1. Hydrogen cyanide, HCN, is a poisonous gas that is also important in industrial chemical synthesis. It is produced from methane, ammonia and oxygen according to

   $2\ CH_4(g) + 2\ NH_3(g) + 3\ O_2(g) \rightarrow 2\ HCN(g) + 6\ H_2O(g)$

   What mass of **oxygen** (in kg) is required to produce 200. kg of hydrogen cyanide?
   .
   A) 149
   B) 423
   C) 257
   D) 317
   E) 355

Amount of HCN to be produced = 200. kg × 1000 g kg^{-1} / 27.0259 g mol^{-1} = $7.40_0 \times 10^3$ mol
Amount of O_2 required = 3/2 × $7.40_0 \times 10^3$ mol = $1.11_0 \times 10^4$ mol
Mass of O_2 required = $1.11_0 \times 10^4$ mol × 32.000 g mol^{-1} /1000 kg g^{-1} = 355 kg

2. What is the **chemical formula** of sodium carbonate?
   .
   A) $NaCO_3$
   B) $NaClO_3$
   C) $Na(CO_3)_2$
   D) Na_2CO_3
   E) Na_2CO_2

Carbonate = CO_3^{2-}
Sodium (in an ionic compound) = Na^+

3. Suppose 25.0 mL of a 0.610 M NaOH solution reacts with 20.0 mL of a 0.245 M H_2SO_4 solution. Which one of the following statements is **TRUE**?
   .
   A) The limiting reagent is H_2SO_4 and the resulting solution is basic
   B) The limiting reagent is NaOH and the resulting solution is basic.
   C) The limiting reagent is H_2SO_4 and the resulting solution is acidic.
   D) The resulting solution is pH neutral.
   E) The limiting reagent is NaOH and the resulting solution is acidic.

Balanced reaction:

$2\ OH^-(aq) + H_2SO_4(aq) \rightarrow SO_4^{2-}(aq) + H_2O(l)$

Amount of OH^- = 0.025 L × 0.610 mol L^{-1} = 0.0152_5 mol
Amount of H_2SO_4 = 0.020 L × 0.245 mol L^{-1} = 0.00490_0 mol

There is not enough H_2SO_4 to consume all of the OH^-. Therefore, H_2SO_4 is the limiting reagent. There is excess OH^- (only $2 \times 0.00490_0$ mol = 0.00980_0 mol of OH^- is consumed, leaving $0.0152_5 - 0.00980_0$ mol of OH^- unreacted). Therefore, the resulting solution is basic.

4. What is the **empirical formula** of the compound formed by gallium and oxygen?

   .

   A) GaO_3
   B) Ga_2O
   C) Ga_3O_2
   D) GaO
   E) Ga_2O_3

Ga is in group 13 (i.e. valence = 3), while O is in group 16 (valence = 8 – 6 = 2).

5. Which **one** of the following statements is **FALSE** regarding a gas initially at 300. K, 1.00 atm pressure, and 1.00 L volume?

   .

   A) Increasing the temperature to 900. K, at constant volume, increases the pressure to 3.00 atm.
   B) Increasing the pressure to 2.00 atm, and volume to 3.00 L, leaves the gas at 1500. K.
   C) Increasing the temperature to 1200. K, at constant pressure, increases the volume to 4.00 L.
   D) Decreasing the pressure to 0.500 atm, while increasing the volume to 4.00 L, leaves the gas at 600. K.
   E) There are 0.0406 moles of gas.

For an ideal gas, $p\,V = n\,R\,T$.
In all of the processes, the amount of gas does not change (i.e. initial and final n are the same).
A) $p_f = n\,R\,T_f / V = n\,R\,T_i / V \times T_f / T_i = p_i \times T_f / T_i$ = 1.00 atm × 900. K/ 300. K = 3.00 atm
B) $T_f = p_f\,V_f / n\,R = p_i\,V_i / n\,R \times p_f / p_i \times V_f / V_i = T_i \times p_f / p_i \times V_f / V_i =$
300. K × 2.00 atm / 1.00 atm × 3.00 L / 1.00 L = 1800 K i.e. not 1500 K
C) $V_f = n\,R\,T_f / p = n\,R\,T_i / p \times T_f / T_i = V_i \times T_f / T_i$ = 1.00 L × 1200. K/ 300. K = 4.00 L
D) $T_f = p_f\,V_f / n\,R = p_i\,V_i / n\,R \times p_f / p_i \times V_f / V_i = T_i \times p_f / p_i \times V_f / V_i =$
300. K × 0.500 atm / 1.00 atm × 4.00 L / 1.00 L = 600 K
E) $n = p\,V / R\,T$ = 1.00 atm × 1.00 L / (0.08206 L atm K^{-1} mol^{-1} × 300. K) = 0.406 mol

6. The density of a **noble gas** is 2.71 g L^{-1} at 3.00 atm and 0 °C. What is the gas?

   .

   A) Xe
   B) Kr
   C) He
   D) Ar
   E) Ne

For an ideal gas,

$p\,V = n\,R\,T$

$p / R\,T = n / V = d / M$ where M is the molar mass and d is the density

= 3.00 atm /(0.08206 L atm K^{-1} mol^{-1} × 273.15 K) = 0.133_8 mol L^{-1} = d / M

Therefore,

$$M = 2.71 \text{ g L}^{-1} / 0.133_8 \text{ mol L}^{-1} = 20.2 \text{ g mol}^{-1}$$

This is consistent with Ne (= 20.18 g mol^{-1}).

7. Ammonium nitrate decomposes according to

   $NH_4NO_3(s) \rightarrow N_2(g) + 2\ H_2O(l) + ½\ O_2(g)$

   What **total volume** of gas (in L) is produced when 10.0 g of ammonium nitrate decomposes, and the product gas is at 1.00 atm total pressure and 25°C?

   .
   A) 3.71
   B) 6.12
   C) 4.11
   D) 5.23
   E) 4.58

Amount of NH_4NO_3 = 10.0 g / 80.05 g mol^{-1} = 0.124_9 mol
Total amount of gas produced (N_2 + O_2) = 1.5 × 0.124_9 mol = 0.187_4 mol

Volume = $V = n\,R\,T / p$ = 0.187_4 mol × 0.08206 L atm K^{-1} mol^{-1} × 298.15 K / 1.00 atm = 4.58 L

8. Which **one** of the following sets of reactants does **not** produce a **visible change** (gas evolved or precipitate) when combined?

   .
   A) $Na_2CO_3(aq) + Ba(ClO_3)_2(aq)$
   B) $Li(s) + H_2O(l)$
   C) $LiCl(aq) + AgCH_3COO(aq)$
   D) $LiClO_3(aq) + AgNO_3(aq)$
   E) $Zn(s) + HCl(aq)$

A) $Na_2CO_3(aq) + Ba(ClO_3)_2(aq) \rightarrow NaClO_3(aq) + BaCO_3(s)$	a precipitate is formed
B) $Li(s) + H_2O(l) \rightarrow LiOH(aq) + H_2(g)$	a gas is formed
C) $LiCl(aq) + AgCH_3COO(aq) \rightarrow LiCH_3COO(aq) + AgCl(s)$	a precipitate is formed
D) $LiClO_3(aq) + AgNO_3(aq)$	no reaction (nitrates & chlorates are soluble)
E) $Zn(s) + 2\ HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$	a gas is formed

9. Classify the reaction $KH(s) + H_2O(l) \rightarrow KOH(aq) + H_2(g)$ according to the following three **reaction types** (choose all that apply):

(i) acid-base
(ii) oxidation-reduction
(iii) precipitation
.
A) ii
B) iii
C) i, ii
D) ii, iii
E) i, iii

KH(s) consists of K+ and H^- ions. Water transfers a H^+ to H^- to form H_2 gas. This is a proton (i.e. H^+) transfer reaction, and therefore an acid-base reaction. It is also an oxidation-reduction reaction. The oxidation number of H in hydride increases from –1 to 0. Hydride is oxidized. The oxidation number of H in water decreases from +1 to 0. Water is reduced.

10. Label the following substances as **strong**, **weak** or **non**, according to whether they are strong or weak electrolytes, or nonelectrolytes, respectively:

HCl HOCl CH_4 $BaCl_2$

In the order they are listed here, the labels are as follows:
.

A)	strong	non	non	weak
B)	strong	non	weak	strong
C)	weak	strong	non	strong
D)	strong	strong	non	strong
E)	strong	weak	non	strong

HCl	HOCl	CH_4	$BaCl_2$
strong	weak	non	strong
a strong acid fully dissociates into ions	a weak acid dissociates to a small extent	methane remains neutral in water solubility is almost nil	a soluble ionic compound

11. Which of the following statements is **FALSE** regarding the given reaction?

$$3\, HOCl(aq) + 2\, NO(g) + H_2O(l) \rightarrow 3\, Cl^-(aq) + 2\, NO_3^-(aq) + 5\, H^+(aq)$$
.
A) NO(g) is the reducing agent.
B) Each nitrogen atom loses 3 electrons.
C) HOCl(aq) is a stronger oxidizing agent than NO_3^-(aq).
D) Cl^-(aq) is a stronger reducing agent than NO(g).
E) Each chlorine atom gains 2 electrons.

$3\ HOCl(aq) + 2\ NO(g) + H_2O(l) \rightarrow 3\ Cl^-(aq) + 2\ NO_3^-(aq) + 5\ H^+(aq)$

ON's +1 +2 −1 +5

HOCl gets reduced to Cl^- (Cl oxidation number changes from +1 to −1)

HOCl is the oxidizing agent

each Cl atom gains 2 electrons

NO gets oxidized (N oxidation number changes from +2 to +5)

NO is the reducing agent

each N atom loses 3 electrons

HOCl is the oxidizing agent on the left, while NO_3^- is the oxidizing agent on the right (i.e. for the reverse reaction). Because the reaction proceeds to the right, HOCl is the stronger oxidizing agent.
NO is the reducing agent on the left, while Cl^- is the reducing agent on the right (i.e. for the reverse reaction). Because the reaction proceeds to the right, NO is the stronger reducing agent.

12. **Balance** the reaction (unbalanced as written),

$OCl^-(aq) + H_2CO(aq) \rightarrow Cl^-(aq) + HCOO^-(aq)$

under basic conditions. If 1 mol of H_2CO is consumed, how much $OH^-(aq)$ is consumed/produced?

.

A) 1 mol of $OH^-(aq)$ is consumed
B) 3 mol of $OH^-(aq)$ is produced
C) 1 mol of $OH^-(aq)$ is produced
D) 2 mol of $OH^-(aq)$ is produced
E) 2 mol of $OH^-(aq)$ is consumed

Write down half reactions (O's and H's not yet balanced):

$OCl^-(aq) + 2\ e^- \rightarrow Cl^-(aq)$ $H_2CO(aq) \rightarrow HCOO^-(aq) + 2\ e^-$

ON's +1 −1 0 +2

The electrons already balance, so the reactions can be added as is:

$OCl^-(aq) + H_2CO(aq) \rightarrow Cl^-(aq) + HCOO^-(aq)$

O's already balance. Balance H's by adding 1 H^+ to right side. Add 1 OH^- to both sides to convert the reaction to basic conditions (the $H^+ + OH^-$ on the right become H_2O):

$OCl^-(aq) + H_2CO(aq) + OH^- \rightarrow Cl^-(aq) + HCOO^-(aq) + H_2O$

13. Which one of the following reactions is an **oxidation-reduction reaction**?

.

A) $NH_4NO_3(s) \rightarrow N_2O(g) + 2\ H_2O(g)$
B) $LiNH_2(aq) + 2\ HBr(aq) \rightarrow LiBr(aq) + NH_4Br(aq)$
C) $CuCl_2(aq) + K_2S(aq) \rightarrow CuS(s) + 2\ KCl(aq)$
D) $Be(OH)_2(s) + 2\ HClO_4(aq) \rightarrow 4\ Be(ClO_4)_2(aq) + 2\ H_2O(l)$
E) $SO_2(g) + H_2O(l) \rightarrow 2\ H_2SO_3(aq)$

Look for changing oxidation numbers:

$NH_4NO_3(s) \rightarrow N_2O(g) + 2\ H_2O(g)$

ON's -3 $+5$ $+1$

One N (the N in NH_4^+) gets oxidized, while the other N (the N in NO_3^-) gets reduced. Since both N's come from the same substance, this is an example of a disproportionation.

B) acid-base reaction C) precipitation reaction D) acid-base reaction E) hydration reaction

14. Given the enthalpy of reaction for the decomposition of ammonium nitrate,

    $NH_4NO_3(s) \rightarrow N_2(g) + 2\ H_2O(l) + ½\ O_2(g)$,

    is $\Delta H°\ =\ -206.0$ kJ mol^{-1} and the enthalpy of formation of liquid water is $\Delta H_f°\ =\ -285.8$ kJ mol^{-1}, determine the **enthalpy of formation** of ammonium nitrate (in kJ mol^{-1})?

    .

    A) −405.7
    B) −254.9
    C) −211.8
    D) −317.1
    E) −365.6

Write $\Delta H°$ in terms of enthalpies of formation of reactants and products ($N_2(g)$ and $O_2(g)$ can be left out, since their enthalpies of formation are zero – they are elements in their standard states):

$\Delta H°\ =\ 2\ \Delta H_f°[H_2O(l)] - \Delta H_f°[NH_4NO_3(s)]\ =\ -206.0\ \text{kJ mol}^{-1}$

Therefore,

$\Delta H_f°[NH_4NO_3(s)]\ =\ 2\ \Delta H_f°[H_2O(l)] - (-206.0\ \text{kJ mol}^{-1})\ =\ 2\ (-285.8) + 206.0\ \text{kJ mol}^{-1}\ =\ -365.6\ \text{kJ mol}^{-1}$

15. A system undergoes an **exothermic** reaction for which work is done **by** the system (i.e. $w < 0$). Which **one** of the following could be the reaction?

    .

    A) $2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(l)$
    B) $NaCl(l) \rightarrow NaCl(s)$
    C) $2\ H_2O_2(aq) \rightarrow 2\ H_2O(l) + O_2(g)$
    D) $CO_2(aq) \rightarrow CO_2(g)$
    E) $CCl_4(l) \rightarrow CCl_4(g)$

If work is done by the system, volume must increase ($w\ =\ -p\ \Delta V$). There must more moles of product gas than reactant gas. This reduces the choices to C, D and E. In D and E, intermolecular bonds are broken (with no new bonds formed). These reactions are therefore endothermic. The answer is C, the decomposition of hydrogen peroxide. This is exothermic. In the demo done in class, the production of steam (from the heat evolved) was visible.

16. A coffee cup calorimeter, including the water it contains, has a heat capacity of 425 J K^{-1}, and is initially at a temperature of 23.07°C. A 16.9 gram piece of nickel metal, initially at a temperature of 4.0°C is placed in the calorimeter. The final temperature of the calorimeter and the metal is 22.74°C. What is the **specific heat of nickel metal (in J g^{-1} K^{-1})** ?

.

A) 0.17
B) 0.44
C) 1.4
D) 145
E) 25

The heat gained by the nickel equals the heat lost by the water – i.e.

$q_{\text{Ni}} = -q_{\text{water}}$

$m_{\text{Ni}}\, s_{\text{Ni}}$ (22.74 – 4.0 K) = $-C_{\text{water}}$ (22.74 – 23.07 K)

Note that the heat capacity of the water is given. We do not need to write it as $C_{\text{water}} = m_{\text{water}}\, s_{\text{water}}$. Therefore,

16.9 g × s_{Ni} × 18.74 K = 425 J K^{-1} × 0.33 K

and

s_{Ni} = 425 J K^{-1} × 0.33 K / (16.9 g × 18.74 K) = 0.44 J g^{-1} K^{-1}

17. Choose the one **FALSE** statement from among the following:

.

A) All diatomic molecules have molar heat capacities that are larger than their specific heat capacities.
B) The process, $CO_2(g) \rightarrow CO_2(s)$, releases energy.
C) For all processes of a closed system, $q = 0$.
D) If two samples absorb the same quantity of heat, the sample with the lower heat capacity has the larger increase in temperature.
E) The process, $O_2(g) \rightarrow 2\,O(g)$, requires an input of energy.

A) A molar heat capacity is the heat capacity per mole of substance. Since 1 mol of any substance has mass greater than 1 g, the molar heat capacity is greater than the specific heat capacity (the heat capacity per gram of substance). The statement is TRUE.
B) $CO_2(g) \rightarrow CO_2(s)$ is exothermic (i.e. it releases energy) because intermolecular bonds are formed while no bonds are broken. Deposition (i.e. gas → solid) is always exothermic. The statement is TRUE.
C) $q = 0$ for all process of an ISOLATED system, but not those of a closed system. “Closed” simply means there is matter cannot enter or leave the system. The statement is FALSE.
D) Since $q = C\,\Delta T$, we have $\Delta T = q/C$. For fixed q, the system with the smaller C has the greatest change in temperature. The statement is TRUE.
E) $O_2(g) \rightarrow 2\,O(g)$ is endothermic. It involves only the breaking of a bond (the O=O bond). The statement is TRUE.

18. Identify the **TRUE** statement(s) from among the following:

(i) $\Delta H° < 0$ for the reaction $2\ K(s) + 2\ H_2O \rightarrow 2\ KOH(aq) + H_2(g)$
(ii) The vaporization of liquid HCl at –85°C is exothermic.
(iii) For $Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s)$, $\Delta H°(\text{reaction}) = \Delta H_f°[CaCO_3(s)]$

.

A) all
B) i, iii
C) ii, iii
D) i
E) i, ii

i) $2\ K(s) + 2\ H_2O \rightarrow 2\ KOH(aq) + H_2(g)$ is exothermic (recall the sodium in water demo done in class – alkalic metals react vigorously with water, releasing energy). The statement is TRUE.
ii) Vaporization is always endothermic – intermolecular bonds are broken when a liquid vaporizes. The statement is FALSE.
iii) $Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s)$ is NOT the formation reaction of calcium carbonate. The reactants must be the elements in their standard states (Ca(s), C(graphite) and $O_2(g)$ in this case). The statement is FALSE.

19. Which **one** of the following statements is **FALSE** regarding the changes in enthalpy, ΔH, and energy, ΔU accompanying a process?

.

A) A "coffee cup" calorimeter operates at constant pressure.
B) ΔH is always larger than ΔU.
C) $\Delta H = \Delta U + \Delta n_{gas} RT$, where Δn_{gas} is the change in the number of moles of gas.
D) $\Delta H = q$, if the pressure is constant.
E) $\Delta U = q$, if the volume is constant.

A) TRUE. This is the definition of a "coffee cup" calorimeter.
B) FALSE. $\Delta H = \Delta U + \Delta n_{gas} RT$ which can be greater than or less than ΔU, depending on the sign of Δn_{gas} .
C) TRUE.
D) TRUE. Recall $\Delta H = q_p$.
E) TRUE. Recall $\Delta U = q_V$.

20. An arsenic atom (Z = 33) is in its ground state. Which one of the following sets of quantum numbers (n, l, m_l, m_s) could **not** possibly describe one of its electrons?

.

A) 4, 2, 2, -1/2
B) 2, 1, -1, ½
C) 4, 1, 0, ½
D) 3, 0, 0, -1/2
E) 3, 2, -2, ½

Ground state electronic configuration of As:

$1s^2\ 2p^6\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^3$

As has electrons with n up to 4. However, only 4s (i.e. l = 0) and 4p (i.e. l = 1) electrons occur – i.e. there are no 4d (i.e. l = 2) electrons.

21. Which **one** of the following is an **excited state** electron configuration for S?
.
A) [Ne] $3s^2\ 3d^1$
B) [Ne] $3s^2\ 3p^4\ 3d^1$
C) [Ne] $3s^2\ 3p^4$
D) [Ne] $3s^2\ 3p^3\ 3d^1$
E) [Ne] $3s^2\ 3p^3$

Ground state electronic configuration of S:

[Ne] $3s^2\ 3p^4$

Promotion of any of the electrons denoted above into a higher level orbital produces an excited state of sulfur. Choices A, B and E have the wrong number of electrons. Choice C is the ground state configuration.

22. If light with a wavelength of 400. nm falls on the surface of sodium metal, electrons with a kinetic energy of 1.31×10^{-19} J are ejected. What is the **minimum frequency** (in THz) of light required to eject an electron from sodium?
.
A) 663
B) 366
C) 750
D) 300
E) 552

A photon of this light has energy,

$$E = h\,\nu = h\,c\,/\,\lambda = 6.6256 \times 10^{-34}\ \text{J s} \times 2.9979 \times 10^{8}\ \text{m s}^{-1} / 400. \times 10^{-9}\ \text{m} = 4.96_6 \times 10^{-19}\ \text{J}$$
$$= E_{\text{thres}} + m\,u^2/2\ ,$$

where E_{thres} is the lowest photon energy that can eject an electron and $m\,u^2/2$ is the kinetic energy of the ejected electron. Since $m\,u^2/2 = 1.31 \times 10^{-19}$ J,

$$E_{\text{thres}} = E - m\,u^2/2 = 4.96_6 \times 10^{-19} - 1.31 \times 10^{-19}\ \text{J} = 3.65_6 \times 10^{-19}\ \text{J}$$

The minimum frequency of light that can eject an electron is the frequency whose photon energy equals the threshold energy.

Therefore,

$$\nu_{\text{min}} = E_{\text{thres}}/h = 3.65_6 \times 10^{-19}\ \text{J} / 6.6256 \times 10^{-34}\ \text{J s} = 5.52 \times 10^{14}\ \text{s}^{-1} = 552\ \text{THz}$$

23. Electrons in an orbital with ℓ = 1 are in a

.

A) p orbital
B) f orbital
C) d orbital
D) g orbital
E) s orbital

24. Which **one** of the following atoms has two **unpaired** electrons in its ground state electronic configuration?

.

A) B
B) He
C) N
D) C
E) Be

Ground state electronic configurations:

B	$1s^2\ 2s^2\ 2p^1$	← 1 unpaired electron in 2p subshell
He	$1s^2$	
N	$1s^2\ 2s^2\ 2p^3$	← 3 unpaired electrons in 2p subshell
C	$1s^2\ 2s^2\ 2p^2$	← 2 unpaired electrons in 2p subshell
Be	$1s^2\ 2s^2$	

25. Calculate the **longest wavelength (in μm)** of light **emitted** by an excited hydrogen atom in which the electron occupies the energy level $n = 6$.

.

A) 21.6
B) 93.9
C) 2.28
D) 3.21
E) 7.46

If light is emitted from the $n = 6$ level, then the final level must have a lower n value. The longest wavelength light corresponds to the smallest frequency, which corresponds to the smallest energy difference. In this case, the final n value must be 5.

$\Delta E = 2.178 \times 10^{-18}\ \text{J}\ (1/5^2 - 1/6^2)$ ← the positive difference between the energy levels
$= 2.662 \times 10^{-20}\ \text{J}$

$\lambda = c / \nu = h\, c / \Delta E = 6.6256 \times 10^{-34}\ \text{J s} \times 2.9979 \times 10^{8}\ \text{m s}^{-1} / 2.662 \times 10^{-20}\ \text{J}$
$= 7.462 \times 10^{-6}\ \text{m} = 7.462\ \mu\text{m}$