasing the number of molecules moving at a speed sufficiently high enough to produce a reactive collision.
(e) decreasing the entropy of the system.

20. Which statement is true regarding the sublimation of dry ice (solid CO_2) at 25 °C?

a) ΔH is positive; ΔS is positive; ΔG is positive.
b) ΔH is positive; ΔS is positive; ΔG is negative.
c) ΔH is negative; ΔS is positive; ΔG is negative.
d) ΔH is positive; ΔS is negative; ΔG is positive.
e) ΔH is negative; ΔS is negative; ΔG is negative.

Answers:

1 (c), 2 (c), 3 (b), 4 (b), 5 (a), 6 (d), 7 (e), 8 (e), 9 (d), 10 (e), 11 (d), 12 (e), 13 (c), 14 (c), 15 (b), 16 (c), 17 (d), 18 (c), 19 (d), 20 (b)

Atomic Number → 1
Symbol → H
1.008 ← Atomic Mass
Hydrogen ← Name

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H 1.0079 Hydrogen																	2 He 4.0026 Helium
2	3 Li 6.941 Lithium	4 Be 9.0122 Beryllium											5 B 10.811 Boron	6 C 12.011 Carbon	7 N 14.0067 Nitrogen	8 O 15.9994 Oxygen	9 F 18.9984 Fluorine	10 Ne 20.1797 Neon
3	11 Na 22.9898 Sodium	12 Mg 24.3050 Magnesium											13 Al 26.9815 Aluminium	14 Si 28.0855 Silicon	15 P 30.9738 Phosphorus	16 S 32.065 Sulfur	17 Cl 35.453 Chlorine	18 Ar 39.948 Argon
4	19 K 39.0983 Potassium	20 Ca 40.078 Calcium	21 Sc 44.9559 Scandium	22 Ti 47.87 Titanium	23 V 50.9415 Vanadium	24 Cr 51.9961 Chromium	25 Mn 54.9380 Manganese	26 Fe 55.85 Iron	27 Co 58.9332 Cobalt	28 Ni 58.6934 Nickel	29 Cu 63.546 Copper	30 Zn 65.38 Zinc	31 Ga 69.723 Gallium	32 Ge 72.64 Germanium	33 As 74.9216 Arsenic	34 Se 78.96 Selenium	35 Br 79.904 Bromine	36 Kr 83.80 Krypton
5	37 Rb 85.4678 Rubidium	38 Sr 87.62 Strontium	39 Y 88.9059 Yttrium	40 Zr 91.224 Zirconium	41 Nb 92.9064 Niobium	42 Mo 95.96 Molybdenum	43 Tc 98 Technetium	44 Ru 101.07 Ruthenium	45 Rh 102.9055 Rhodium	46 Pd 106.42 Palladium	47 Ag 107.8682 Silver	48 Cd 112.411 Cadmium	49 In 114.82 Indium	50 Sn 118.710 Tin	51 Sb 121.76 Antimony	52 Te 127.60 Tellurium	53 I 126.9045 Iodine	54 Xe 131.29 Xenon
6	55 Cs 132.9055 Caesium	56 Ba 137.327 Barium	**57 / 71**	72 Hf 178.49 Hafnium	73 Ta 180.9479 Tantalum	74 W 183.84 Tungsten	75 Re 186.207 Rhenium	76 Os 190.2 Osmium	77 Ir 192.22 Iridium	78 Pt 195.08 Platinum	79 Au 196.9665 Gold	80 Hg 200.59 Mercury	81 Tl 204.3833 Thallium	82 Pb 207.2 Lead	83 Bi 208.9804 Bismuth	84 Po 209 Polonium	85 At 210 Astatine	86 Rn 222 Radon
7	87 Fr 223 Francium	88 Ra 226 Radium	**89 / 103**	104 Rf 267 Rutherfordium	105 Db 268 Dubnium	106 Sg 269 Seaborgium	107 Bh 270 Bohrium	108 Hs 269 Hassium	109 Mt 278 Meitnerium	110 Ds 281 Darmstadtium	111 Rg 281 Roentgenium	112 Cn 285 Copernicium	113 Uut 286 Ununtrium	114 Fl 289 Flerovium	115 Uup 289 Ununpentium	116 Lv 293 Livermorium	117 Uus 294 Ununseptium	118 Uuo 294 Ununoctium

Lanthanide Series	57 La 138.9055 Lanthanum	58 Ce 140.116 Cerium	59 Pr 140.9076 Praseodymium	60 Nd 144.24 Neodymium	61 Pm 145 Promethium	62 Sm 150.36 Samarium	63 Eu 151.964 Europium	64 Gd 157.25 Gadolinium	65 Tb 158.9253 Terbium	66 Dy 162.50 Dysprosium	67 Ho 164.9303 Holmium	68 Er 167.26 Erbium	69 Tm 168.9342 Thulium	70 Yb 173.054 Ytterbium	71 Lu 174.967 Lutetium
Actinide Series	89 Ac 227 Actinium	90 Th 232.0381 Thorium	91 Pa 231.0359 Protactinium	92 U 238.0289 Uranium	93 Np 237 Neptunium	94 Pu 244 Plutonium	95 Am 243 Americium	96 Cm 247 Curium	97 Bk 247 Berkelium	98 Cf 251 Californium	99 Es 252 Einsteinium	100 Fm 257 Fermium	101 Md 258 Mendelevium	102 No 259 Nobelium	103 Lr 262 Lawrencium

SOME USEFUL CONSTANTS

(a more complete list appears in Appendix B)

Atomic mass unit	1 amu = 1.6606×10^{-24} g
Avogadro's number	$N = 6.02214179 \times 10^{23}$ particles/mol
Electronic charge	$e = 1.60218 \times 10^{-19}$ coulombs
Faraday constant	$F = 96{,}485.3399$ coulombs/mol e^-
Gas constant	$R = 0.08206 \frac{\text{L atm}}{\text{mol K}} = 1.987 \frac{\text{cal}}{\text{mol K}}$
	$= 8.314472 \frac{\text{J}}{\text{mol K}} = 8.314472 \frac{\text{kPa dm}^3}{\text{mol K}}$
Pi	$\pi = 3.1415927$
Planck's constant	$h = 6.62606896 \times 10^{-34}$ J s
Speed of light (in vacuum)	$c = 2.99792458 \times 10^8$ m/s

SOME USEFUL RELATIONSHIPS

Mass and Weight

SI Base Unit: Kilogram (kg)

1 kilogram = 1000 grams = 2.205 pounds
1 gram = 1000 milligrams
1 pound = 453.59 grams
1 amu = 1.6606×10^{-24} grams
1 gram = 6.022×10^{23} amu
1 ton = 2000 pounds

Length

SI Base Unit: Meter (m)

1 inch = 2.54 centimeters (exactly)
1 meter = 100 centimeters = 39.37 inches
1 yard = 0.9144 meter
1 mile = 1.609 kilometers
1 kilometer = 1000 meters = 0.6215 mile
1 Ångstrom = 1.0×10^{-10} meters = 1.0×10^{-8} centimeters

Volume

SI Base Unit: Cubic Meter (m^3)

1 liter = 0.001 cubic meter
1 liter = 1000 cubic centimeters = 1000 mL
1 liter = 1.056 quarts
1 quart = 0.9463 liter
1 milliliter = 0.001 liter = 1 cubic centimeter
cubic foot = 7.475 gallons = 28.316 liters
1 gallon = 4 quarts

Energy

SI Base Unit: Joule (J)

1 calorie = 4.184 joules = 4.129×10^{-2} L atm

$$1 \text{ joule} = 1 \frac{\text{kg m}^2}{\text{s}^2} = 0.23901 \text{ calorie}$$

1 joule = 1×10^7 ergs
1 electron volt = 1.6022×10^{-19} joule
1 electron volt = 96.485 kJ/mol
1 L atm = 24.217 calories = 101.325 joules

Pressure

SI Base Unit: Pascal (Pa)

$$1 \text{ pascal} = \frac{\text{kg}}{\text{m s}^2} = 1 \text{ Newton/m}^2$$

1 atmosphere = 760 torr
= 760 millimeters of mercury
= 1.01325×10^5 pascals
= 1.01325 bar
= 14.70 pounds per square inch
1 torr = 1 millimeter of mercury

Temperature

SI Base Unit: Kelvin (K)

0 K = −273.15°C
K = °C + 273.15°
°F = 1.8(°C) + 32°

$$°\text{C} = \frac{°\text{F} - 32°}{1.8°}$$