Thermodynamics Review

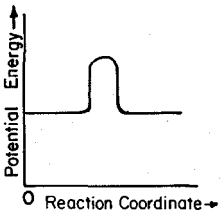
1. According to Reference Table I, the dissolving of $NH_4Cl(s)$ in water is
   1) exothermic and the heat of reaction is negative
   2) exothermic and the heat of reaction is positive
   3) endothermic and the heat of reaction is negative
   4) endothermic and the heat of reaction is positive

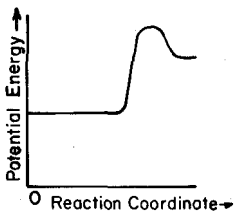
2. Changes in activation energy during a chemical reaction are represented by a
   1) cooling curve
   2) heating curve
   3) ionization energy diagram
   4) potential energy diagram

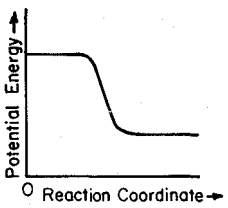
3. In a rechargeable battery system, the discharging reaction is
   1) exothermic and the charging reaction is exothermic
   2) exothermic and the charging reaction is endothermic
   3) endothermic and the charging reaction is exothermic
   4) endothermic and the charging reaction is endothermic

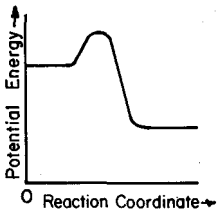
4. Which statement best describes a chemical reaction in which energy is released?
   1) It is exothermic and has a negative (H.
   2) It is exothermic and has a positive (H.
   3) It is endothermic and has a negative (H.
   4) It is endothermic and has a positive (H.

5. Which graph represents an endothermic reaction?

   1)
   

   3)
   

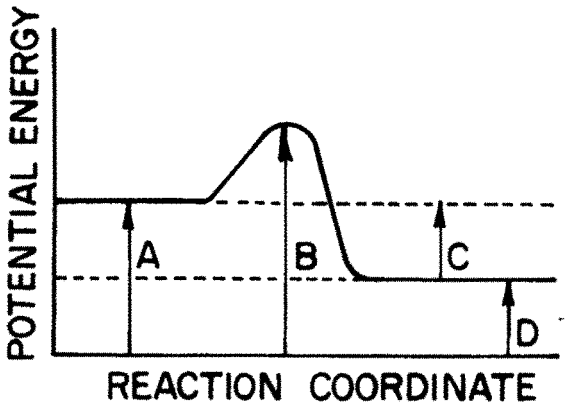
   2)
   

   4)
   

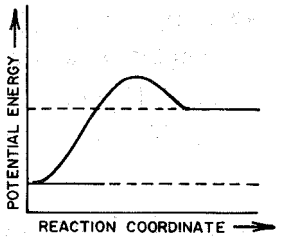
6. Which change is exothermic?
   1) freezing of water
   2) melting of iron
   3) vaporization of ethanol
   4) sublimation of iodine

7. Which of the following best describes exothermic chemical reactions?
   1) They never release heat.
   2) They always release heat.
   3) They never occur spontaneously.
   4) They always occur spontaneously.

8. In the potential energy diagram below, which letter represents the potential energy of the activated complex?



   1) *A*
   2) *B*
   3) *C*
   4) *D*

9.


   According to the potential energy diagram shown above, the chemical reaction in the forward direction is
   1) exothermic because it absorbs energy
   2) exothermic because it releases energy
   3) endothermic because it absorbs energy
   4) endothermic because it releases energy

10. According to Table I, which compound has a higher potential energy than the elements from which it is formed?
    1) aluminum oxide (s)
    2) hydrogen oxide (.)
    3) carbon dioxide (g)
    4) nitrogen (II) oxide (g)

11. According to Table I, which salt releases energy as it dissolves?
    1) KNO_3
    2) LiBr
    3) NH_4NO_3
    4) NaCl

12. The difference between the potential energy of the reactants and the potential energy of the products is
    1) ΔG
    2) ΔH
    3) ΔS
    4) ΔT

13. Which phase change represents a *decrease* in entropy?
    1) solid to liquid
    2) gas to liquid
    3) liquid to gas
    4) solid to gas

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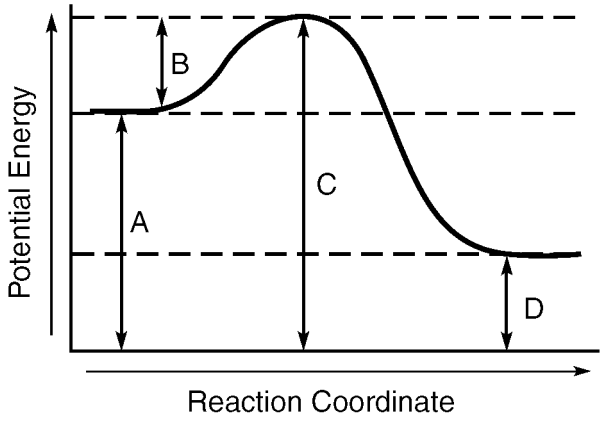
14. Salt *A* and salt *B* were each dissolved in separate beakers of water at 21°C. The temperature of the salt *A* solution decreased, and the temperature of the salt *B* solution increased.

    Based on these results, which conclusion is correct?

    1) The water gained energy from both salt *A* and salt *B*.
    2) The water lost energy to both salt *A* and salt *B*.
    3) The water gained energy from salt *A* and lost energy to salt *B*.
    4) The water lost energy to salt *A* and gained energy from salt *B*.

15. The potential energy diagram below represents a reaction.

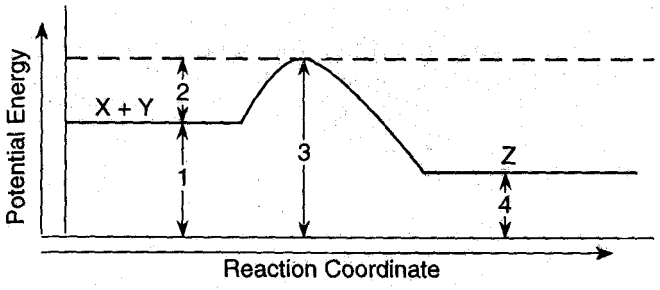


    Which arrow represents the activation energy of the forward reaction?

    1) *A*
    2) *B*
    3) *C*
    4) *D*

16. The potential energy diagram below shows the reaction

$$X + Y \rightarrow Z.$$



    When a catalyst is added to the reaction, it will change the value of

    1) 1 and 2
    2) 1 and 3
    3) 2 and 3
    4) 3 and 4

17. According to Table I, the least amount of energy would be evolved by the formation of one mole of

    1) H_2O (g)
    2) SO_2 (g)
    3) CO_2 (g)
    4) CO (g)

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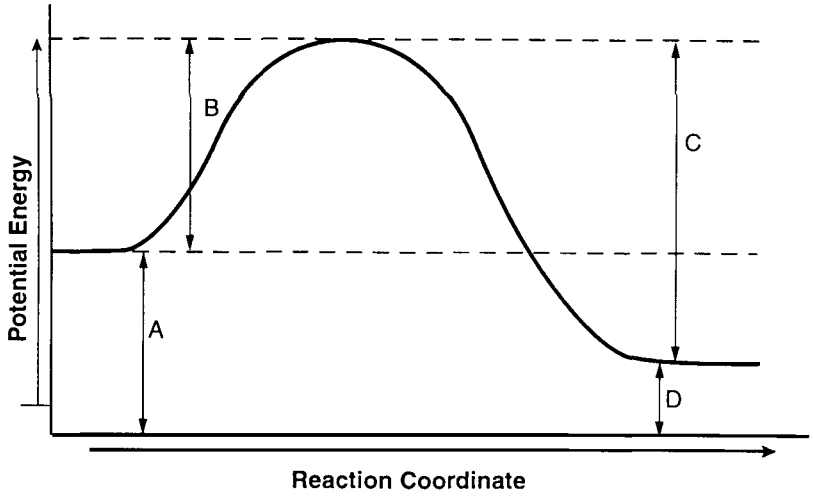
18. A potential energy diagram is shown below.



Which letters represent the activation energy of the forward and reverse reactions, respectively?

1) *A* and *C*
2) *A* and *D*
3) *B* and *C*
4) *B* and *D*

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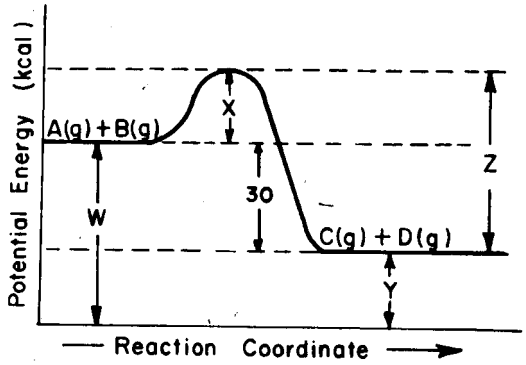
19. Base your answers on the potential energy diagram below.



The potential energy of the activated complex is equal to the sum of

1) $X + Y$
2) $X + W$
3) $X + Y + W$
4) $X + W + Z$

20. The reaction

$$A(g) + B(g) \rightarrow C(g) + D(g) + 30\ kJ$$

has a forward activation energy of 20 kJ. What is the activation energy for the reverse reaction?

1) 10 kJ
2) 20 kJ
3) 30 kJ
4) 50 kJ

21. According to Reference Table I, which compound released the greatest amount of energy per mole when it is formed from its elements?

1) hydrogen iodide
2) carbon dioxide
3) ethyne
4) ethene

22. The reaction of hydrogen and oxygen to form water is best described as

1) exothermic, because energy is released
2) endothermic, because energy is released
3) exothermic, because energy is absorbed
4) endothermic, because energy is absorbed

23. Given the reaction:

$$H_2O(\ell) + 286\ kJ \leftrightarrow H_2(g) + \frac{1}{2} O_2(g)$$

Which statement describes the reverse reaction?

1) It is endothermic and releases 286 kJ.
2) It is endothermic and absorbs 286 kJ.
3) It is exothermic and releases 286 kJ.
4) It is exothermic and absorbs 286 kJ.

24. In a chemical reaction, the difference between the potential energy of the products and the potential energy of the reactants is called

1) activation energy
2) kinetic energy
3) activated complex
4) heat of reaction

25. Which balanced equation represents an endothermic reaction?

1) $C(s) + O_2(g) \rightarrow CO_2(g)$
2) $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(\ell)$
3) $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$
4) $N_2(g) + O_2(g) \rightarrow 2NO(g)$

26. According to Reference Table I, the decomposition of which compound is exothermic?

1) ethane
2) nitrogen (II) oxide
3) carbon dioxide
4) ammonia

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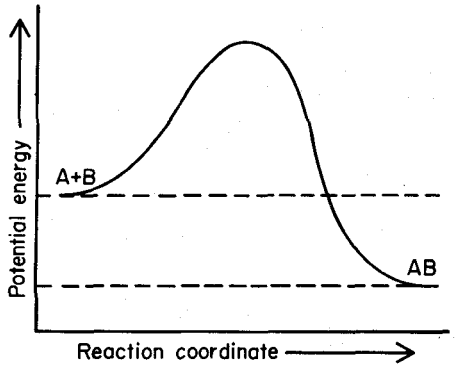
27. Given the potential energy diagram:



With reference to energy, the reaction $A + B \rightarrow AB$ can best be described as

1) endothermic, having a $+\Delta H$
2) endothermic, having a $-\Delta H$
3) exothermic, having a $+\Delta H$
4) exothermic, having a $-\Delta H$

28. Given the reaction:

$$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(\ell) + 571.6\ kJ$$

What is the approximate $(H$ for the formation of 1 mole of $H_2O(\ell)$?

1) –285.8 kJ
2) +285.8 kJ
3) –571.6 kJ
4) +571.6 kJ

29. Given the balanced equation:

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe2O_3(s) + 1640\ kJ$$

Which phrase best describes this reaction?

1) endothermic with $(H = +1640$ kJ
2) endothermic with $(H = -1640$ kJ
3) exothermic with $(H = +1640$ kJ
4) exothermic with $(H = -1640$ kJ

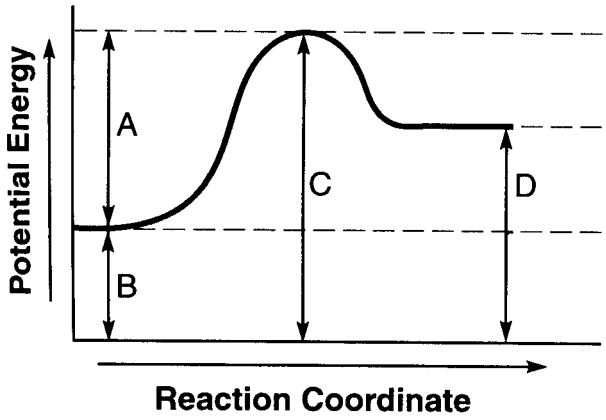
30. A thermometer is in a beaker of water. Which statement best explains why the thermometer reading initially increases when LiBr(s) is dissolved in the water?

1) The entropy of the LiBr(aq) is greater than the entropy of the water.
2) The entropy of the LiBr(aq) is less than the entropy of the water.
3) The dissolving of the LiBr(s) in water is an endothermic process.
4) The dissolving of the LiBr(s) in water is an exothermic process.

31. According to Reference Table I, what happens when two moles of gaseous ethane are formed from its elements?

1) 42 kJ are absorbed
2) 42 kJ are released
3) 84 kJ are absorbed
4) 84 kJ are released

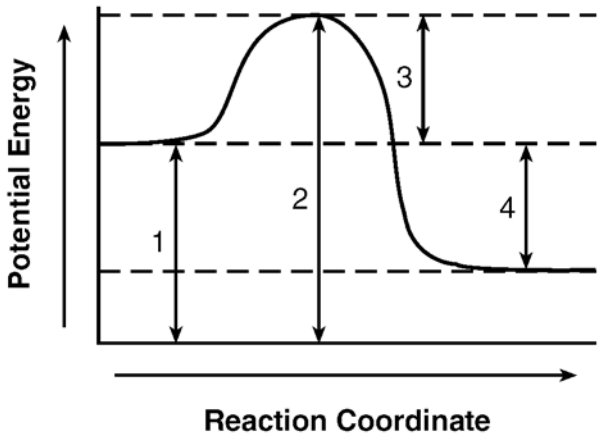
32. Given the potential energy diagram of a chemical reaction:



Which arrow represents the potential energy of the reactants?

1) *A*
2) *B*
3) *C*
4) *D*

33. Given the potential energy diagram for a reaction:



Which interval on this diagram represents the difference between the potential energy of the products and the potential energy of the reactants?

1) 1
2) 2
3) 3
4) 4

34. The heat of reaction (ΔH) is equal to the

1) heat content of the products minus the heat content of the reactants
2) heat content of the reactants minus the heat content of the products
3) entropy of the products minus the entropy of the reactants
4) entropy of the reactants minus the entropy of the products

35. According to Reference Table I, which compound forms exothermically?

1) ethane
2) ethene
3) ethyne
4) hydrogen iodide

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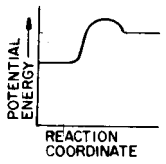
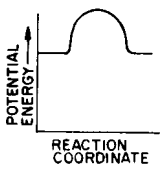
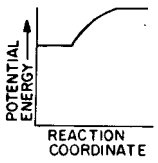
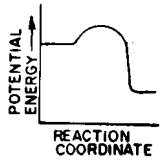
36. Which diagram represents the potential energy of an exothermic reaction?

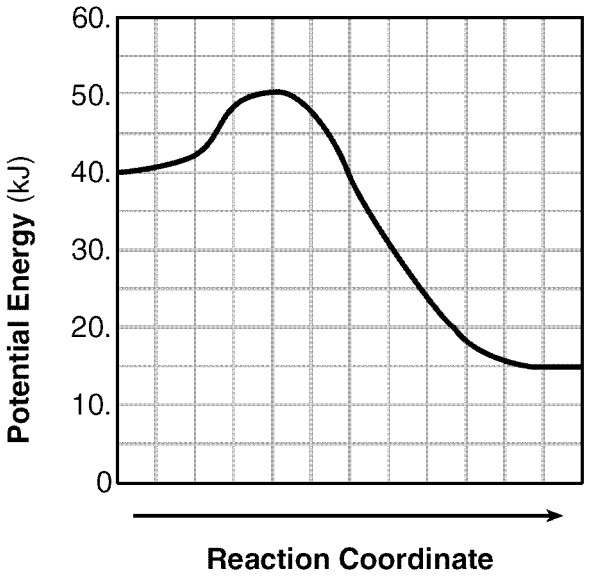
1) 

3) 

2) 

4) 

37. Given the potential energy diagram for a chemical reaction:



Which statement correctly describes the energy changes that occur in the forward reaction?

1) The activation energy is 10. kJ and the reaction is endothermic.
2) The activation energy is 10. kJ and the reaction is exothermic.
3) The activation energy is 50. kJ and the reaction is endothermic.
4) The activation energy is 50. kJ and the reaction is exothermic.

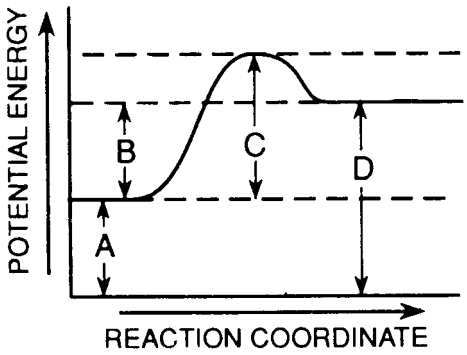
38. According to Reference Table I, which reaction has a ΔH equal to –283 kJ/mole at 25°C and 1 atmosphere?

1) $C(s) + O_2(g) \rightarrow CO_2(g)$
2) $CO(g) + \frac{1}{2} O_2(g) \rightarrow CO_2(g)$
3) $\frac{1}{2} N_2 + \frac{3}{2} O_2 \rightarrow NH_3(g)$
4) $2\ C + 3\ H_2 \rightarrow C_2H_6$

39. Which 1-mole sample has the *least* entropy?

1) $Br_2(s)$ at 266 K
2) $Br_2(\ell)$ at 266 K
3) $Br_2(\ell)$ at 332 K
4) $Br_2(g)$ at 332 K

40. Base your answer to the following question on the reaction coordinate shown below:



Which interval represents the activation energy of the forward reaction?

1) *A*
2) *B*
3) *C*
4) *D*

41. According to Reference Table I, when 1.0 mole of ethene is formed from its elements, 52.4 kiloJoules is

1) stored as potential energy
2) given off as potential energy
3) stored as kinetic energy
4) given off as kinetic energy

42. In a potential energy diagram, the difference between the potential energy of the products and the potential energy of the reaction is equal to the

1) heat of reaction
2) entropy of the reaction
3) activation energy of the forward reaction
4) activation energy of the reverse reaction

43. Based on Reference Table I, which reaction is endothermic?

1) $NaOH(s) \rightarrow Na^+(aq) + OH^-(aq)$
2) $NH_4Cl(s) \rightarrow NH_4^+(aq) + Cl^-(aq)$
3) $CO(g) + O_2(g) \rightarrow CO_2(g)$
4) $CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(\ell)$

44. Which expression represents the ΔH for a chemical reaction in terms of the potential energy, *PE*, of its products and reactants?

1) *PE* of products + *PE* of reactants
2) *PE* of products – *PE* of reactants
3) *PE* of products × *PE* of reactants
4) *PE* of products ^ *PE* of reactants

45. Which reaction will occur spontaneously? [Refer to Reference Table U.]

1) $\frac{1}{2} N_2(g) + \frac{1}{2} O_2(g) \rightarrow NO(g)$
2) $\frac{1}{2} N_2(g) + O_2(g) \rightarrow NO_2(g)$
3) $2\ C(s) + 3\ H_2(g) \rightarrow C_2H_6(g)$
4) $2\ C(s) + 2\ H_2(g) \rightarrow C_2H_4(g)$

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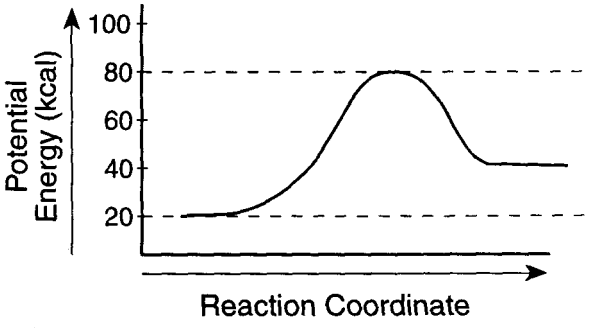
46. A potential energy diagram of a chemical reaction is shown below.



What is the difference between the potential energy of the reactants and the potential energy of the products?

1) 20. kcal
2) 40. kcal
3) 60. kcal
4) 80. kcal

47. For the reaction

$A + B \rightarrow C$ + heat,

the potential energy of the products, compared to the potential energy of the reactants, is

1) less and the reaction is exothermic
2) less and the reaction is endothermic
3) greater and the reaction is exothermic
4) greater and the reaction is endothermic

48. Given the reaction:

$A + B \leftrightarrow C + D$ + heat

Which statement best describes this reaction?

1) The forward reaction is exothermic, and the reverse reaction is always exothermic.
2) The forward reaction is exothermic, and the reverse reaction is always endothermic.
3) The forward reaction is exothermic, and the reverse reaction can be either exothermic or endothermic.
4) The forward reaction is endothermic, and the reverse reaction can be either endothermic or exothermic.

49. Based on Reference Table *U*, which of the following compounds is the most stable?

1) NaCl
2) CO_2
3) SO_2
4) KCl

50. Which equation correctly represents the free energy change in a chemical reaction?

1) $\Delta G = \Delta H + T\Delta S$
2) $\Delta G = \Delta H - T\Delta S$
3) $\Delta G = \Delta T - \Delta H\Delta S$
4) $\Delta G = \Delta S - T\Delta H$

51. Under the same conditions of temperature and pressure, which sample contains particles having the *lowest* entropy?

1) $CO_2(g)$
2) $CO_2(\ell)$
3) $CO_2(s)$
4) $CO_2(aq)$

52. Systems in nature tend to undergo changes toward

1) lower energy and lower entropy
2) lower energy and higher entropy
3) higher energy and lower entropy
4) higher energy and higher entropy

53. Which reaction results in an increase in the entropy of the system?

1) $H_2O(g) \rightarrow H_2O(\ell)$
2) $H_2O(\ell) \rightarrow H_2O(s)$
3) $2\ H_2O(\ell) \rightarrow 2\ H_2(g) + O_2(g)$
4) $2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(\ell)$

54. The free energy change, ΔG, must be negative when

1) ΔH is positive and ΔS is positive
2) ΔH is positive and ΔS is negative
3) ΔH is negative and ΔS is positive
4) ΔH is negative and ΔS is negative

55. Which reaction results in an increase in entropy?

1) $CO_2(g) \rightarrow CO_2(s)$
2) $H_2O(\ell) \rightarrow H_2O(s)$
3) $Ca(s) + 2\ H_2O(\ell) \rightarrow Ca(OH)_2(aq) + H_2(g)$
4) $NaCl(aq) + AgNO_3(aq) \rightarrow AgCl(s) + NaNO_3(aq)$

56. An endothermic reaction might proceed spontaneously if there is an increase in

1) potential energy
2) order
3) entropy
4) concentration

57. According to Reference Table U, which compound forms spontaneously from its elements?

1) C_2H_4
2) C_2H_2
3) NO_2
4) CO_2

58. What occurs when a sample of $CO_2(s)$ changes to $CO_2(g)$?

1) The gas has greater entropy and less order.
2) The gas has greater entropy and more order.
3) The gas has less entropy and less order.
4) The gas has less entropy and more order.

59. According to Reference Table U, which compound will form spontaneously from its elements?

1) ethene
2) hydrogen iodide
3) nitrogen (II) oxide
4) magnesium oxide

60. Based on Reference Table *U*, which compound forms spontaneously from its elements?

1) nitrogen (IV) oxide
2) nitrogen (II) oxide
3) water
4) ethyne

61. What is the free energy change for a system at equilibrium?

1) one
2) greater than one
3) zero
4) less than zero

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62. Based on Reference Table *U*, which of the following compounds is *least* stable?
    1) $C_2H_6(g)$
    2) $HF(g)$
    3) $SO_2(g)$
    4) $CO_2(g)$

63. Which list of the phases of H_2O is arranged in order of increasing entropy?
    1) ice, steam, and liquid water
    2) ice, liquid water, and steam
    3) steam, liquid water, and ice
    4) steam, ice, and liquid water

64. According to Reference Table *U*, ICl(g) is formed from its elements in a reaction that is
    1) exothermic and spontaneous
    2) exothermic and not spontaneous
    3) endothermic and spontaneous
    4) endothermic and not spontaneous

65. According to Reference Table U, which substance will form spontaneously from its elements in their standard states at 1 atmosphere and 298 K?
    1) ethene
    2) ethyne
    3) hydrogen iodide
    4) hydrogen fluoride

66. As the randomness of a system increases, the entropy of the system
    1) decreases
    2) increases
    3) remains the same

67. During which phase change does 1 mole of carbon dioxide increase in entropy?
    1) $CO_2(g) \rightarrow CO_2(\ell)$
    2) $CO_2(\ell) \rightarrow CO_2(g)$
    3) $CO_2(g) \rightarrow CO_2(s)$
    4) $CO_2(\ell) \rightarrow CO_2(s)$

68. A reaction will be spontaneous if it results in products that have
    1) lower potential energy and less randomness
    2) lower potential energy and more randomness
    3) greater potential energy and less randomness
    4) greater potential energy and more randomness

69. When a reaction is exothermic and the products have more entropy than the reactants, the reaction is
    1) spontaneous, with a negative ΔG
    2) spontaneous, with a positive ΔG
    3) non-spontaneous, with a negative ΔG
    4) non-spontaneous, with a positive ΔG

70. Given the reaction:

    $$A(g) + B(g) \rightarrow AB(g)$$

    with $\Delta H_f^{\circ} = -10$ kilocalories per mole and $\Delta G_f^{\circ} = +2$ kilocalories per mole. This reaction is
    1) exothermic and will occur spontaneously
    2) exothermic and will not occur spontaneously
    3) endothermic and will occur spontaneously
    4) endothermic and will not occur spontaneously

71. Which of these changes produces the greatest increase in entropy?
    1) $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$
    2) $2\ Mg(s) + O_2(g) \rightarrow 2\ MgO(s)$
    3) $H_2O(g) \rightarrow H_2O(\ell)$
    4) $CO_2(g) \rightarrow CO_2(s)$

72. Given the equilibrium system:

    $$H_2O(\ell) + \text{heat} \leftrightarrow H_2O(g)$$

    Which will occur if the temperature of the system is increased?
    1) The average kinetic energy of the system will decrease.
    2) The entropy of the system will increase.
    3) The number of moles of $H_2O(g)$ will decrease.
    4) The number of moles of $H_2O(\ell)$ will increase.

73. Based on Reference Table U, which compound will form spontaneously from its elements?
    1) carbon dioxide (g)
    2) nitrogen (II) oxide (g)
    3) ethene (g)
    4) ethyne (g)

74. Above 0ºC, ice changes spontaneously to water according to the following equation:

    $$H_2O(s) + \text{heat} \rightarrow H_2O(\ell).$$

    The changes in $H_2O(s)$ involve
    1) an absorption of heat and a decrease in entropy
    2) a release of heat and a decrease in entropy
    3) an absorption of heat and an increase in entropy
    4) a release of heat and an increase in entropy

75. Based on Reference Table U, which compound forms spontaneously under standard conditions?
    1) NaCl
    2) HI
    3) C_2H_4
    4) NO_2

Thermodynamics Review

Reference Tables

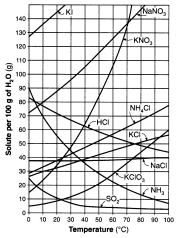
Table I
Heats of Reaction at 101.3 kPa and 298 K

Reaction	ΔH (kJ)*
$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(\ell)$	−890.4
$C_3H_8(g) + 5O_2(g) \longrightarrow 3CO_2(g) + 4H_2O(\ell)$	−2219.2
$2C_8H_{18}(\ell) + 25O_2(g) \longrightarrow 16CO_2(g) + 18H_2O(\ell)$	−10943
$2CH_3OH(\ell) + 3O_2(g) \longrightarrow 2CO_2(g) + 4H_2O(\ell)$	−1452
$C_2H_5OH(\ell) + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(\ell)$	−1367
$C_6H_{12}O_6(s) + 6O_2(g) \longrightarrow 6CO_2(g) + 6H_2O(\ell)$	−2804
$2CO(g) + O_2(g) \longrightarrow 2CO_2(g)$	−566.0
$C(s) + O_2(g) \longrightarrow CO_2(g)$	−393.5
$4Al(s) + 3O_2(g) \longrightarrow 2Al_2O_3(s)$	−3351
$N_2(g) + O_2(g) \longrightarrow 2NO(g)$	+182.6
$N_2(g) + 2O_2(g) \longrightarrow 2NO_2(g)$	+66.4
$2H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$	−483.6
$2H_2(g) + O_2(g) \longrightarrow 2H_2O(\ell)$	−571.6
$N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$	−91.8
$2C(s) + 3H_2(g) \longrightarrow C_2H_6(g)$	−84.0
$2C(s) + 2H_2(g) \longrightarrow C_2H_4(g)$	+52.4
$2C(s) + H_2(g) \longrightarrow C_2H_2(g)$	+227.4
$H_2(g) + I_2(g) \longrightarrow 2HI(g)$	+53.0
$KNO_3(s) \xrightarrow{H_2O} K^+(aq) + NO_3^-(aq)$	+34.89
$NaOH(s) \xrightarrow{H_2O} Na^+(aq) + OH^-(aq)$	−44.51
$NH_4Cl(s) \xrightarrow{H_2O} NH_4^+(aq) + Cl^-(aq)$	+14.78
$NH_4NO_3(s) \xrightarrow{H_2O} NH_4^+(aq) + NO_3^-(aq)$	+25.69
$NaCl(s) \xrightarrow{H_2O} Na^+(aq) + Cl^-(aq)$	+3.88
$LiBr(s) \xrightarrow{H_2O} Li^+(aq) + Br^-(aq)$	−48.83
$H^+(aq) + OH^-(aq) \longrightarrow H_2O(\ell)$	−55.8

*Minus sign indicates an exothermic reaction.

Reference Tables

Table G Solubility Curves



Reference Tables

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STANDARD ENERGIES OF FORMATION OF COMPOUNDS AT 1 atm AND 298 K

Compound	*Heat (Enthalpy) of Formation** kcal/mol ($\triangle Hf$)	*Free Energy of Formation* kcal/mol ($\triangle Gf$)
Aluminum oxide $Al_2O_3(s)$	−400.5	−378.2
Ammonia $NH_3(g)$	−11.0	−3.9
Barium sulfate $BaSO_4(s)$	−352.1	−325.6
Calcium hydroxide $Ca(OH)_2(s)$	−235.7	−214.8
Carbon dioxide $CO_2(g)$	−94.1	−94.3
Carbon monoxide CO(g)	−26.4	−32.8
Copper (II) sulfate $CuSO_4(s)$	−184.4	−158.2
Ethane $C_2H_6(g)$	−20.2	−7.9
Ethene (ethylene) $C_2H_4(g)$	12.5	16.3
Ethyne (acetylene) $C_2H_2(g)$	54.2	50.0
Hydrogen fluoride HF(g)	−64.8	−65.3
Hydrogen iodide HI(g)	6.3	0.4
Iodine chloride ICl(g)	4.3	−1.3
Lead (II) oxide PbO(s)	−51.5	−45.0
Magnesium oxide MgO(s)	−143.8	−136.1
Nitrogen (II) oxide NO(g)	21.6	20.7
Nitrogen (IV) oxide $NO_2(g)$	7.9	12.3
Potassium chloride KCl(s)	−104.4	−97.8
Sodium chloride NaCl(s)	−98.3	−91.8
Sulfur dioxide $SO_2(g)$	−70.9	−71.7
Water $H_2O(g)$	−57.8	−54.6
Water $H_2O(\ell)$	−68.3	−56.7

* Minus sign indicates an exothermic reaction.

Sample equations:

$2Al(s) + \frac{3}{2} O_2(g) \rightarrow Al_2O_3(s) + 400.5$ kcal

$2Al(s) + \frac{3}{2} O_2(g) \rightarrow Al_2O_3(s) \quad \triangle H = -400.5$ kcal/mol

Thermodynamics Review
Answer Key
[New Exam]

1. 4
2. 4
3. 2
4. 1
5. 3
6. 1
7. 2
8. 2
9. 3
10. 4
11. 2
12. 2
13. 2
14. 4
15. 2
16. 3
17. 4
18. 3
19. 2
20. 4
21. 2
22. 1
23. 3
24. 4
25. 4
26. 2
27. 4
28. 1
29. 4
30. 4
31. 3
32. 2
33. 4
34. 1
35. 1
36. 4
37. 2
38. 2
39. 1
40. 3
41. 1
42. 1
43. 2
44. 2
45. 3
46. 1
47. 1
48. 2
49. 4
50. 2
51. 3
52. 2
53. 3
54. 3
55. 3
56. 3
57. 4
58. 1
59. 4
60. 3

Thermodynamics Review
Answer Key
[New Exam]

61. 3
62. 1
63. 2
64. 3
65. 4
66. 2
67. 2
68. 2
69. 1
70. 2
71. 1
72. 2
73. 1
74. 3
75. 1