Name_____

MULTIPLE CHOICE. Choose the one alternative that best completes the statement or answers the question.

1) When a system _____, ΔE is <u>always</u> negative.
   A) absorbs heat and does work
   B) gives off heat and does work   → *both cases energy is leaving the system*
   C) gives off heat and has work done on it
   D) absorbs heat and has work done on it
   E) none of the above is <u>always</u> negative.

2) Which one of the following is an exothermic process?
   A) ice melting
   B) boiling soup
   C) water evaporating
   D) condensation of water vapor
   E) Ammonium thiocyanate and barium hydroxide are mixed at 25°C: the temperature drops.

3) A _____ ΔH corresponds to an _____ process.
   A) negative, endothermic
   B) negative, exothermic
   C) positive, exothermic
   D) zero, exothermic
   E) zero, endothermic

4) The internal energy *(energy of the system)* can be increased by _____.

   (a) transferring heat from the surroundings to the system
   (b) transferring heat from the system to the surroundings
   (c) doing work on the system

   A) c only   B) a only   C) a and c   D) b and c   E) b only

5) The value of ΔH for the reaction below is –126 kJ. How much heat (in kJ) is released when 2.00 mol of NaOH is formed in the reaction?
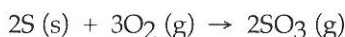
   $$2Na_2O_2 (s) + 2H_2O (l) \rightarrow 4NaOH (s) + O_2 (g)$$
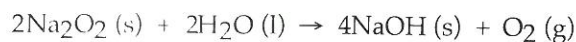
   A) –126   B) 7.8   C) 63   D) 3.9   E) 252

   ↑ *they should be consistent and put a negative sign!*

   $-126 kJ \times \dfrac{2 mol\ NaOH}{4 mol\ NaOH}$

1

6) The value of ΔH° for the reaction below is –790 kJ. The enthalpy change accompanying the reaction of 0.95 g of S is _____ kJ.

$$.95g\ S \times \frac{1\ mol\ S}{32.06g} \times \frac{-790kJ}{2\ mol\ S}$$

$$2S\ (s)\ +\ 3O_2\ (g)\ \rightarrow\ 2SO_3\ (g)$$

A) 12   B) 23   C) –23   (D) –12   E) –790

7) The molar heat capacity of a compound with the formula C_2H_6SO is 88.0 J/mol–K. The specific heat of this substance is _____ J/j–K.

A) –88.0   (B) 1.13   C) 88.0   D) 6.88×10^3 E) 4.89

$$\frac{88J}{mol \cdot K} \times \frac{1\ mol}{78g}$$

8) A sample of aluminum metal absorbs 9.86 J of heat, upon which the temperature of the sample increases from 23.2°C to 30.5°C. Since the specific heat capacity of aluminum is 0.90 J/g–K, the mass of the sample is _____ g.

(A) 1.5   B) 6.6   C) 65   D) 8.1   E) 72

9) The specific heat of liquid bromine is 0.226 J/g–K. How much heat (J) is required to raise the temperature of 10.0 mL of bromine from 25.00°C to 27.30°C? The density of liquid bromine: 3.12 g/mL.

A) 5.20   (B) 16.2   C) 10.4   D) 300   E) 32.4

$$10mL \times \frac{3.12g}{mL}\ (2.3)(.226)$$

→ 10) The ΔH for the solution process when solid sodium hydroxide dissolves in water is 44.4 kJ/mol. When a 13.9–g sample of NaOH dissolves in 250.0 g of water in a coffee–cup calorimeter, the temperature increases from 23.0° C to _____°C. Assume that the solution has the same specific heat as liquid water, i.e., 4.18 J/g–K.

A) 37.8°C   B) 35.2°C   C) 40.2°C   D) 37.0 C   E) 14.0°C
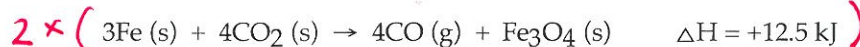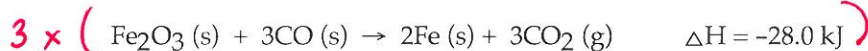
heat lost by rxn: $13.9g \times \frac{1\ mol}{40g} \times \frac{44.4kJ}{mol} = 15429J$

$$15429J = (263.9)(4.18)\Delta T$$
↑ heat gained by solution

11) Given the following reactions

$$3 \times \left(Fe_2O_3\ (s)\ +\ 3CO\ (s)\ \rightarrow\ 2Fe\ (s)\ +\ 3CO_2\ (g) \qquad \Delta H = -28.0\ kJ \right)$$

$$2 \times \left(3Fe\ (s)\ +\ 4CO_2\ (s)\ \rightarrow\ 4CO\ (g)\ +\ Fe_3O_4\ (s) \qquad \Delta H = +12.5\ kJ \right)$$

no need to flip either one

the enthalpy of the reaction of Fe_2O_3 with CO

$$3Fe_2O_3\ (s)\ +\ CO\ (g)\ \rightarrow\ CO_2\ (g)\ +\ 2Fe_3O_4\ (s)$$

is _____ kJ.

A) 40.5   B) –15.5   (C) –59.0   D) –109   E) +109

12) The value of ΔH° for the reaction below is –186 kJ.

$$H_2\ (g)\ +\ Cl_2\ (g)\ \rightarrow\ 2HCl\ (g)$$
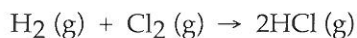
The value of $\Delta H_f°$ for HCl (g) is _____ kJ/mol.

A) –186   B) $–3.72 \times 10^2$ C) $–1.27 \times 10^2$ (D) –93.0   E) +186

$\Delta H_f°$ is for 1 mole of a compound formed $-186/2$

2

13) For which one of the following reactions is $\Delta H°_{rxn}$ equal to the heat of formation of the product?

A) $12C (g) + 11H_2 (g) + 11O (g) \rightarrow C_6H_{22}O_{11} (g)$ ← O found as O_2 ← 1 mole of product (compound) made from its elements in their "standard states"

B) $(1/2)N_2 (g) + O_2 (g) \rightarrow NO_2 (g)$

C) $6C (s) + 6H (g) \rightarrow C_6H_6 (l)$ ← H found as H_2

D) $P (g) + 4H (g) + Br (g) \rightarrow PH_4Br (l)$ ← H + Br diatomic

E) $N_2 (g) + 3H_2 (g) \rightarrow 2NH_3 (g)$ ← 2 moles product

14) Of the following, ΔH_f is not zero for _____.

A) $Cl_2 (g)$ B) $N_2 (g)$ C) $F_2 (s)$ ← F_2 + Cl_2 are gases, Br_2 is a liquid, I_2 is a solid   D) C (graphite)   E) $O_2 (g)$

15) For the species in the reaction below, $\Delta H_f°$ is zero for _____.

$$2Co (s) + H_2 (g) + 8PF_3 (g) \rightarrow 2HCo(PF_3)_4 (l)$$

A) $PF_3 (g)$

B) $H_2 (g)$

C) $Co (s)$

D) $HCo(PF_3)_4 (l)$

E) both $Co(s)$ and $H_2 (g)$

$\Delta H°_f$ is zero for elements (in their standard states)

16) Given the data in the table below, $\Delta H°_{rxn}$ for the reaction

$$Ca(OH)_2 + 2H_3AsO_4 \rightarrow Ca(H_2AsO_4)_2 + 2H_2O$$

is _____ kJ.

$[(-2346) + (2)(-285.9)] - [(-986.6) + (2)(-900.4)] =$

Substance	$\Delta H_f°$ (kJ/mol)
$Ca(OH)_2$	−986.6
H_3AsO_4	−900.4
$Ca(H_2AsO_4)_2$	−2346.0
H_2O	−285.9

A) −130.4   B) −76.4   C) −744.9   D) −4519   E) −4219

17) The value of ΔH for the reaction below is 44 kJ:

$$H2O (l) \rightarrow H_2O (g)$$

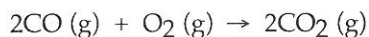The value of ΔH_f of $H_2O (g)$ is _____ kJ/mol.

A) −242

B) 330

C) 242

D) −330

E) More information is needed.

Sneaky question. Need $\Delta H°_f$ for liquid water to completely answer this question

3

18) Given the data in the table below, $\Delta H°$ for the reaction

$$2CO\ (g)\ +\ O_2\ (g)\ \rightarrow\ 2CO_2\ (g)$$

is _____ kJ.

Substance	$\Delta H_f°$ (kJ/mol)
$CO\ (g)$	–110.5
$CO_2\ (g)$	–393.7
$CaCO_3\ (s)$	–1207.0

$$[(2)(-393.7)] - [(2)(-110.5) + 0]$$

A) –677.0
B) 283.3
C) –566.4
D) –283.3
E) The $\Delta H°_f$ of O_2 (g) is needed for the calculation.

19) For which one of the following reactions is the value of $\Delta H°_{rxn}$ equal to $\Delta H°_f$ for the product?

A) $N_2\ (g)\ +\ O_2\ (g)\ \rightarrow\ 2\ NO\ (g)$ ← 2 moles product
B) $2\ H_2\ (g)\ +\ O_2\ (g)\ \rightarrow\ 2\ H_2O\ (l)$
C) $H_2O\ (l)\ +\ 1/2\ O_2\ (g)\ \rightarrow\ H_2O_2\ (l)$ ← H2O not an element
D) $2\ H_2\ (g)\ +\ O_2\ (g)\ \rightarrow\ 2\ H_2O\ (g)$ ← H2O standard state is a liquid
E) $2\ C\ (s,\ graphite)\ +\ 2\ H_2\ (g)\ \rightarrow\ C_2H_4\ (g)$

20) A 50.0–g sample of liquid water at 25.0 C is mixed with 29.0 g of water at 45.0 C. The final temperature of the water is _____ °C. The specific heat capacity of liquid water is 4.18 J/g–K.

A) 27.6   B) 102   C) 142   D) 32.3   E) 35.0

21) A reaction that is spontaneous as written _____.

A) will proceed without outside intervention
B) is also spontaneous in the reverse direction
C) is very rapid
D) has an equilibrium position that lies far to the left
E) is very slow

$(50)(4.18)(T-25) = (29)(4.18)(45-T)$
$T = 32.3$

22) ΔS is be positive for the reaction _____.

A) $BaF_2\ (s)\ \rightarrow\ Ba^{2+}\ (aq)\ +\ 2F^-\ (aq)$
B) $2NO_2\ (g)\ \rightarrow\ N_2O_4\ (g)$
C) $2Hg\ (l)\ +\ O_2\ (g)\ \rightarrow\ 2HgO\ (s)$
D) $2H_2\ (g)\ +\ O_2\ (g)\ \rightarrow\ 2H_2O\ (g)$
E) $CO_2\ (g)\ \rightarrow\ CO_2\ (s)$

Synthesis: usually ΔS is neg.

23) Which one of the following processes produces a decrease in the entropy of the system?

   A) freezing water to form ice
   B) melting ice to form water
   C) dissolution of solid KCl in water
   D) mixing of two gases into one container
   E) boiling water to form steam

24) Which one of the following processes produces a decrease of the entropy of the system?

   A) dissolving sodium chloride in water
   B) sublimation of naphthalene
   C) boiling of alcohol
   D) explosion of nitroglycerine
   E) dissolving oxygen in water

g → aq is more ordered

25) ΔS is negative for the reaction _____.

   A) $NH_4Cl\ (s) \rightarrow NH_3\ (g) + HCl\ (g)$
   B) $PbCl_2\ (s) \rightarrow Pb^{2+}\ (aq) + 2Cl^-\ (aq)$
   C) $2C\ (s) + O_2\ (g) \rightarrow 2CO_2\ (g)$
   D) $H_2O\ (l) \rightarrow H_2O\ (g)$
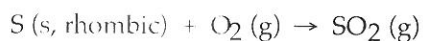   E) $2SO_2\ (g) + O_2\ (g) \rightarrow 2SO_3\ (g)$

decomposing
dissociating } *more disorder*
solid → gas
liquid → gas
3 moles gas → 2 moles gas (more order)

26) The value of ΔG at 373 K for the oxidation of solid elemental sulfur to gaseous sulfur dioxide,

$$S\ (s, rhombic) + O_2\ (g) \rightarrow SO_2\ (g)$$

$\Delta G = -269.9\,kJ - (373)(.0116\ kJ/k)$

is _____ kJ/mol. At 298K, $\Delta H°$ for this reaction is –269.9 kJ/mol, and $\Delta S°$ is +11.6 J/K.

   A) +4,597   B) +300.4   C) –4,597   D) –300.4   E) –274.2

27) A common name for methanol (CH_3OH) is wood alcohol. The normal boiling point of methanol is 64.7°C and the molar enthalpy of vaporization if 71.8 kJ/mol. The value of ΔS when 2.15 mol of CH_3OH (l) vaporizes at 64.7°C is _____ J/K.

   A) 5.21×10^7 B) 2.39×10^3 C) 457   D) 2.39   E) 0.457

AT B.P. $\Delta G = 0$

$0 = 71.8\ kJ/mol - (337.7k)\ \Delta S$

$\Delta S = 212.6\ J/mol\cdot k \times 2.15\ mol =$

5

Use the table below to answer the questions that follow.

Thermodynamic Quantities for Selected Substances at 298.15 K (25°C)

Substance	$\Delta H°f$ (kJ/mol)	$\Delta G°f$ (kJ/mol)	S (J/K–mol)
Carbon			
C (s, diamond)	1.88	2.84	2.43
C (s, graphite)	0	0	5.69
C_2H_2 (g)	226.7	209.2	200.8
C_2H_4 (g)	52.30	68.11	219.4
C_2H_4 (g)	–84.68	–32.89	229.5
CO (g)	–110.5	–137.2	197.9
CO_2 (g)	–393.5	–394.4	213.6
Hydrogen			
H_2(g)	0	0	130.58
Oxygen			
O_2 (g)	0	0	205.0
H_2O (l)	–285.83	–237.13	69.91

$$\left[(4)(213.6) + (2)(69.91)\right] - \left[(2)(200.8) + (5)(205.0)\right]$$

28) The combustion of acetylene in the presence of excess oxygen yields carbon dioxide and water:

$$2C_2H_2 \text{ (g)} + 5O_2 \text{ (g)} \rightarrow 4CO_2 \text{ (g)} + 2H_2O \text{ (l)}$$
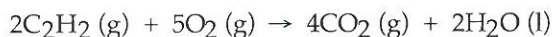
The value of ΔS for this reaction is _____ J/K.

A) +432.4   B) +689.3   C) +122.3   D) –122.3   (E) –432.4

29) For the reaction

$$C(s) + H_2O(g) \rightarrow CO(g) + H_2(g)$$
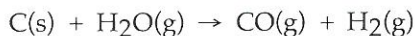
$\Delta H° = 131.3$ kJ/mol and $\Delta S° = 133.6$ J/K • mol at 298K. At temperatures greater than _____ °C this reaction is spontaneous under standard conditions.

A) 273   (B) 710   C) 552   D) 983   E) 325

$$0 = 131.3 \text{ kJ/mol} - (T)(.1336 \text{ kJ}/mol \cdot k)$$

$$T = 983 K - 273$$

32) A reaction that is not spontaneous at low temperature can become spontaneous at high temperature if ΔH is _____ and ΔS is _____.

   A) +, +   B) –, –   C) +, –   D) –, +   E) +, 0

33) Given the following table of thermodynamic data,

Substance	ΔH_f (kJ/mol)	$S°$ (J/mol · K)
PCl3 (g)	–288.07	311.7
PCl3 (l)	–319.6	217

complete the following sentence. The vaporization of PCl3 (l) is _____.

   A) nonspontaneous at all temperatures
   B) spontaneous at low temperature and nonspontaneous at high temperature
   C) nonspontaneous at low temperature and spontaneous at high temperature
   D) spontaneous at all temperatures
   E) not enough information given to draw a conclusion

(handwritten notes:) $\Delta G = \Delta H - T\Delta S$; + ↑ + ; ← not spontaneous at low T, but spontaneous at high T ; PCl3 (l) → PCl3 (g) ; $\Delta H = +31.5$ kJ/mol ; $\Delta S = +94.7$ kJ/mol

34) The value of $\Delta G°$ at 141.0°C for the formation of phosphorous trichloride from its constituent elements,

$$P_2 (g) + 3Cl_2 (g) \rightarrow 2PCl_3 (g)$$

is _____ kJ/mol. At 25.0 C for this reaction, $\Delta H°$ is –720.5 kJ/mol, $\Delta G°$ is –642.9 kJ/mol, and $\Delta S°$ is –263.7 J/K.

   A) 1.08×10^5 B) –829.7   C) 3.65×10^4 D) –683.3   E) –611.3

(handwritten: did not do this yet)

35) For a given reaction, $\Delta H = 35.5$ kJ/mol and $\Delta S = 83.6$ J/K–mol. The reaction is spontaneous _____. Assume that ΔH and ΔS do not vary with temperature.

   A) at T > 425 K
   B) at T < 298 K
   C) at T > 298 K
   D) at T < 425 K
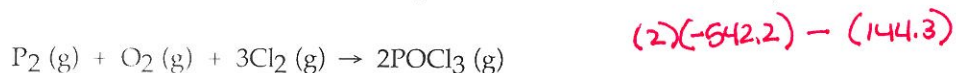   E) at all temperatures

(handwritten:) $0 = 35.5 - T(.0836)$

Use the table below to answer the questions that follow.

Thermodynamic Quantities for Selected Substances at 298.15 K (25°C)

Substance	$\Delta H°_f$ (kJ/mol)	$\Delta G°_f$ (kJ/mol)	S (J/K–mol)
Calcium			
Ca (s)	0	0	41.4
$CaCl_2$ (s)	–795.8	–748.1	104.6
Ca_2^+ (aq)	226.7	209.2	200.8
Chlorine			
Cl_2 (g)	0	0	222.96
Cl– (aq)	–167.2	–131.2	56.5
Oxygen			
O_2 (g)	0	0	205.0
H_2O (l)	–285.83	–237.13	69.91
Phosphorus			
P_2 (g)	144.3	103.7	218.1
PCl_3 (g)	–288.1	–269.6	311.7
$POCl_3$ (g)	–542.2	–502.5	325
Sulfur			
S (s, rhombic)	0	0	31.88
SO_2(g)	–269.9	–300.4	248.5
SO_3(g)	–395.2	–370.4	256.2

30) The value of ΔH for the formation of $POCl_3$ from its constituent elements,

$$P_2 (g) + O_2 (g) + 3Cl_2 (g) \rightarrow 2POCl_3 (g)$$

(handwritten) (2)(-542.2) – (144.3)

is _____ kJ/mol.

A) +686.5   B) –1228.7 *(circled)*   C) –686.5   D) –397.7   E) +1228.7

31) For the reaction

$$C_2H_6 (g) \rightarrow C_2H_4 (g) + H_2 (g)$$
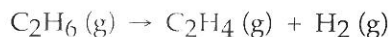
$\Delta H°$ is +137 kJ/mol and ΔS is +120 J/K·mol. This reaction is _____.

A) spontaneous only at low temperature

B) unreliable

C) nonspontaneous at all temperatures

D) spontaneous only at high temperature *(circled)*

E) spontaneous at all temperatures

(handwritten)
0 = 137 – T(.120)
T = 1141K
↑ above this temp to be spontaneous

7

MULTIPLE CHOICE. Choose the one alternative that best completes the statement or answers the question.

1) B
2) D
3) B
4) C
5) C
6) D
7) B
8) A
9) B
10) D
11) C
12) D
13) B
14) C
15) E
16) A
17) E
18) C
19) E
20) D
21) A
22) A
23) A
24) E
25) E
26) E
27) C
28) E
29) B
30) B
31) D
32) A
33) C
34) E
35) A