

## Quiz 2 review exercise

### Part I. Gas

1.

A flexible container at an initial volume of 8.15 L contains 5.51 mol of gas. More gas is then added to the container until it reaches a final volume of 14.9 L. Assuming the pressure and temperature of the gas remain constant, calculate the number of moles of gas added to the container.

( )mol

2.

For each set of values, calculate the missing variable using the ideal gas law.

	$P$	$V$	$T$	$n$
Set 1	2.61 atm	1.69 L	36.1 °C	$n_1$
Set 2	302 kPa	2382 mL	$T_2$	3.23 mol
Set 3	$P_3$	0.0250 m <sup>3</sup>	288 K	1.08 mol
Set 4	782 torr	$V_4$	303 K	5.26 mol

$n_1 =$  ( )mol

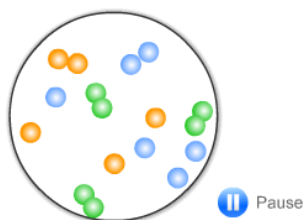
$P_3 =$  ( )kPa

$T_2 =$  ( )K

$V_4 =$  ( )L

3.

Consider this molecular-level representation of a gas.



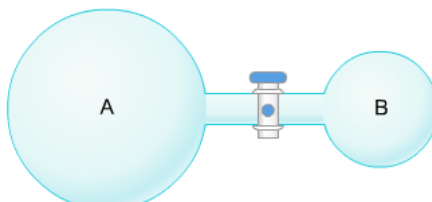
If the partial pressure of the diatomic gas is 0.510 atm, what is the total pressure?

( )atm

4.

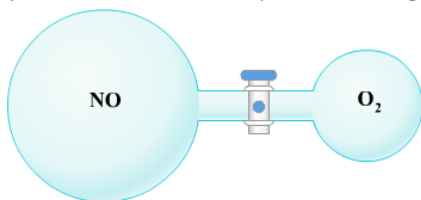
Container A holds 757 mL of ideal gas at 2.70 atm. Container B holds 134 mL of ideal gas at 4.30 atm. If the gases are allowed to mix together, what is the resulting pressure?

( )atm

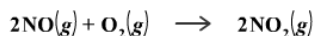


5.

The picture below shows two bulbs connected by a stopcock. The large bulb, with a volume of 6.00 L, contains nitric oxide at a pressure of 0.400 atm, and the small bulb, with a volume of 1.50 L, contains oxygen at a pressure of 2.50 atm. The temperature at the beginning and the end of the experiment is 22 °C.



After the stopcock is opened, the gases mix and react:



Which gases are present at the end of the experiment?

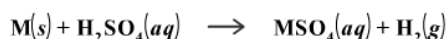
NO  
O<sub>2</sub>  
NO<sub>2</sub>

What are the partial pressures of the gases? If the gas was consumed completely, put 0 for the answer.

P(NO)=( )atm    P(O<sub>2</sub>)=( )atm    P(NO<sub>2</sub>)=( )atm

6.

A 0.691 gram sample of a metal, M, reacts completely with sulfuric acid according to:



A volume of 299 mL of hydrogen is collected over water; the water level in the collecting vessel is the same as the outside level. Atmospheric pressure is 756.0 Torr and the temperature is 25 °C. The vapor pressure of water at various temperatures can be found in this [table](#). Calculate the molar mass of the metal.

( )g/mol

7.

A sample of gaseous arsine, AsH<sub>3</sub>, in a sealed 500.0-mL flask at 290.0 Torr and 223 K is heated to 473 K at which arsine decomposes to solid arsenic and hydrogen gas. After heating, the flask was cooled to 273 K. The final pressure in the flask was 485.0 Torr. Calculate the percentage of arsine molecules that have decomposed.

( )%

8.

When 0.701 g of impure zinc reacted with an excess of hydrochloric acid, 211 mL of hydrogen gas was collected over water at 10.0 °C. The external pressure was 715.24 Torr. The vapor pressure of water at various temperatures can be found in this [table](#).

a. Calculate the volume the dry hydrogen would occupy at 1.00 atm and 298 K.

Number  
 mL

b. What amount, in moles, of H<sub>2</sub> gas was collected at 10.0 °C?

Number  
 mol

c. Calculate the percentage purity of the zinc assuming that all of the zinc present reacted completely with HCl and that the impurities did not react with HCl to produce hydrogen gas.

Number  
 %



Correct.

9.

Ne(g) effuses at a rate that is \_\_\_\_\_ times that of Cl<sub>2</sub>(g) under the same conditions.

$$\frac{\text{rate}_{\text{Ne}}}{\text{rate}_{\text{Cl}_2}} =$$

Number

10.

The average kinetic energy of the molecules in a gas sample depends only on the temperature,  $T$ . But given the same kinetic energies, a lighter molecule will move faster than a heavier molecule.

$$\text{rms speed} = \sqrt{\frac{3RT}{M}}$$

where  $R=8.314 \text{ J/(mol} \cdot \text{K)}$  and  $M$  is molar mass in *kilograms* per mole.  
Note that a joule is the same as a  $\text{kg} \cdot \text{m}^2/\text{s}^2$ .

What is the rms speed of O<sub>2</sub> molecules at 399 K?

Number

 m / s

What is the rms speed of He atoms at 399 K?

Number

 m / s

11.

The molecules of a certain gas sample at 321 K have a root-mean-square (rms) speed of 285 m/s. Calculate the most probable speed and the mass of a molecule.

Most probable speed:

Number

 m / s

Molecular mass:

Number

 kg

12.

The formula for the Maxwell-Boltzmann distribution is given below,

$$y(u, m, T) = 4\pi \left( \frac{m}{2\pi k_B T} \right)^{3/2} u^2 e^{-\left( \frac{mu^2}{2k_B T} \right)}$$

where  $y$  is proportional to the fraction of particles of molecular mass  $m$  at temperature  $T$  traveling at speed  $u$ . The expression  $\text{frac}(u_1, u_2)$  gives the fraction of particles between speeds of  $u_1$  and  $u_2$ .

$$\text{frac}(u_1, u_2) = 4\pi \left( \frac{m}{2\pi k_B T} \right)^{3/2} \int_{u_1}^{u_2} u^2 e^{-\left( \frac{mu^2}{2k_B T} \right)} du$$

Determine the fraction of particles with speeds greater than the root-mean-square speed of the particles at 215.0 K to two significant figures. Be very careful with units and magnitudes here. Note that in this formulation,  $\text{frac}$  is unitless.

$\text{frac}(u_1, u_2) =$

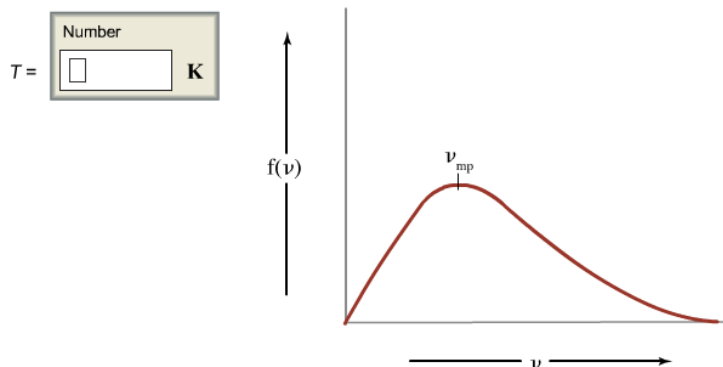
13.

The most probable velocity of a gas molecule,  $v_{mp}$ , is the velocity that the greatest number of gas molecules has at that temperature. Find the temperature of a collection of Kr molecules if 0.290% of the molecules have the most probable velocity.

The following equation gives the fraction of molecules with a given velocity,  $v$ .

$$f(v) = 4\pi \left( \frac{M}{2\pi RT} \right)^{3/2} v^2 e^{-\frac{Mv^2}{2RT}}$$

Where  $T$  is the Kelvin temperature,  $M$  is the molar mass of the gas, and  $R$  is the ideal gas constant.



14.

Which of the following statements are evidence that gases do not always behave ideally? Check all that apply.

- ☐ It is impossible to compress a gas enough so that it takes up no volume.
- ☐ At 4 K and 1 atm, helium is a liquid.
- ☐ CO<sub>2</sub> gas becomes dry ice (solid CO<sub>2</sub>) at 1 atm and  $-78.5^\circ\text{C}$ .
- ☐ When two gases are mixed, they follow Dalton's law of partial pressures.

15.

Use the van der Waals equation of state to calculate the pressure of 2.40 mol of  $\text{CH}_4$  at 451 K in a 5.80 L vessel. Van der Waals constants can be found [here](#).

$P =$   atm

Use the ideal gas equation to calculate the pressure under the same conditions.

$P =$   atm

16. Rank the following ions by their expected hydration energy:  $\text{Ca}^{2+}$ ,  $\text{K}^+$ ,  $\text{Ga}^{3+}$ .

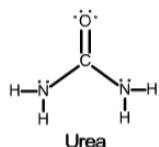
17.

If a solid line represents a covalent bond and a dotted line represents intermolecular attraction, which of these choices shows a hydrogen bond? Check all that apply.

☐  $\text{—C}\cdots\text{H—F—}$   
☐  $\text{—O}\cdots\text{H—C—}$   
☐  $\text{—N}\cdots\text{H—O—}$   
☐  $\text{H—H}$

18.

Urea is an organic compound widely used as a fertilizer. Its solubility in water allows it to be made into aqueous fertilizer solutions and applied to crops in a spray.



What is the maximum theoretical number of water molecules that one urea molecule can hydrogen bond with? (Ignore shape for the purposes of this answer.)

Number  water molecules

*Urea could theoretically form hydrogen bonds with this number of water molecules. (Note, however, that the size and shape of a molecule may limit the number of hydrogen bonds formed by one urea molecule.)*

19.

Match the following properties of liquids to what they indicate about the relative strength of the intermolecular forces in that liquid.

Strong intermolecular forces:

Weak intermolecular forces:

A. high boiling point   B. high surface tension   C. high vapor pressure   D. high viscosity

20. Rank these compounds by boiling point

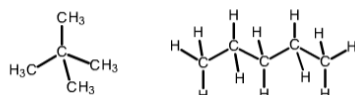
pentane:  $\text{H}_3\text{C}-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_3$

neopentane:  $\begin{array}{c} \text{CH}_3 \\ | \\ \text{H}_3\text{C}-\text{C}-\text{CH}_3 \\ | \\ \text{CH}_3 \end{array}$

hexane:  $\text{H}_3\text{C}-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_3$

21.

The structures of 2,2-dimethylpropane and pentane are shown below.



2,2-dimethylpropane

pentane

Calculate the surface area of each compound, assuming that 2,2-dimethylpropane is approximately spherical with a radius of 254 pm and that pentane is approximately a rectangular prism with dimensions of 295 pm  $\times$  692 pm  $\times$  766 pm.

surface area of  
2,2-dimethylpropane =

Number   $\text{pm}^2$

surface area of pentane =

Number   $\text{pm}^2$

Select the molecule that has the larger surface area.

[Scroll down](#)

2,2-dimethylpropane  
pentane

Select the true statement about the boiling points of these two molecules.

- ☐ 2,2-Dimethylpropane has the higher boiling point because it has the smaller surface area.
- ☐ Pentane has the higher boiling point because it has the larger surface area.
- ☐ Pentane has the higher boiling point because it has the smaller surface area.
- ☐ 2,2-Dimethylpropane has the higher boiling point because it has the larger surface area.

22.

The presence of intermolecular forces in liquids is observed through several different phenomena. Match each phenomenon with its corresponding definition.

capillary  
action

the ability of a liquid to flow up a narrow tube  
unassisted against gravity

cohesion

the attraction between molecules of the same  
substance

meniscus

the curvature of the surface of a liquid at the  
interface with the container

adhesion

the attraction between dissimilar molecules

viscosity

the resistance of a liquid to flow

surface  
tension

the elasticity of the surface layer of a liquid due  
to the liquid trying to minimize its surface area

Correct.

23.

What amount of energy is required to change a spherical drop of water with a diameter of 2.00 mm to four smaller spherical drops of equal size? The surface tension,  $\gamma$ , of water at room temperature is  $72.0 \text{ mJ/m}^2$ .

Number
<input type="text"/>

 mJ

24.

Identify the definition for each of these terms.

Coordination number:

the number of atoms (or ions) surrounding an atom (or ion) in a crystal lattice

Unit cell:

the basic repeating structural unit of a crystalline solid

Crystalline solid:

a solid that possesses long-range order (e.g., table salt)

the number of atoms (or ions) bordering a cavity (or interstice) in a crystal lattice

the smallest dimensions of a crystal that can be measured with a microscope

a solid that lacks regular, three-dimensional arrangement of atoms (e.g., glass)

25. Classify each statement as true or false

If there is an atom present at the corner of a unit cell, there must be the same type of atom at all corners of the unit cell.

If one face of a unit cell has an atom in its center, then the face opposite that face must also have an atom at its center.

A unit cell must be defined so that there are atoms at the corners.

If one face of a unit cell has an atom in its center, all the faces of the unit cell must also have atoms at their centers.

26.

The density of solid Cr is  $7.15 \text{ g/cm}^3$ . How many atoms are present per cubic centimeter of Cr?

Number  
 **atoms /  $\text{cm}^3$**

As a solid, Cr adopts a body-centered cubic unit cell. How many unit cells are present per cubic centimeter of Cr?

Number  
 **unit cells /  $\text{cm}^3$**

What is the volume of a unit cell of this metal?

Number  
  **$\text{cm}^3$**

What is the edge length of a unit cell of Cr?

Number  
 **cm**

Correct

27.

Metals with body-centered cubic (bcc) structures, such as molybdenum, are not close packed. If they were to change to a cubic close-packed (ccp) structure (under pressure, for instance), their densities would be greater. What would the density of molybdenum be if its structure were ccp rather than bcc? Its actual density is  $10.2 \text{ g} \cdot \text{cm}^{-3}$ .

Number  
  **$\text{g} \cdot \text{cm}^{-3}$**

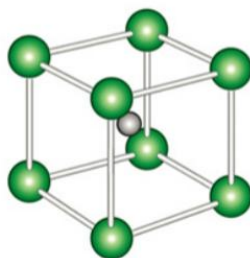
28.

Given that the density of  $\text{CaO(s)}$  is  $3.34 \text{ g/cm}^3$  and that the length of an edge of a unit cell is  $481 \text{ pm}$ , determine how many formula units of  $\text{CaO}$  there are in a unit cell.

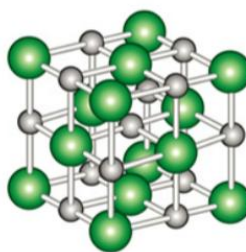
Number  
 **formula units**

Based on your answer above, how is the unit cell of  $\text{CaO(s)}$  likely to be structured?

same as  $\text{NaCl(s)}$   
 same as  $\text{CsCl(s)}$   
 neither



$\text{CsCl(s)}$



$\text{NaCl(s)}$

29.

Calculate the radius ratio for  $\text{NaCl}$  if the ionic radii of  $\text{Na}^+$  and  $\text{Cl}^-$  are  $102 \text{ pm}$  and  $181 \text{ pm}$ , respectively.

Number

Based on the radius ratio above, what is the expected coordination number of  $\text{NaCl}$ ? The range of radius ratios for each coordination number is given in parentheses.

2 ( $< 0.155$ )  
 3 ( $0.155 - 0.225$ )  
 4 ( $0.225 - 0.414$ )  
 6 ( $0.414 - 0.732$ )  
 8 ( $0.732 - 1.000$ )



## Part II. Thermodynamic

1.

A constant-volume calorimeter was calibrated by carrying out a reaction known to release 1.04 kJ of heat in 0.600 L of solution in the calorimeter ( $q = -1.04$  kJ), resulting in a temperature rise of 2.49 °C. In a subsequent experiment, 300.0 mL of 0.40 M  $\text{HClO}_2(\text{aq})$  and 300.0 mL of 0.40 M  $\text{NaOH}(\text{aq})$  were mixed in the same calorimeter and the temperature rose by 6.90 °C. What is the change in the internal energy of the reaction mixture as a result of the neutralization reaction?

$\Delta U =$   **kJ**

2.

A researcher studying the nutritional value of a new candy places a 4.60-gram sample of the candy inside a bomb calorimeter and combusts it in excess oxygen. The observed temperature increase is 3.00 °C. If the heat capacity of the calorimeter is 30.70 kJ · K<sup>-1</sup>, how many nutritional Calories are there per gram of the candy?

**Cal / g**

3.

At constant volume, the heat of combustion of a particular compound, compound A, is -3701.0 kJ/mol. When 1.127 g of compound A (molar mass = 116.13 g/mol) was burned in a bomb calorimeter, the temperature of the calorimeter (including its contents) rose by 6.423 °C.

Using this data, what is the heat capacity (calorimeter constant) of the calorimeter?

**kJ / ° C**

Suppose a 3.083 g sample of a second compound, compound B, was combusted in the same calorimeter, and the temperature rose from 23.89 °C to 27.20 °C.

What is the heat of combustion per gram of compound B?

**kJ / g**

4.

A sample of an ideal gas in a cylinder of volume 4.06 L at 298 K and 2.25 atm expands to 8.89 L by two different pathways. Path A is an isothermal, reversible expansion. Path B has two steps. In the first step, the gas is cooled at constant volume to 1.22 atm. In the second step, the gas is heated and allowed to expand against a constant external pressure of 1.22 atm until the final volume is 8.89 L.

Calculate the work for path A.

$w =$   **J**

Calculate the work for path B.

$w =$   **J**

5.

An 80.0-gram sample of a gas was heated from 25 °C to 225 °C. During this process, 346 J of work was done by the system and its internal energy increased by 6335 J. What is the specific heat of the gas?

**J / (g · ° C)**

6.

macmillan learning

A 0.253 mol sample of  $\text{N}_2(\text{g})$  initially at 298 K and 1.00 atm is held at constant volume while enough heat is applied to raise the temperature of the gas by 18.9 K.

Assuming ideal gas behavior, calculate the amount of heat in joules ( $q$ ) required to affect this temperature change and the total change in internal energy,  $\Delta U$ . Note that some books use  $\Delta E$  as the symbol for internal energy instead of  $\Delta U$ .

Type of gas	Molar heat capacity at constant volume ( $C_{V,m}$ )
atoms	$\frac{3}{2}R$
linear molecules	$\frac{5}{2}R$
nonlinear molecules	$3R$

where  $R$  is the ideal gas constant

$q =$   Number  J  $\Delta U =$   Number  J

7.

The French chemists Pierre L. Dulong and Alexis T. Petit noted in 1819 that the molar heat capacity of many solids at ordinary temperatures is proportional to the number of atoms per formula unit of the solid. They quantified their observations in what is known as Dulong and Petit's rule, which says that the molar heat capacity,  $C_p$ , of a solid can be expressed as

$$C_p = N \cdot 3R$$

where  $N$  is the number of atoms per formula unit and  $R$  is the universal gas constant.

The observed heat capacity per gram of a compound containing thallium and chlorine is  $0.21 \text{ J} \cdot \text{K}^{-1} \cdot \text{g}^{-1}$ . Use Dulong and Petit's rule to determine the empirical formula of the compound.

8.

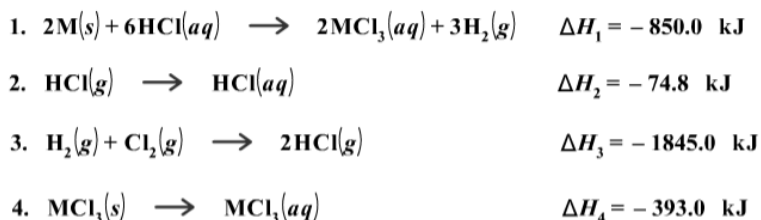
A 0.201-mol sample of  $\text{Xe}(\text{g})$  initially at 298 K and 1.00 atm is held at constant pressure while enough heat is applied to raise the temperature of the gas by 19.3 K. Calculate the amount of heat  $q$  required to bring about this temperature change, and find the corresponding total change in the internal energy  $\Delta U$  of the gas.

Assume that the constant-pressure molar specific heat for  $\text{Xe}(\text{g})$ , which consists of single atoms, is equal to  $5R/2$ , where  $R$  is the ideal gas constant.

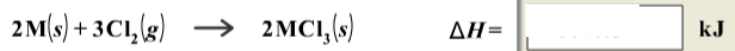
$q =$   Number  J  $\Delta U =$   Number  J

9.

Consider these reactions, where M represents a generic metal.



Use the information above to determine the enthalpy of the following reaction.


 Number  kJ

10.

Many power plants produce energy by burning carbon-based fuels, which also produces carbon dioxide. Carbon dioxide is a greenhouse gas, so over-production can have negative effects on the environment.

Use [enthalpy of formation](#) data to calculate the number of moles of  $\text{CO}_2(g)$  produced per megajoule of heat released from the combustion of each fuel under standard conditions (1 atm and 25 °C).

(a) coal,  $\text{C}(s, \text{graphite})$ ;

Number		$\text{mol} \cdot \text{MJ}^{-1}$
--------	--	-----------------------------------

(b) natural gas,  $\text{CH}_4(g)$ ;

Number		$\text{mol} \cdot \text{MJ}^{-1}$
--------	--	-----------------------------------

(c) propane,  $\text{C}_3\text{H}_8(g)$ ;

Number		$\text{mol} \cdot \text{MJ}^{-1}$
--------	--	-----------------------------------

(d) octane,  $\text{C}_8\text{H}_{18}(l)$  ( $\Delta H_f^\circ = -250.1 \text{ kJ} \cdot \text{mol}^{-1}$ ).

Number		$\text{mol} \cdot \text{MJ}^{-1}$
--------	--	-----------------------------------

11.

The standard internal energy change for a reaction can be symbolized as  $\Delta U_{\text{rxn}}^\circ$  or  $\Delta E_{\text{rxn}}^\circ$ . For the following reaction equations, calculate the energy change of the reaction at 25 °C and 1.00 bar.

Reaction equation	$\Delta H_{\text{rxn}}^\circ (\text{kJ} \cdot \text{mol}^{-1})$	$\Delta U_{\text{rxn}}^\circ$ (also known as $\Delta E_{\text{rxn}}^\circ$ )			
$2\text{H}_2(g) + \text{O}_2(g) \rightarrow 2\text{H}_2\text{O}(l)$	- 571.6	<table border="1"> <tr> <td>Number</td> <td></td> <td><math>\text{kJ} \cdot \text{mol}^{-1}</math></td> </tr> </table>	Number		$\text{kJ} \cdot \text{mol}^{-1}$
Number		$\text{kJ} \cdot \text{mol}^{-1}$			
$\text{H}_2(g) + \text{Cl}_2(g) \rightarrow 2\text{HCl}(g)$	- 184.6	<table border="1"> <tr> <td>Number</td> <td></td> <td><math>\text{kJ} \cdot \text{mol}^{-1}</math></td> </tr> </table>	Number		$\text{kJ} \cdot \text{mol}^{-1}$
Number		$\text{kJ} \cdot \text{mol}^{-1}$			

12.

For the combustion of 1.00 mol of benzene,  $\text{C}_6\text{H}_6$ , at 25 °C and 1.00 bar

Calculate the work that must be done against the atmosphere for the expansion of the gaseous products.

$w =$ 

Number		$\text{kJ}$
--------	--	-------------

Using the enthalpy of formation data [here](#), calculate the standard enthalpy of reaction,  $\Delta H^\circ$ .

$\Delta H^\circ =$ 

Number		$\text{kJ}$
--------	--	-------------

Calculate the change in internal energy,  $\Delta U^\circ$ , of the system.

$\Delta U^\circ =$ 

Number		$\text{kJ}$
--------	--	-------------

13.

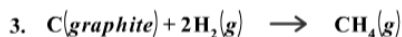
For each of the following reactions, identify another quantity that is equal to  $\Delta H^\circ_{\text{rxn}}$ .



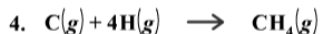
enthalpy of combustion of  $\text{CH}_4$   
enthalpy of formation of  $\text{CO}_2(g)$   
 $4 \times$  bond energy of C–H  
 $-4 \times$  bond energy of C–H



enthalpy of combustion of  $\text{CH}_4$   
enthalpy of formation of  $\text{C}(g)$   
 $4 \times$  bond energy of C–H  
 $-4 \times$  bond energy of C–H



enthalpy of combustion of  $\text{CH}_4$   
enthalpy of formation of  $\text{CH}_4(g)$   
 $4 \times$  bond energy of C–H  
 $-4 \times$  bond energy of C–H



enthalpy of combustion of C  
enthalpy of formation of  $\text{CH}_4(g)$   
 $4 \times$  bond energy of C–H  
 $-4 \times$  bond energy of C–H

14.

Given that

$$\Delta H_f^\circ[\text{Cl}(g)] = 121.3 \text{ kJ} \cdot \text{mol}^{-1}$$

$$\Delta H_f^\circ[\text{C}(g)] = 716.7 \text{ kJ} \cdot \text{mol}^{-1}$$

$$\Delta H_f^\circ[\text{CCl}_4(g)] = -95.7 \text{ kJ} \cdot \text{mol}^{-1}$$

calculate the average molar bond enthalpy of the carbon-chlorine bond in a  $\text{CCl}_4$  molecule.

Number

  $\text{kJ} \cdot \text{mol}^{-1}$ 

15.

Two moles of an ideal gas with a constant-volume molar specific heat of  $26.0 \text{ J} / \text{mol} \cdot \text{K}$  started out at a temperature of  $23.8^\circ\text{C}$  and a pressure of  $5.110 \times 10^4 \text{ Pa}$ . The state of the gas was then changed to a final temperature of  $43.6^\circ\text{C}$  and a final pressure of  $3.810 \times 10^4 \text{ Pa}$ .

What was the change in the entropy of the gas during this process?

Number

  $\text{J} / \text{K}$ 

16.

On the basis of the structures of each of the following molecules, predict which compounds would be most likely to have a residual entropy in their crystalline forms at  $T = 0 \text{ K}$ . Select all that apply.

NO  
 $\text{N}_2\text{O}$   
 $\text{Cl}_2$   
 $\text{CO}_2$

17.

The heat capacity,  $C_p$ , of liquid carbon disulfide is a relatively constant  $78 \text{ J/(mol} \cdot \text{K)}$ . However, the heat capacity of solid carbon disulfide varies greatly with temperature. From  $89 \text{ K}$  to its melting point at  $161 \text{ K}$ , the heat capacity of solid carbon disulfide increases linearly from  $42 \text{ J/(mol} \cdot \text{K)}$  to  $57 \text{ J/(mol} \cdot \text{K)}$ .

The enthalpy of fusion of carbon disulfide is  $\Delta H_{\text{fus}} = 4390 \text{ J/mol}$ .

The absolute entropy of liquid carbon disulfide at  $298 \text{ K}$  is  $S = 151 \text{ J/(mol} \cdot \text{K)}$ .

Estimate the absolute entropy of carbon disulfide at  $89 \text{ K}$ .

$S =$    $\text{J / (mol} \cdot \text{K)}$

18.

At very low temperatures, heat capacity,  $C$ , is directly proportional to  $T^3$  for most substances. Find an expression for the absolute molar entropy,  $S$ , at a low temperature  $T$ , in terms of  $C$ .

$S =$

19.

Calculate the standard molar entropy of vaporization of water at  $39.0^\circ\text{C}$ , given that its standard molar entropy of vaporization at  $100.0^\circ\text{C}$  is  $109.0 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$  and the molar heat capacities at constant pressure for liquid water and water vapor are  $75.3 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$  and  $33.6 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$ , respectively, in this temperature range.

$\Delta S_{\text{vap}}^\circ =$    $\text{J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$

20.

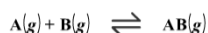
A closed vessel of volume  $2.20 \text{ L}$  contains a mixture of neon and fluorine gas. The total pressure of the mixture in the vessel is  $4.00 \text{ atm}$  at  $0.0^\circ\text{C}$ . When the mixture is heated to  $21.0^\circ\text{C}$ , the entropy of the mixture increases by  $0.521 \text{ J} \cdot \text{K}^{-1}$ . Calculate the number of moles of neon and fluorine in the mixture.

$\text{mol Ne}$

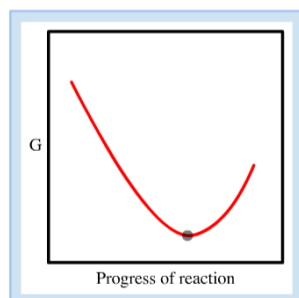
$\text{mol F}_2$

21.

The diagram shows the free energy change of the reaction



The reaction progress starts on the left with pure reactants, A and B, each at  $1 \text{ atm}$  and moves to pure product, AB, also at  $1 \text{ atm}$  on the right. Click on the point of the curve where  $\Delta G = 0$ .



When  $\Delta G = 0$

all of A and B have reacted to give pure AB.  
the reaction is at equilibrium.  
the reaction mixture will shift toward the reactants.  
only the reactants A and B are present.

22.

For a particular reaction,  $\Delta H^\circ$  is -93.8 kJ and  $\Delta S$  is -156.1 J/K. Assuming these values change very little with temperature, over what temperature range is the reaction spontaneous in the forward direction?

The reaction is spontaneous for temperatures

greater than  
less than

$T =$

Number

K

23.

Under standard conditions (298 K and 1 atm), which statement is true?

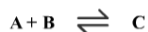
diamond converts to graphite spontaneously  
graphite converts to diamond spontaneously  
none of the above

How can the spontaneity of the reaction be reversed?

increase the temperature  
decrease the temperature  
none of the above

24.

Use the data given here to calculate the values of  $\Delta G^\circ_{\text{rxn}}$  at 25 °C for the reaction described by the equation



Compound	$\Delta G^\circ_f$ (kJ/mol)
A	+387.7
B	+665.0
C	+402.0

$\Delta G^\circ_{\text{rxn}} =$

Number

kJ / mol

If  $\Delta H^\circ_{\text{rxn}}$  and  $\Delta S^\circ_{\text{rxn}}$  are both positive values, what drives the spontaneous reaction and in what direction at standard conditions?

The spontaneous reaction is

entropy-driven to the right.  
enthalpy-driven to the left.  
enthalpy-driven to the right.  
entropy-driven to the left.

25.

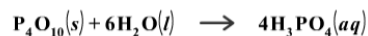
Use the data from this [table](#) of thermodynamic properties to calculate the maximum amount of work that can be obtained from the combustion of 1.00 mole of ethane,  $\text{CH}_3\text{CH}_3(\text{g})$ , at 25 °C and standard conditions.

Number

kJ · mol<sup>-1</sup>

26.

Calculate the standard enthalpy, entropy, and Gibbs free energy at 298 K for the following reaction, using the thermodynamic data in this [table](#).



$$\Delta H_{\text{rxn}}^{\circ} = \text{Number} \text{ kJ} \cdot \text{mol}^{-1}$$

$$\Delta S_{\text{rxn}}^{\circ} = \text{Number} \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$$

$$\Delta G_{\text{rxn}}^{\circ} = \text{Number} \text{ kJ} \cdot \text{mol}^{-1}$$

## Part III. Physical Equilibria

1.

For liquids, which of the following factors affect vapor pressure? Check all that apply.

☒ intermolecular forces
 ☐ temperature
 ☐ surface area
 ☐ humidity
 ☐ volume

2.

Arsine,  $\text{AsH}_3$ , is a highly toxic compound used in the production of semiconductors. At  $-22.75^\circ\text{C}$ , the vapor pressure of  $\text{AsH}_3$  is 58.00 Torr and at  $25.05^\circ\text{C}$  the vapor pressure is 512.0 Torr.

Calculate the standard enthalpy of vaporization,  $\Delta H_{\text{vap}}^{\circ}$ , of arsine.

$$\Delta H_{\text{vap}}^{\circ} = \text{Number} \text{ kJ} / \text{mol}$$

Calculate the standard entropy of vaporization,  $\Delta S_{\text{vap}}^{\circ}$ , of arsine.

$$\Delta S_{\text{vap}}^{\circ} = \text{Number} \text{ J} / (\text{mol} \cdot \text{K})$$

Calculate the standard Gibbs free energy of vaporization,  $\Delta G_{\text{vap}}^{\circ}$ , of arsine.

$$\Delta G_{\text{vap}}^{\circ} = \text{Number} \text{ kJ} / \text{mol}$$

Calculate the normal boiling point temperature,  $T_{\text{B}}$ , of arsine.

$$T_{\text{B}} = \text{Number} ^\circ\text{C}$$

3.

Based on these data,

Solid	Triple point	Normal melting point
A	0.91 atm, 124 °C	108 °C
B	0.35 atm, − 17 °C	50 °C
C	0.0072 atm, 88 °C	89 °C

which solids will melt under applied pressure? Check all that apply.

A

B

C

4.

A solution is made by mixing 50.0 mL of ethanol,  $\text{C}_2\text{H}_6\text{O}$ , and 50.0 mL of water. Assuming ideal behavior, what is the vapor pressure of the solution at 20 °C?

Number  
  
 Torr

Values at 20 °C

Liquid	Density (g/mL)	Vapor Pressure, $P^\circ$ (Torr)
ethanol	0.789	43.9
water	0.998	17.5

5.

1-propanol ( $P_1^\circ = 20.9$  Torr at 25 °C) and 2-propanol ( $P_2^\circ = 45.2$  Torr at 25 °C) form ideal solutions in all proportions.

Let  $x_1$  and  $x_2$  represent the mole fractions of 1-propanol and 2-propanol in a liquid mixture, respectively, and  $y_1$  and  $y_2$  represent the mole fractions of each in the vapor phase.

For a solution of these liquids with  $x_1 = 0.310$ , calculate the composition of the vapor phase at 25 °C.

$y_1 =$ 

Number

$y_2 =$ 

Number

6.

At 25 °C and 775 Torr, carbon dioxide has a solubility of 0.0347 M in water. What is its solubility at 25 °C and 1410 Torr?

Number  
  
 M



7.

At 298 K, the Henry's law constant for oxygen is 0.00130 M/atm. Air is 21.0% oxygen.

At 298 K, what is the solubility of oxygen in water exposed to air at 1.00 atm?

Number
<input type="text"/>
M

At 298 K, what is the solubility of oxygen in water exposed to air at 0.893 atm?

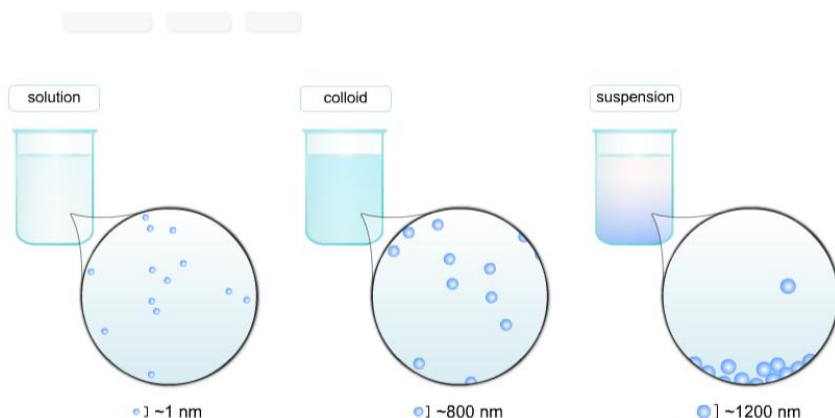
Number
<input type="text"/>
M

If atmospheric pressure suddenly changes from 1.00 atm to 0.893 atm at 298 K, how much oxygen will be released from 3.00 L of water in an unsealed container?

Number
<input type="text"/>
mol

8.

The following animations depict the movement of solid particles in a liquid. Label each mixture as a colloid, suspension, or true solution.



9.

What is the mole fraction,  $X$ , of solute and the molality,  $m$  (or  $b$ ), for an aqueous solution that is 17.0% NaOH by mass?

mole fraction	molality
Number	Number
$X =$ <input type="text"/>	$m =$ <input type="text"/>
	$m$

10.

a. Calculate the molality of chloride ions in an aqueous solution of magnesium chloride in which the mole fraction of magnesium chloride is 0.0700.

Number
<input type="text"/>
$m$

b. Calculate the molality of 6.95 g of sodium hydroxide dissolved in  $3.30 \times 10^2$  g of water.

Number
<input type="text"/>
$m$

c. Calculate the molality for 1 L of a 1.50 M HCl aqueous solution that has a density of  $1.0745 \text{ g} \cdot \text{cm}^{-3}$ .

Number
<input type="text"/>
$m$

11.

Vitamin K is involved in normal blood clotting.

When 1.47 g of vitamin K is dissolved in 25.0 g of camphor, the freezing point of the solution is lowered by 4.94 °C. The freezing point and  $K_f$  constant for camphor can be found [here](#).

Calculate the molar mass of vitamin K.

Number  
 g / mol

12.

At -11.5 °C (a common temperature for household freezers), what is the maximum mass of sucralose ( $C_{12}H_{19}Cl_3O_8$ ) you can add to 2.50 kg of pure water and still have the solution freeze? Assume that sucralose is a molecular solid and does not ionize when it dissolves in water.  $K_f$  values are given [here](#).

Number  
 g

13.

Imagine two solutions with the *same concentration* and the *same boiling point*, but one has ethanol as the solvent and the other has carbon tetrachloride as the solvent. Determine that molal concentration,  $m$  (or  $b$ ), and boiling point,  $T_b$ .

$m =$    $m$

$T_b =$   °C

Solvent	Normal boiling point (°C)	$K_b$ (°C/m)
ethanol	78.4	1.22
carbon tetrachloride	76.8	5.03

14.

Assuming 100% dissociation, calculate the freezing point and boiling point of 1.96  $m$   $\text{SnCl}_4(aq)$ . Constants may be found [here](#).

$T_f =$   °C

$T_b =$   °C

15.

When 3.06 g of a nonelectrolyte solute is dissolved in water to make 395 mL of solution at 23 °C, the solution exerts an osmotic pressure of 819 torr.

What is the molar concentration of the solution?

Number  
 M

How many moles of solute are in the solution?

Number  
 mol

What is the molar mass of the solute?

Number  
 g / mol

16.

What is the minimum pressure in kPa that must be applied at 25 °C to obtain pure water by reverse osmosis from water that is 0.216 M in sodium chloride and 0.098 M in zinc sulfate? Assume complete dissociation for electrolytes.

Number
<input type="text"/> kPa

17.

In reverse osmosis, water flows out of a salt solution until the osmotic pressure of the solution equals the applied pressure. If a pressure of 43.0 bar is applied to seawater, what will be the final concentration of the seawater at 20 °C when reverse osmosis stops?

Number
<input type="text"/> M <sub>c</sub>

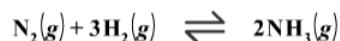
Assuming that seawater has a total ion concentration (a.k.a colligative molarity) of 1.10 M<sub>c</sub>, calculate how many liters of seawater are needed to produce 49.7 L of fresh water at 20 °C with an applied pressure of 43.0 bar.

Number
<input type="text"/> L

## Part IV. Chemical Equilibrium

1.

For a gaseous reaction, standard conditions are 298 K and a partial pressure of 1 bar for all species. For the reaction



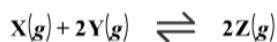
the *standard* change in Gibbs free energy is  $\Delta G^\circ = -32.8$  kJ/mol. What is  $\Delta G$  for this reaction at 298 K when the partial pressures are

$P_{\text{N}_2} = 0.100$  bar,  $P_{\text{H}_2} = 0.100$  bar, and  $P_{\text{NH}_3} = 0.950$  bar

Number
$\Delta G =$ <input type="text"/> kJ / mol

2.

At 385 K, this reaction has a  $K_c$  value of 0.0496.

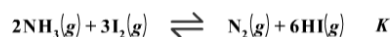


Calculate  $K_p$  at 385 K.

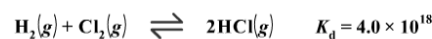
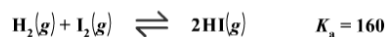
Number
$K_p =$ <input type="text"/>

3.

Consider the reaction of  $\text{NH}_3$  and  $\text{I}_2$  to give  $\text{N}_2$  and  $\text{HI}$ .



Using two or more of the equations below, determine the equilibrium constant,  $K$ , for the reaction of  $\text{NH}_3$  with  $\text{I}_2$ .

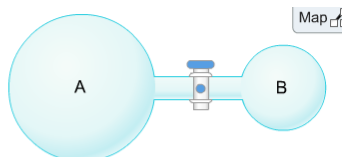


$K =$

4.

Consider an apparatus in which A and B are two flasks joined by a stopcock. The volume of flask A is 3.25 L, the volume of flask B is 2.00 L, and the volume of the stopcock is negligible. Initially, A and B are evacuated, the stopcock is closed, and 3.30 g of diethyl ether,  $\text{C}_2\text{H}_5\text{OC}_2\text{H}_5$ , is introduced into flask A.

The vapor pressure of diethyl ether is 57 Torr at  $-45^\circ\text{C}$ , 185 Torr at  $0^\circ\text{C}$ , 534 Torr at  $25^\circ\text{C}$ , and negligible below  $-86^\circ\text{C}$ .



a. If the stopcock is left closed and the flask is brought to equilibrium at  $-45^\circ\text{C}$ , what will be the pressure of diethyl ether in flask A? Assume ideal behavior.

 Torr

b. If the temperature is raised to  $25^\circ\text{C}$ , what will be the pressure of diethyl ether in flask A? Assume ideal behavior.

 Torr

c. If the temperature of the assembly is returned to  $-45^\circ\text{C}$  and the stopcock is opened, what will be the pressure of diethyl ether in the apparatus? Assume ideal behavior.

 Torr

Scroll down.

d. If flask A is maintained at  $-45^\circ\text{C}$  and flask B is cooled with liquid nitrogen (boiling point,  $-196^\circ\text{C}$ ) with the stopcock open, what will be the vapor pressure of diethyl ether in the apparatus? Assume ideal behavior.

 Torr

Correct.