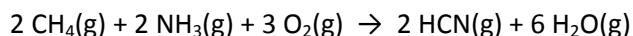


1. Hydrogen cyanide, HCN, is a poisonous gas that is also important in industrial chemical synthesis. It is produced from methane, ammonia and oxygen according to



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 = $200. \text{ kg} \times 1000 \text{ g kg}^{-1} / 27.0259 \text{ g mol}^{-1} = 7.40_0 \times 10^3 \text{ mol}$

Amount of O_2 required = $3/2 \times 7.40_0 \times 10^3 \text{ mol} = 1.11_0 \times 10^4 \text{ mol}$

Mass of O_2 required = $1.11_0 \times 10^4 \text{ mol} \times 32.000 \text{ g mol}^{-1} / 1000 \text{ g kg}^{-1} = 355 \text{ kg}$

2. What is the **chemical formula** of sodium carbonate?

- .
A) NaCO_3
B) NaClO_3
C) $\text{Na}(\text{CO}_3)_2$
D) Na_2CO_3
E) Na_2CO_2

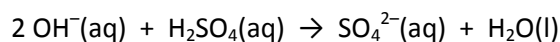
Carbonate = CO_3^{2-}

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:



Amount of OH^- = $0.025 \text{ L} \times 0.610 \text{ mol L}^{-1} = 0.0152_5 \text{ mol}$

Amount of H_2SO_4 = $0.020 \text{ L} \times 0.245 \text{ mol L}^{-1} = 0.00490_0 \text{ mol}$

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 $2 \times 0.00490_0 \text{ mol} = 0.00980_0 \text{ mol}$ of OH^- is consumed, leaving $0.0152_5 - 0.00980_0 \text{ mol}$ 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, $pV = nRT$.

In all of the processes, the amount of gas does not change (i.e. initial and final n are the same).

$$\text{A) } p_f = nRT_f/V = nRT_i/V \times T_f/T_i = p_i \times T_f/T_i = 1.00 \text{ atm} \times 900. \text{ K} / 300. \text{ K} = 3.00 \text{ atm}$$

$$\text{B) } T_f = p_f V_f / nR = p_i V_i / nR \times p_f / p_i \times V_f / V_i = T_i \times p_f / p_i \times V_f / V_i = 300. \text{ K} \times 2.00 \text{ atm} / 1.00 \text{ atm} \times 3.00 \text{ L} / 1.00 \text{ L} = 1800 \text{ K} \text{ i.e. not } 1500 \text{ K}$$

$$\text{C) } V_f = nRT_f/p = nRT_i/p \times T_f/T_i = V_i \times T_f/T_i = 1.00 \text{ L} \times 1200. \text{ K} / 300. \text{ K} = 4.00 \text{ L}$$

$$\text{D) } T_f = p_f V_f / nR = p_i V_i / nR \times p_f / p_i \times V_f / V_i = T_i \times p_f / p_i \times V_f / V_i = 300. \text{ K} \times 0.500 \text{ atm} / 1.00 \text{ atm} \times 4.00 \text{ L} / 1.00 \text{ L} = 600 \text{ K}$$

$$\text{E) } n = pV/RT = 1.00 \text{ atm} \times 1.00 \text{ L} / (0.08206 \text{ L atm K}^{-1} \text{ mol}^{-1} \times 300. \text{ K}) = 0.406 \text{ mol}$$

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,

$$pV = nRT$$

$$p/RT = n/V = d/M \quad \text{where } M \text{ is the molar mass and } d \text{ is the density}$$

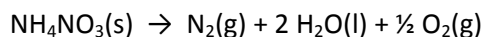
$$= 3.00 \text{ atm} / (0.08206 \text{ L atm K}^{-1} \text{ mol}^{-1} \times 273.15 \text{ K}) = 0.133_8 \text{ mol L}^{-1} = d/M$$

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



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

$$\text{Amount of NH}_4\text{NO}_3 = 10.0 \text{ g} / 80.05 \text{ g mol}^{-1} = 0.124_9 \text{ mol}$$

$$\text{Total amount of gas produced (N}_2 + \text{O}_2) = 1.5 \times 0.124_9 \text{ mol} = 0.187_4 \text{ mol}$$

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

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

- .
A) $\text{Na}_2\text{CO}_3(\text{aq}) + \text{Ba}(\text{ClO}_3)_2(\text{aq})$
B) $\text{Li}(\text{s}) + \text{H}_2\text{O}(\text{l})$
C) $\text{LiCl}(\text{aq}) + \text{AgCH}_3\text{COO}(\text{aq})$
D) $\text{LiClO}_3(\text{aq}) + \text{AgNO}_3(\text{aq})$
E) $\text{Zn}(\text{s}) + \text{HCl}(\text{aq})$

- | | |
|---|--|
| A) $\text{Na}_2\text{CO}_3(\text{aq}) + \text{Ba}(\text{ClO}_3)_2(\text{aq}) \rightarrow \text{NaClO}_3(\text{aq}) + \text{BaCO}_3(\text{s})$ | a precipitate is formed |
| B) $\text{Li}(\text{s}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{LiOH}(\text{aq}) + \text{H}_2(\text{g})$ | a gas is formed |
| C) $\text{LiCl}(\text{aq}) + \text{AgCH}_3\text{COO}(\text{aq}) \rightarrow \text{LiCH}_3\text{COO}(\text{aq}) + \text{AgCl}(\text{s})$ | a precipitate is formed |
| D) $\text{LiClO}_3(\text{aq}) + \text{AgNO}_3(\text{aq})$ | no reaction (nitrates & chlorates are soluble) |
| E) $\text{Zn}(\text{s}) + 2 \text{HCl}(\text{aq}) \rightarrow \text{ZnCl}_2(\text{aq}) + \text{H}_2(\text{g})$ | a gas is formed |

9. Classify the reaction $\text{KH(s)} + \text{H}_2\text{O(l)} \rightarrow \text{KOH(aq)} + \text{H}_2\text{(g)}$ 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:

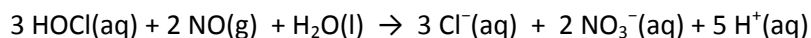
HCl HOCl CH_4 BaCl_2

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

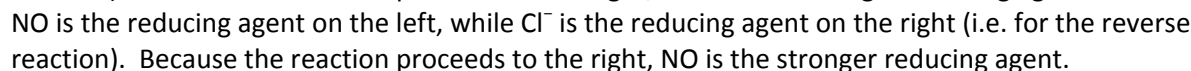
- A) strong non non weak
- B) strong non weak strong
- C) weak strong non strong
- D) strong strong non strong
- E) strong weak non strong**

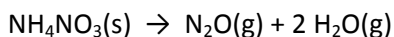
HCl	HOCl	CH_4	BaCl_2
strong	weak	non	strong
a strong acid fully	a weak acid	methane remains	a soluble ionic compound
dissociates into ions	dissociates to	neutral in water	
	a small extent	solubility is almost nil	

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



- A) NO(g) is the reducing agent.
- B) Each nitrogen atom loses 3 electrons.
- C) HOCl(aq) is a stronger oxidizing agent than $\text{NO}_3^-\text{(aq)}$.
- D) $\text{Cl}^-\text{(aq)}$ is a stronger reducing agent than NO(g) .**
- E) Each chlorine atom gains 2 electrons.



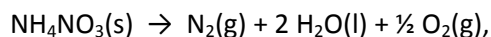


ON's -3 +5 +1

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,



is $\Delta H^\circ = -206.0 \text{ kJ mol}^{-1}$ and the enthalpy of formation of liquid water is $\Delta H_f^\circ = -285.8 \text{ kJ mol}^{-1}$, 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 ΔH° in terms of enthalpies of formation of reactants and products ($\text{N}_2(\text{g})$ and $\text{O}_2(\text{g})$ can be left out, since their enthalpies of formation are zero – they are elements in their standard states):

$$\Delta H^\circ = 2 \Delta H_f^\circ[\text{H}_2\text{O}(\text{l})] - \Delta H_f^\circ[\text{NH}_4\text{NO}_3(\text{s})] = -206.0 \text{ kJ mol}^{-1}$$

Therefore,

$$\Delta H_f^\circ[\text{NH}_4\text{NO}_3(\text{s})] = 2 \Delta H_f^\circ[\text{H}_2\text{O}(\text{l})] - (-206.0 \text{ kJ mol}^{-1}) = 2(-285.8) + 206.0 \text{ kJ mol}^{-1} = -365.6 \text{ kJ mol}^{-1}$$

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) $2 \text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2 \text{H}_2\text{O}(\text{l})$
B) $\text{NaCl}(\text{l}) \rightarrow \text{NaCl}(\text{s})$
C) **$2 \text{H}_2\text{O}_2(\text{aq}) \rightarrow 2 \text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$**
D) $\text{CO}_2(\text{aq}) \rightarrow \text{CO}_2(\text{g})$
E) $\text{CCl}_4(\text{l}) \rightarrow \text{CCl}_4(\text{g})$

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 g 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 $\text{J g}^{-1} \text{ K}^{-1}$)** ?

- 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.

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

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

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,

$$16.9 \text{ g} \times s_{\text{Ni}} \times 18.74 \text{ K} = 425 \text{ J K}^{-1} \times 0.33 \text{ K}$$

and

$$s_{\text{Ni}} = 425 \text{ J K}^{-1} \times 0.33 \text{ K} / (16.9 \text{ g} \times 18.74 \text{ K}) = 0.44 \text{ J g}^{-1} \text{ K}^{-1}$$

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, $\text{CO}_2(\text{g}) \rightarrow \text{CO}_2(\text{s})$, 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, $\text{O}_2(\text{g}) \rightarrow 2 \text{ O}(\text{g})$, 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) $\text{CO}_2(\text{g}) \rightarrow \text{CO}_2(\text{s})$ is exothermic (i.e. it releases energy) because intermolecular bonds are formed while no bonds are broken. Deposition (i.e. gas \rightarrow 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) $\text{O}_2(\text{g}) \rightarrow 2 \text{ O}(\text{g})$ 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) $\Delta H^\circ < 0$ for the reaction $2 \text{K(s)} + 2 \text{H}_2\text{O} \rightarrow 2 \text{KOH(aq)} + \text{H}_2\text{(g)}$
- (ii) The vaporization of liquid HCl at -85°C is exothermic.
- (iii) For $\text{Ca}^{2+}(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{CaCO}_3(\text{s})$, $\Delta H^\circ(\text{reaction}) = \Delta H_f^\circ[\text{CaCO}_3(\text{s})]$

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

i) $2 \text{K(s)} + 2 \text{H}_2\text{O} \rightarrow 2 \text{KOH(aq)} + \text{H}_2\text{(g)}$ 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) $\text{Ca}^{2+}(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{CaCO}_3(\text{s})$ is NOT the formation reaction of calcium carbonate. The reactants must be the elements in their standard states (Ca(s), C(graphite) and $\text{O}_2(\text{g})$ 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) $\Delta H = \Delta U + \Delta n_{\text{gas}} RT$, 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. $\Delta H = \Delta U + \Delta n_{\text{gas}} RT$ which can be greater than or less than ΔU , depending on the sign of Δn_{gas} .

C) TRUE.

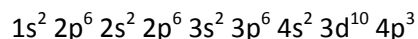
D) TRUE. Recall $\Delta H = q_p$.

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, $\frac{1}{2}$
- C) 4, 1, 0, $\frac{1}{2}$
- D) 3, 0, 0, -1/2
- E) 3, 2, -2, $\frac{1}{2}$

Ground state electronic configuration of As:

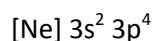


As has electrons with n up to 4. However, only 4s (i.e. $l = 0$) and 4p (i.e. $l = 1$) electrons occur – i.e. there are no 4d (i.e. $l = 2$) electrons.

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:



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,

$$E = h\nu = hc/\lambda = 6.6256 \times 10^{-34} \text{ J s} \times 2.9979 \times 10^8 \text{ m s}^{-1} / 400. \times 10^{-9} \text{ m} = 4.96_6 \times 10^{-19} \text{ J}$$

$$= E_{\text{thres}} + m u^2/2,$$

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 $\ell = 1$ 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.

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

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