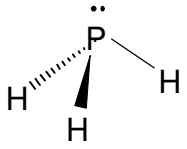
1. Which of the following species are **planar** (i.e., all atoms are in a single plane)?

i. PH_3 ii. BH_3 iii. XeF_4 iv. SF_4 v. ICl_3

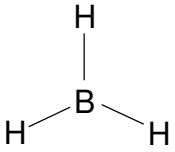
.

A) iii, iv and v
B) i, ii and iv
C) ii, iv and v
D) ii, iii and v
E) i, iii and v



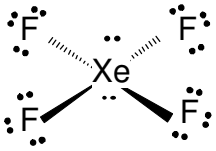
trigonal pyramidal

- NOT planar



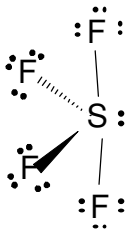
trigonal planar

- planar



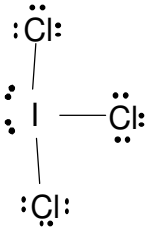
square planar

- planar



seesaw

- NOT planar



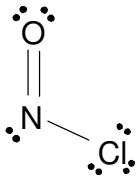
T-shaped

- planar

2. Which of the following statements is **FALSE** regarding the best Lewis structure for NOCl, a reactive material used as an ionizing solvent. Note that nitrogen is the central atom.

.

A) The N-O bond is a double bond.
B) The nitrogen atom has an unpaired electron in its valence shell.
C) The nitrogen atom has one lone pair of electrons.
D) All formal charges are zero.
E) The N-Cl bond is a single bond.



3. In which one of the following species is the central atom (the first atom in the formula) an **exception** to the octet rule?

.

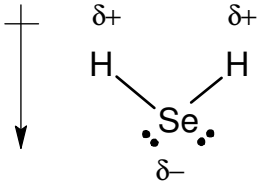
A) BH_4^-
B) I_2
C) SF_6
D) NH_4^+
E) NH_3

In SF_6, the sulfur atom has six single bonds (there are no lone pairs). This corresponds to 12 valence electrons on sulfur.

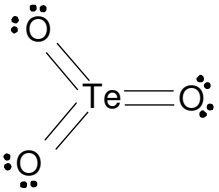
4. Which of the following has **no net dipole** moment?

.

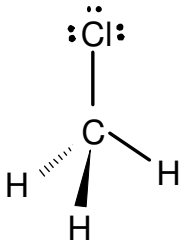
A) H_2Se
B) TeO_3
C) CH_3Cl
D) N_2O
E) NF_3



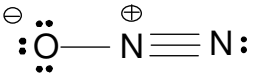
net dipole



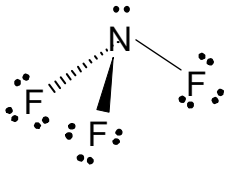
NO net dipole



net dipole



net dipole

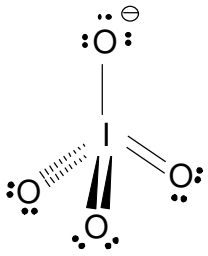


net dipole

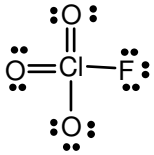
5. What is the **average bond order** in the charge minimized Lewis structure of periodate, IO_4^-?

.

A) 5/4
B) 7/4
C) 4/3
D) 1
E) 3/2



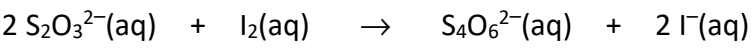
6. In the following Lewis structure for ClO_3F, chlorine has a **formal charge** of ____ and an **oxidation number** of ____ .



A) 1, 1
B) 1, 7
C) 1, -1
D) 7, -1
E) 7, 7

This is not a charge minimized Lewis structure. Chlorine has a formal charge of +1, while the singly-bonded oxygen atom has a formal charge of −1. Chlorine has a core charge of +7. Since it has no lone pairs, and all bonding pairs are with more electronegative atoms, it has an oxidation number of +7.

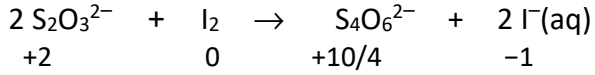
7. Sodium thiosulfate, $Na_2S_2O_3$, is used as a "fixer" in black and white photography. Which of the following statements is **FALSE** regarding the reaction of thiosulfate with iodine.



.

A) $S_2O_3^{2-}(aq)$ gets oxidized in this reaction. T
B) $I_2(aq)$ is the oxidizing agent.
C) $S_2O_3^{2-}(aq)$ is a stronger reducing agent than $I^-(aq)$.
D) The average oxidation number of sulfur atoms increases by one in this reaction.
E) $I_2(aq)$ is a stronger oxidizing agent than $S_4O_6^{2-}(aq)$.

Oxidation numbers (on sulfur and iodine):



These are average oxidation numbers for sulfur atoms. The average oxidation number of sulfur increases by +1/2.

$S_2O_3^{2-}$ gets oxidized by I_2 – i.e., it is the reducing agent. I_2 is the oxidizing agent.
I^- is the reducing agent on the right. $S_4O_6^{2-}$ is the oxidizing agent on the right. $S_2O_3^{2-}$ is the stronger reducing agent, while I_2 is the stronger oxidizing agent because the reaction goes in the forward direction.

8. Which of the following statements are **TRUE**?

(i) Alkali metal hydrides produce $H_2(g)$ when they react with water.
(ii) The formation of $H_2(g)$ is a characteristic of the reaction of *all* metals with dilute acids.
(iii) HF(aq) is a stronger acid than HCl(aq).
(iv) Mixing saturated aqueous solutions of phosphoric acid and calcium hydroxide produces no visible reaction.

.

A) i and ii
B) iii and iv
C) i
D) iv
E) ii and iii

(i) True. Li, Na and K all react with water, producing bubbles of hydrogen gas.
(ii) False. Zinc reacts with dilute acid, producing hydrogen gas. However, copper does not. This is not a characteristic of all metals.
(iii) False. HF(aq) is a weaker acid than HCl(aq), which is a strong acid (HF is not).
(iv) False. Calcium phosphate precipitates. The acid is neutralized by hydroxide.

9. A student left before completing the Cycles of Copper experiment. The last product had a mass of 0.381 g when dried. The student's notebook indicates they started with 0.248 g of Cu(s). Assuming 100% yield at every step completed, what was the **last product**?

.

A) $CuSO_4$
B) CuO
C) $Cu(OH)_2$
D) $Cu(NO_3)_2$
E) Cu

0.248 g of copper corresponds to 0.248 g / 63.55 g mol^{-1} = 0.00390 mol
The additional mass of 0.381 – 0.248 g = 0.133 g or
0.133 / 0.00390 g (mol of Cu)$^{-1}$ = 34.1 g mol^{-1} which is twice the molar mass of OH.

10. Consider the following acid-base equilibria which are **all product-favored**:

$H_2SO_3(aq) + HCO_3^-(aq) \rightleftharpoons HSO_3^-(aq) + H_2CO_3(aq)$
$HSO_4^-(aq) + HSO_3^-(aq) \rightleftharpoons SO_4^{2-}(aq) + H_2SO_3(aq)$
$H_2CO_3(aq) + SO_3^{2-}(aq) \rightleftharpoons HCO_3^-(aq) + HSO_3^-(aq)$

Which of the following orderings, with respect to "**strength as an acid**", is correct?

.

A) $SO_3^{2-} < HSO_3^- < SO_4^{2-} < HCO_3^-$
B) $HSO_4^- < HSO_3^- < H_2CO_3 < H_2SO_3$
C) $HSO_3^- < H_2CO_3 < H_2SO_3 < HSO_4^-$
D) $H_2CO_3 < HSO_3^- < HSO_4^- < H_2SO_3$
E) $HSO_3^- < H_2SO_3 < H_2CO_3 < HSO_4^-$

An acid-base equilibrium is shifted away from the stronger acid. Identify the acid on both sides. Here, the reactant acid is stronger than the product acid.
Reaction 1 gives $H_2CO_3 < H_2SO_3$
Reaction 2 gives $H_2SO_3 < HSO_4^-$
Reaction 3 gives $HSO_3^- < H_2CO_3$

11. When one mole of the following substances is dissolved in water, which solutions have the lowest and highest electrical conductivity (**lowest**, followed by **highest**)?

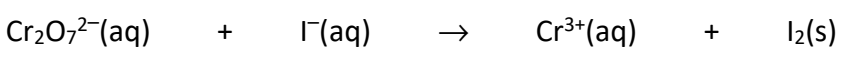
i) $CaCl_2$ ii) HNO_3 iii) NH_3 iv) $C_6H_{12}O_6$ (glucose) v) CO_2

.

A) iv and i
B) v and iii
C) iii and ii
D) v and i
E) iv and ii

$CaCl_2$ produces one mole of aqueous 2+ ions, and two moles of 1− ions. HNO_3 is a strong acid – i.e., it fully dissociates. It produces one mole of both 1+ and 1− ions. NH_3 is a weak base that produces small concentrations of ions. CO_2 reacts with water, producing the weak acid, H_2CO_3.
Glucose is molecular, and is neither acid nor base. Dissolving glucose produces aqueous neutral molecules – no ions.

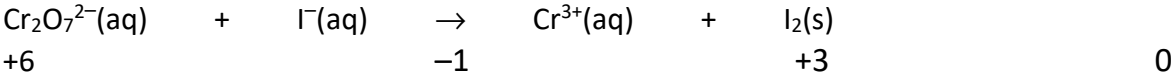
12. What are the **coefficients of Cr^{3+} and H^+** (in that order) in the following redox reaction, balanced in acidic aqueous solution with the smallest whole number stoichiometric coefficients?



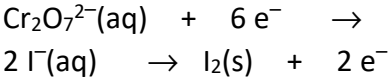
.

A) 3 and 16
B) 2 and 12
C) 1 and 10
D) 1 and 12
E) 2 and 14

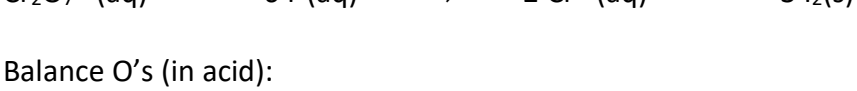
Assign oxidation numbers to identify half reactions:



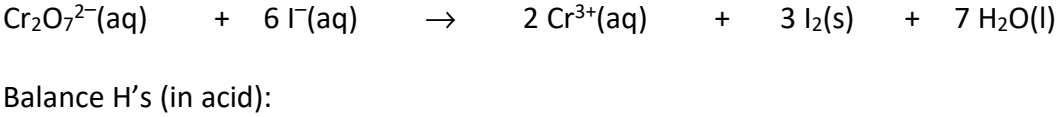
Half reactions (note that we balance Cr and I here):



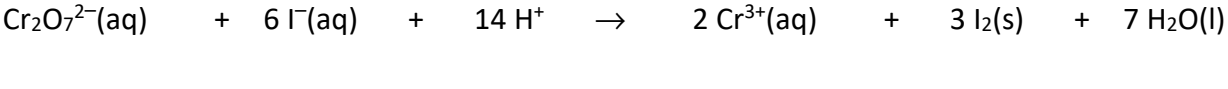
Balance electrons:



Balance O's (in acid):



Balance H's (in acid):



13. Which of the following statements are **TRUE** regarding reactions 1 and 2?

Reaction 1: $2\ H_2O_2(aq) \rightarrow 2\ H_2O(l) + O_2(g)$
Reaction 2: $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

i. H_2O_2 is the reducing agent in reaction 1.
ii. H_2O_2 is the oxidizing agent in reaction 1.
iii. Reaction 2 is a redox reaction.
iv. Calcium atoms lose two electrons in reaction 2.
.

A) i and iii
B) i and ii
C) ii and iii
D) ii and iv
E) iii and iv

i and ii are both true. Reaction 1 is a disproportionation reaction. Reaction 2 is a decomposition reaction. It is not a redox reaction.

14. Determine the **equilibrium constant** for the formation of ozone,

$$O_2(g) + O(g) \rightleftharpoons O_3(g),$$

from the following data:

$$NO_2(g) \rightleftharpoons NO(g) + O(g) \qquad K_1 = 6.8\times10^{-49}$$
$$O_3(g) + NO(g) \rightleftharpoons NO_2(g) + O_2(g) \qquad K_2 = 5.8\times10^{-34}$$

.

A) 3.7×10^{-82}
B) 1.9×10^{82}
C) 8.1×10^{-81}
D) 5.6×10^{83}
E) 2.5×10^{81}

Adding reactions 1 and 2 gives the reverse of the target reaction. Therefore,

$K = 1/(K_1 K_2) = 1/(6.8\times10^{-49} \times 5.8\times10^{-34}) = 2.5\times10^{81}$

15. A vessel is filled with $N_2O_4(g)$ to an initial pressure of 3.01 bar, at some temperature. The equilibrium constant for the decomposition,

$N_2O_4(g) \rightleftharpoons 2\ NO_2(g)$

at this temperature, is 0.133. What is the **partial pressure of $NO_2(g)$** when equilibrium is established?

.

A) 0.277
B) 0.600
C) 0.981
D) 0.710
E) 0.400

	$N_2O_4(g)$	$\rightleftharpoons$	$2\ NO_2(g)$
I	3.01		0
C	−x		2 x
E	3.01−x		2 x

$0.133 = 4\ x^2/(3.01-x)$

$4\ x^2 + 0.133\ x - 0.133*3.01 = 0$

x = 0.300

16. Select the one **FALSE** statement concerning the equilibrium,

$MgCO_3(s) \rightleftharpoons MgO(s) + CO_2(g)$ $\Delta H° = 100.6$ kJ.

.

A) Removing $CO_2(g)$ increases the amount of MgO(s).
B) Doubling the amount of all three species (with the volume of the reaction vessel fixed) has no effect on the equilibrium.
C) Adding MgO(s) does not change the amount of $MgCO_3(s)$.
D) Halving the size of the reaction vessel increases the amount of $MgCO_3(s)$.
E) Increasing the temperature increases the amount of MgO(s).

While doubling the amount of the solids does not affect the equilibrium, doubling the amount of CO_2 (with volume fixed) doubles the partial pressure of CO_2 and shifts the reaction back towards reactant.

17. At 986°C, the equilibrium constant, *K*, for the reaction

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

is 0.63. A rigid cylinder at that temperature contains 1.2 bar carbon monoxide, 0.20 bar water vapor, 0.30 bar carbon dioxide, and 0.27 bar hydrogen. Which of the following statements is **TRUE**?

.

A) The reaction quotient, *Q*, is less than *K*, and there is net forward reaction.
B) The reaction quotient, *Q*, is greater than *K*, and there is net reverse reaction.
C) The gas mixture is at equilibrium.
D) The reaction quotient, *Q*, is greater than *K*, and there is net forward reaction.
E) The reaction quotient, *Q*, is less than *K*, and there is net reverse reaction.

$Q = P(H_2)\,P(CO_2) / (\,P(CO)\,P(H_2O)\,)$
$= 0.27 \times 0.30 / (\,1.2 \times 0.20\,) = 0.338 < 0.63 = K$

There is net forward reaction.

18. When 0.152 mol of solid PH_3BCl_3 is introduced into a 3.00 L container at 25°C, it decomposes according to

$$PH_3BCl_3(s) \rightleftharpoons PH_3(g) + BCl_3(g)$$

0.144 mol of PH_3 is present when equilibrium is reached. What is the **equilibrium constant** for the above reaction, at 25°C?

.

A) 9.82
B) 1.42
C) 5.43
D) 6.71
E) 1.97

0.144 mol of PH_3 present at equilibrium corresponds to partial pressure,
$P(PH_3) = nRT/V = 0.144\ \text{mol} \times 0.08314\ \text{L bar K}^{-1}\ \text{mol}^{-1} \times 298.15\ \text{K} / 3.00\ \text{L} = 1.19\ \text{bar}$

There are as many moles of $BCl_3(g)$. Therefore, $P(BCl_3) = 1.19$ bar also.
The equilibrium constant equals
$K = P(PH_3)\,P(BCl_3) = 1.19^2 = 1.42.$

19. Which one of the following equilibria is **unaffected** when the volume of the reaction vessel is doubled?

.

A) $Br_2(g) \rightleftharpoons 2\ Br(g)$
B) $N_2(g) + O_2(g) \rightleftharpoons 2\ NO(g)$
C) $2\ SO_2(g) + O_2(g) \rightleftharpoons 2\ SO_3(g)$
D) $2\ NO_2(g) + 7\ H_2(g) \rightleftharpoons 2\ NH_3(g) + 4\ H_2O(l)$
E) $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$

The equilibrium will be unaffected if $\Delta n_{gas} = 0$.

20. Octane (C_8H_{18}) undergoes combustion according to the following thermochemical equation:

$2\ C_8H_{18}(l) + 25\ O_2(g) \rightarrow 16\ CO_2(g) + 18\ H_2O(l)$ $\Delta H°_{rxn} = -11020$ kJ mol^{-1}

Data: $\Delta H°_f[CO_2(g)] = -393.5$ kJ mol^{-1}
$\Delta H°_f[H_2O(l)] = -285.8$ kJ mol^{-1}

What is the **enthalpy of formation** of octane, $\Delta H°_f$, in kJ mol^{-1}?

.

A) −11340
B) +420
C) −420
D) +5510
E) −210

-11020 kJ mol^{-1} $= \Delta H°_{rxn} = 16\ \Delta H°_f[CO_2(g)] + 18\ \Delta H°_f[H_2O(l)] - 2\ \Delta H°_f[C_8H_{18}(l)]$
or $\Delta H°_f[C_8H_{18}(l)] = (16 \times (-393.5) + 18 \times (-285.8) + 11020\ \text{kJ mol}^{-1})/2$
$= -210$ kJ mol^{-1}

21. What is $\Delta H°$ (in kJ mol^{-1}) for the reaction,

$NO(g) + O(g) \rightarrow NO_2(g)$?

Data:

	$\Delta H°$ (kJ mol^{-1})
$2\ O_3(g) \rightarrow 3\ O_2(g)$	−427
$O_2(g) \rightarrow 2\ O(g)$	495
$NO(g) + O_3(g) \rightarrow NO_2(g) + O_2(g)$	−199

.

A) −376
B) 411
C) −233
D) −317
E) 279

Note that

$NO(g) + O_3(g) \rightarrow NO_2(g) + O_2(g)$	Rxn 3
$O(g) \rightarrow 1/2\ O_2(g)$	−1/2 Rxn 2
$3/2\ O_2(g) \rightarrow O_3(g)$	−1/2 Rxn 1
$NO(g) + O(g) \rightarrow NO_2(g)$	

Therefore, the target reaction $\Delta H°$ = −199 − 495/2 + 427/2 = −233 kJ mol^{-1}.

22. In which of the following processes does the system **do work** on the surroundings?

(i) $2\ NH_3(g) + 3\ N_2O(g) \rightarrow 4\ N_2(g) + 3\ H_2O(l)$
(ii) $N_2H_4(l) + H_2O(l) \rightarrow N_2O(g) + 3\ H_2(g)$
(iii) $N_2H_4(l) + H_2O(l) \rightarrow 2\ NH_3(g) + 1/2\ O_2(g)$
(iv) $H_2(g) + 1/2\ O_2(g) \rightarrow H_2O(l)$
(v) $N_2(g) + 2\ H_2O(l) \rightarrow N_2H_4(l) + O_2(g)$

.

A) all
B) i, iv
C) none
D) i, ii, iii, v
E) ii, iii

Work done on surroundings = work done by system. Look for $\Delta n_{gas} > 0$

23. The Starship Enterprise is caught in a time warp and Spock is forced to use the primitive techniques of the 20th century to determine the specific heat capacity of an unknown mineral. The 307 g sample was heated to 98.7°C, and placed into a calorimeter with heat capacity, 319 J K^{-1}, and initial temperature, 23.6°C. The final temperature in the calorimeter was 32.4°C. What is the **specific heat capacity** of the mineral?

.

A) 0.131 J K^{-1} g^{-1}
B) 0.138 J K^{-1} g^{-1}
C) 0.145 J K^{-1} g^{-1}
D) 0.124 J K^{-1} g^{-1}
E) none of the above

For the calorimeter,
$q = C\,\Delta T = 319\text{ J K}^{-1} \times (32.4^\circ\text{C} - 23.6^\circ\text{C}) = 319\text{ J K}^{-1} \times 8.8\text{ K} = 2800\text{ J}$

This heat was lost by the unknown mineral. For the mineral,
$q = C\,\Delta T = C \times (32.4^\circ\text{C} - 98.7^\circ\text{C}) = -2800\text{ J}$

So, $C = 2800\text{ J} / 66.3\text{ K} = 42.2\text{ J K}^{-1}$
Since $C = m\,s$,
the specific heat capacity of the mineral is
$s = 42.2\text{ J K}^{-1} / 307\text{ g} = 0.138\text{ J K}^{-1}\text{ g}^{-1}$

24. A system receives 575 J of heat, from its surroundings, while 425 J of work is done by the system. What is the **change in the energy** of the system, ΔU?

.

A) 1000 J
B) 575 J
C) –150 J
D) 150 J
E) –1000 J

$\Delta U = q + w$
$= 575\text{ J} - 425\text{ J} = 150\text{ J}$

25. Estimate the **enthalpy of sublimation** of graphite, in kJ mol^{-1}; i.e., estimate $\Delta H°$ for

$$C(graphite) \rightarrow C(g)$$

Data:

The standard enthalpy of formation for ethyne (H-C≡C-H) gas:	226.7 kJ mol^{-1}
The average bond enthalpy for a carbon-carbon triple bond (C≡C):	837 kJ mol^{-1}
The average bond enthalpy of a C-H bond:	414 kJ mol^{-1}
The bond enthalpy for H-H:	436 kJ mol^{-1}

.

A) 521
B) 501
C) 728
D) 1042
E) 1456

The formation reaction for ethyne is

$$2\ C(graphite) + H_2(g) \rightarrow C_2H_2(g)$$

which is the sum of

$$2\ C(graphite) \rightarrow 2\ C(g)$$

and

$$2\ C(g) + H\text{-}H(g) \rightarrow H\text{-}C{\equiv}C\text{-}H(g)$$

Thus, $226.7 = 2\ \Delta H°_{sub}[C(graphite)] + D(H\text{-}H) - 2\ D(C\text{-}H) - D(C{\equiv}C)$

or

$\Delta H°_{sub}[C(graphite)] = (226.7 - 436 + 2 \times 414 + 837)/2$
$= 728$ kJ mol^{-1}