Efnafræðifélag Íslands
The Icelandic Chemical Society

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# 19. General national chemistry competition

## for high school students

**Wednesday February 19, 2020**

**time: 8-10 (120 min.)**

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HÁSKÓLI ÍSLANDS

TANDUR
- þegar hreinlæti skiptir máli

**Háskóli Íslands**

**Tandur hf**

# 19. Chemistry competition

February 19 2020

**Name:** ______________________________

**Kennitala:** ______________________________

**Phone number:** ______________________________

**Email:** ______________________________

**School:** ______________________________

**Year of study:** 1st year 2nd year 3rd year 4th year

**General instructions**

1. 1 This booklet contains 21 questions on 15 enumerated pages, as well as a formula sheet and a periodic table. make sure that you have all the pages.
   The first 10 questions give 3 points each, the next 8 give 5 points each and finally, the last 3 questions give 10 points each.
2. 2 Your results and answers must be written in the exam papers (this booklet). Answers on on scratch papers will not be graded.
3. There will be no negative marking for wrong answers.
4. 4 You are only allowed to use a non-programmable calculators and the next two pages, which include formulas, constants and the periodic table. You may tear the formula sheets from the project.
5. In the multiple choice questions, there is only one correct answer to each question.
6. Some of the questions are in several sections. If any section is answered incorrectly and the answer is used in subsequent sections there will not be deducted any points in the later sections as long as the calculations are correct.

# Formulas and constants

| | | |
|---|---|---|
| $\Delta G = \Delta H - T\Delta S$ | $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ | $\Delta G = \Delta G^\circ + RT\ln Q$ |
| $\Delta x = \sum_{mynd} x - \sum_{hvarf} x$ | $p = \sum_i p_i$ | $[\mathrm{H_3O^+}] = \frac{K_a}{2}\left(-1 + \sqrt{1 + \frac{4C_0}{K_a}}\right)$ |
| $k = Ae^{-\frac{E_a}{RT}}$ | $\ln\left(\frac{k_1}{k_2}\right) = -\frac{E_a}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$ | $E = E^\circ - \frac{RT}{nF}\ln Q$ |
| $\Delta G^\circ = -RT\ln K = -nFE^\circ$ | $q = C\Delta T$ | $q = mc\Delta T$ |
| $pH = -\log[\mathrm{H_3O^+}]$ | $pK_a = -\log K_a$ | $pH = pK_a + \log\frac{[A^-]}{[HA]}$ |
| $A = \epsilon bc$ | $PV = nRT$ | $E = \frac{hc}{\lambda}$ |
| $N_A = 6.0223 \cdot 10^{23}\mathrm{mól}^{-1}$ | $F = 96485\frac{\mathrm{C}}{\mathrm{mól}\ e^-}$ | $T_K = T_{^\circ\mathrm{C}} + 273.15$ |
| $1\mathrm{atm} = 760\mathrm{torr} = 101325\mathrm{Pa}$ | $K_w = 1.00 \cdot 10^{-14}$ | $1\mathrm{bar} = 10^5\mathrm{Pa} = 0.9869\mathrm{atm}$ |
| $h = 6.626 \cdot 10^{-34}\mathrm{J}\cdot\mathrm{s}$ | $c = 3 \cdot 10^8\mathrm{m/s}$ | $R = 8.3144\frac{\mathrm{J}}{\mathrm{K\cdot mól}} = 0.08206\frac{\mathrm{L\cdot atm}}{\mathrm{K\cdot mól}}$ |
| $A = A_0 \cdot e^{-kt}$ | $1\mathrm{J} = 1\mathrm{kg}\cdot\mathrm{m}^2\cdot\mathrm{s}^{-2}$ | $1\ \mathrm{calorie} = 4.184\mathrm{J}$ |
| $ax^2 + bx + c = 0 \Rightarrow x = \frac{-b\pm\sqrt{b^2-4ac}}{2a}$ | | |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 **H** hydrogen 1,008 | | | | | | | | | | | | | | | | | 2 **He** helium 4,003 |
| 3 **Li** lithium 6,941 | 4 **Be** beryllium 9,012 | | | | | | | | | | | 5 **B** boron 10,81 | 6 **C** carbon 12,01 | 7 **N** nitrogen 14,01 | 8 **O** oxygen 16,00 | 9 **F** fluorine 19,00 | 10 **Ne** neon 20,18 |
| 11 **Na** sodium 22,99 | 12 **Mg** magnesium 24,31 | | | | | | | | | | | 13 **Al** aluminum 26,98 | 14 **Si** silicon 28,09 | 15 **P** phosphorus 30,97 | 16 **S** sulfur 32,07 | 17 **Cl** chlorine 35,45 | 18 **Ar** argon 39,95 |
| 19 **K** potassium 39,10 | 20 **Ca** calcium 40,08 | 21 **Sc** scandium 44,96 | 22 **Ti** titanium 47,88 | 23 **V** vanadium 50,94 | 24 **Cr** chromium 52,00 | 25 **Mn** manganese 54,94 | 26 **Fe** iron 55,85 | 27 **Co** cobalt 58,93 | 28 **Ni** nickel 58,69 | 29 **Cu** copper 63,55 | 30 **Zn** zinc 65,39 | 31 **Ga** gallium 69,72 | 32 **Ge** germanium 72,61 | 33 **As** arsenic 74,92 | 34 **Se** selenium 78,96 | 35 **Br** bromine 79,90 | 36 **Kr** krypton 83,80 |
| 37 **Rb** rubidium 85,47 | 38 **Sr** strontium 87,62 | 39 **Y** yttrium 88,91 | 40 **Zr** zirconium 91,22 | 41 **Nb** nubidium 92,91 | 42 **Mo** molybdenum 95,94 | 43 **Tc** technetium (98) | 44 **Ru** ruthenium 101,1 | 45 **Rh** rhodium 102,9 | 46 **Pd** palladium 106,4 | 47 **Ag** silver 107,9 | 48 **Cd** cadmium 112,4 | 49 **In** indium 114,8 | 50 **Sn** tin 118,7 | 51 **Sb** antimony 121,8 | 52 **Te** tellurium 127,6 | 53 **I** iodine 126,9 | 54 **Xe** xenon 131,3 |
| 55 **Cs** caesium 132,9 | 56 **Ba** barium 137,3 | 71 **Lu** lutetium 175,0 | 72 **Hf** hafnium 178,5 | 73 **Ta** tantalum 180,9 | 74 **W** tungsten 183,8 | 75 **Re** rhenium 186,2 | 76 **Os** osmium 190,2 | 77 **Ir** iridium 192,2 | 78 **Pt** platinum 195,1 | 79 **Au** gold 197,0 | 80 **Hg** mercury 200,6 | 81 **Tl** thallium 204,4 | 82 **Pb** lead 207,2 | 83 **Bi** bismuth 209,0 | 84 **Po** polonium (209) | 85 **At** astatine (210) | 86 **Rn** radon (222) |
| 87 **Fr** francium (223) | 88 **Ra** radium 226 | 103 **Lr** lawrencium (262) | 104 **Rf** rutherfordium (261) | 105 **Db** dubnium (262) | 106 **Sg** seaborgium (266) | 107 **Bh** bohrium (264) | 108 **Hs** hassium (269) | 109 **Mt** meitnerium (268) | 110 **Ds** darmstadtium (281) | 111 **Rg** roentgenium (272) | 112 **Cn** copernicium (285) | 113 **Uut** ununtrium | 114 **Fl** flerovium (289) | 115 **Uup** ununpentium | 116 **Lv** livermorium (293) | 117 **Uus** ununseptium | 118 **Uuo** ununoctium |
| | | | | 57 **La** lanthanum 138,9 | 58 **Ce** cerium 140,1 | 59 **Pr** praseodymium 140,9 | 60 **Nd** neodymium 144,2 | 61 **Pm** promethium (145) | 62 **Sm** samarium 150,4 | 63 **Eu** europium 152,0 | 64 **Gd** gadolinium 157,3 | 65 **Tb** terbium 158,9 | 66 **Dy** dysprosium 162,5 | 67 **Ho** holmium 164,9 | 68 **Er** erbium 167,3 | 69 **Tm** thulium 168,9 | 70 **Yb** ytterbium 173,0 |
| | | | | 89 **Ac** actinium (227) | 90 **Th** thorium 232,0 | 91 **Pa** protactinium 231,0 | 92 **U** uranium 238,0 | 93 **Np** neptunium (237) | 94 **Pu** plutonium (244) | 95 **Am** americium (243) | 96 **Cm** curium (247) | 97 **Bk** berkelium (247) | 98 **Cf** californium (251) | 99 **Es** einsteinium (252) | 100 **Fm** fermium (257) | 101 **Md** mendelevium (258) | 102 **No** nobelium (259) |

# Part I - 3 point questions

### Question 1

Which one of the following elements is an alkaline earth metal?

- ☐ Zink (Zn)
- ☐ Silver (Ag)
- ☐ Magnesium (Mg)
- ☐ Lithium (Li)
- ☐ Nickel (Ni)

### Question 2

Valgerður the scientist must pour 20.0 mL of strong acid into her solution. The acid is stored in a large glass bottle. How should Valgerður measure the volume she needs?

- ☐ Pour from the bottle into a beaker and read from the scale.
- ☐ Pipette from the bottle into her solution.
- ☐ Pour from the bottle into a beaker and from the beaker into a graduated cylinder.
- ☐ Pour from the bottle straight into the solution.
- ☐ Pour from the bottle into a volumetric flask and fill up to the line with deionised water.

### Question 3

Aluminum in the Earth is mostly on the form of alumina. Another name for alumina is aluminum oxide. What is the chemical formula for aluminum oxide?

- ☐ $Al_2O$
- ☐ $Al_3O_2$
- ☐ $AlO_3$
- ☐ $Al_2O_3$
- ☐ $Al_2O$

## Question 4

Guttormur the bull is probably the most loved Icelandic bull of all time. Icelanders loved it so much that some argued that it was worth its weight in gold. When Guttormur was at his heaviest he weighed 942 kg. How many moles of gold (Au) was Guttormur worth?

- ☐ 4780 moles
- ☐ $1.86 \cdot 10^8$ moles
- ☐ $1.86 \cdot 10^5$ moles
- ☐ 4.78 moles
- ☐ $2.09 \cdot 10^{-4}$ moles

## Question 5

Mercury (Hg) is the only metal that is in liquid phase at room temperature. When this metal reacts with chlorine it produced $HgCl_2$ which is, on the other hand, a solid at room temperature.
What is the number of protons (p), neutrons (n) and electrons (e) in the mercury ion $^{200}Hg^{2+}$ in the $HgCl_2$?

- ☐ 80 p, 120 n, 80 e
- ☐ 80 p, 120 n, 82 e
- ☐ 78 p, 200 n, 78 e
- ☐ 80 p, 120 n, 78 e
- ☐ 82 p, 200 n, 78 e

## Question 6

Gunnar wants to prepare a buffer solution with pH around 4.7. What two substances could he mix together to achieve such a solution?

- ☐ HCl and NaOH
- ☐ Acetic acid ($CH_3COOH$) and HCl
- ☐ $NH_3$ and NaOH
- ☐ NaCl and NaOH
- ☐ Acetic acid ($CH_3COOH$) and NaOH

**Question 7**

Electromagnetic rays that have energies between $6.63 \cdot 10^{-17}$ J and $6.63 \cdot 10^{-15}$ J are classified as X-rays. What is the lowest and highest possible wavelenght of an X-ray?

- ☐ 0.03 and 3.00 nm
- ☐ $1.00 \cdot 10^{17}$ and $1.00 \cdot 10^{19}$ nm
- ☐ 0.03 and 3.00 m
- ☐ 450 and 700 nm
- ☐ 3.00 and 300 nm

**Question 8**

Fire extinguishers contain carbon dioxide ($CO_2$) under high pressure which causes it to be on a liquid state, but when it is sprayed out of the extinguisher it turns into gas. 5 L fire extinguisher contains 2.00 kg af $CO_2$. What will the volume of the gas be at 25 °C and 1.00 atm once all the substance in the extinguisher has been sprayed out?

- ☐ 93.3 L
- ☐ $9.50 \cdot 10^{3}$ L
- ☐ $1.12 \cdot 10^{5}$ L
- ☐ $1.11 \cdot 10^{3}$ L
- ☐ 473 L

**Question 9**

The following reaction is exothermic. Which change will shift the equilibrium to the right?

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

- ☐ Raising the temperature
- ☐ Adding $SO_2$
- ☐ Removing $O_2$
- ☐ All of the above
- ☐ None of the above

### Question 10

Iceland spar is a mineral called "silver rock" in Icelandic. Despite the name, Iceland spar does not contain any silver. It is pure crystallized calcium carbonate ($CaCO_3$). In order to be classified as a crystal, the crystal must have at least $1 \cdot 10^{14}$ $CaCO_3$ units. What is the lowest possible mass of Iceland spar so that it can be classified as a crystal?

- ☐ 11.31 ng
- ☐ 16.62 ng
- ☐ 11.31 g
- ☐ $6.809 \cdot 10^{15}$ g
- ☐ $1.001 \cdot 10^{16}$ g

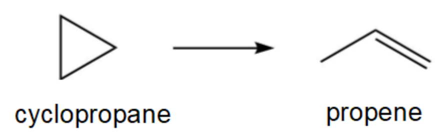
## Part II - 5 point questions

### Question 11

A buffer solution is 0.100 M $CH_3COONa$ and 0.100 M $CH_3COOH$. 12.36 mL of 0.134 M HCl was added to 25.00 mL of the solution. What is the pH after the addition? $pK_a(CH_3COOH) = 4.76$.

- ☐ 4.07
- ☐ 4.29
- ☐ 4.76
- ☐ 5.07
- ☐ 5.23

### Question 12




Kinetic measurements were done on the transformation of cyclopropane to propene. The values of the rate constant were collected at different temperatures. Two measurements were used to determine the activation energy of the reaction. At 750 K the rate constant was $k = 0.00018\ s^{-1}$ and at 850 K the rate constant was $k = 0.030\ s^{-1}$. What is the activation energy for the reaction?

- ☐ $6.7 \cdot 10^{-3}$ J/mól
- ☐ 17 kJ/mól
- ☐ 33 kJ/mól
- ☐ $1.2 \cdot 10^{2}$ kJ/mól
- ☐ $2.7 \cdot 10^{2}$ kJ/mól

## Question 13

The mass percent of oxygen (O) in the human body is 65%, but the atomic percent is 24%. What is the total number of all atoms in a human body which weighs 62 kg?

- [ ] $6.32 \cdot 10^{30}$ atoms
- [ ] $1.62 \cdot 10^{30}$ atoms
- [ ] $6.32 \cdot 10^{27}$ atoms
- [ ] $1.62 \cdot 10^{27}$ atoms
- [ ] $1.52 \cdot 10^{27}$ atoms

## Question 14

Consider the following reaction

$$Al_2S_3(s) + 6H_2O(l) \rightarrow 2Al(OH)_3(s) + H_2S(g)$$

What amount of $Al_2S_3$ remains after the reaction of 0.133 mol $Al_2S_3$ and 0.111 mol $H_2O$?

- [ ] 17.2 g
- [ ] 28.3 g
- [ ] 14.0 g
- [ ] 8.33 g
- [ ] 19.8 g

## Question 15

When sulfite reacts with permanganate the following oxidation-reduction reaction takes place:

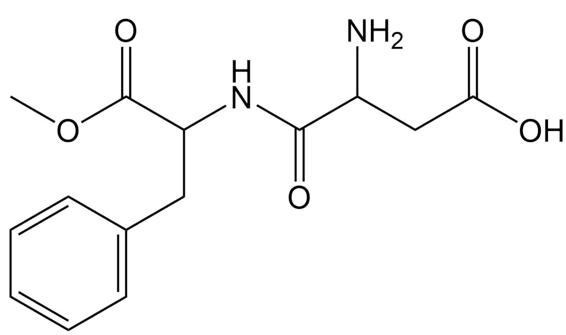
$$SO_3^{2-} + MnO_4^{-} \rightarrow SO_4^{2-} + MnO_2$$

Write the balanced equation for the raction when it takes place in a basic solution.

Balanced chemical equation:________________________________________

## Question 16

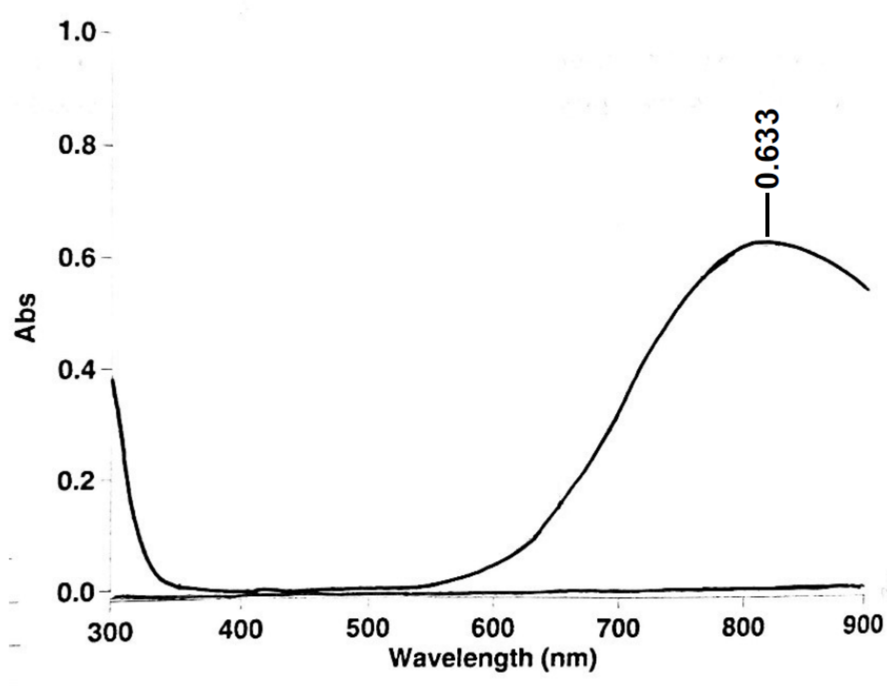
Aspartame is a sweetener which is 200 times sweeter than sugar. There are five functional groups in an aspartame molecule. **Draw circle** around these functional groups and write their names.




Aspartame

## Question 17

The concentration of solutions can be determined by using spectroscopy. Fanney chemistry student measured the absorbance of a $CuCl_2$ solution, in order to determine the concentration of $Cu^{2+}$ in the solution. The graph below shows the absorbance (Abs) of the solution as a function of wavelength. At the maximum absorbance the extinction coefficient was $\epsilon = 12.39 \frac{\text{L}}{\text{mol·cm}}$.




a) Use Beer's law ($A = \epsilon bc$) to calculate the molarity of $Cu^{2+}$ in the solution.

$C_{Cu^{2+}} =$ ____________________ M

b) What is the electron configuration of the $Cu^{2+}$ ion?

## Question 18

Gunnar the chemist is interested in kinetics and decided to study the following reaction:

$$2HgCl_2(aq) + C_2O_4^{2-}(aq) \rightarrow 2Cl^-(aq) + 2CO_2(g) + Hg_2Cl_2(s)$$

He measured the initial rate of the reaction with different initial concentrations of $HgCl_2$ and $C_2O_4^{2-}$ and gathered the following results:

| Measurement | $[HgCl_2]$ [M] | $[C_2O_4^{2-}]$ [M] | Initial rate [mol $L^{-1}min^{-1}$] |
|---|---|---|---|
| 1 | 0.105 | 0.15 | $1.8 \cdot 10^{-5}$ |
| 2 | 0.052 | 0.30 | $7.1 \cdot 10^{-5}$ |
| 3 | 0.052 | 0.15 | $8.9 \cdot 10^{-6}$ |

The rate law of the reaction has the form

$$\text{rate} = k[HgCl_2]^a[C_2O_4^{2-}]^b$$

Determine the values of $a$ and $b$ in the kinetic equation.

$a =$ ____________________

$b =$ ____________________

## Part III - 10 point questions

**Question 19 Methanol**

Methanol ($CH_3OH$) is used as a substitute for gasoline in some vehicles. To design engines that will run on methanol, we must understand its thermochemistry

Standard enthalpy of formation for a few substances are given in the following table

| Substance | $\Delta H_f^o$ [kJ/mol] |
| --- | --- |
| $CH_3OH(l)$ | −238.66 |
| $CH_3OH(g)$ | −200.66 |
| $CO_2(g)$ | −393.51 |
| $CO_2(aq)$ | −413.80 |
| $H_2O(l)$ | −285.83 |
| $H_2O(g)$ | −241.82 |

a) The methanol in an automobile engine must be in the gas phase before it can react. Calculate the heat (in kJ) that must be added to 1.00 kg liquid methanol to increase its temperature from 25.0 °C to its boiling point, 65.0 °C. The molar heat capacity of liquid methanol is 81.6 J $K^{-1}$ $\text{mól}^{-1}$.

$q =$ ______________________ kJ

b) Calculate the heat that must be added to vaporize 1.00 kg of methanol. The molar enthalpy of vaporization for methanol is 38 kJ $\text{mól}^{-1}$.

$q =$ ______________________ kJ

c) Once it is in the vapor phase, the methanol can react with oxygen in the air according to

$$CH_3OH(g) + \frac{3}{2}O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

Calculate the heat of cumbustion of methanol (in kJ/mol), that is, calculate $\Delta H^o$ for the reaction.

$\Delta H^o =$ ____________________ $\frac{\text{kJ}}{\text{mol}}$

d) Calculate the heat released when 1.00 kg of gaseous methanol is burned in air at constant pressure.

$q =$ ____________________ kJ

e) Suppose that the methanol is burned inside the cylinder of an automobile. Taking the radius of the cylinder to be 4.0 cm and the distance moved by the piston during one stroke to be 12 cm. The work done by the gas is called work ($w$) and is given by $w = -P\Delta V$, where $P$ is the external pressure and $\Delta V$ is the volume change. Calculate the work done (in J) per stroke as the gas expands against an external pressure of 1.00 atm. ($1 \text{ L} \cdot \text{atm} = 101.3$ J and the volume of a cylinder is $\pi r^2 h$).

$w =$ ____________________ J

## Question 20 Equilibrium constant

Air pollution contains, among other substances, NO, $NO_2$ and $SO_2$. These substances are released to the atmosphere when oil is burned. The equilibrium constants for the following reactions are known at 25 °C:

$$SO_2(g) + \frac{1}{2}O_2(g) \rightleftharpoons SO_3(g) \qquad K_{c1} = 2{,}2 \qquad (1)$$

$$NO(g) + \frac{1}{2}O_2(g) \rightleftharpoons NO_2(g) \qquad K_{c2} = 0{,}25 \qquad (2)$$

The equilibrium constant, $K_c$, for the reaction of $SO_2$ with $NO_2$, is unknown.

$$SO_2(g) + NO_2(g) \rightleftharpoons SO_3(g) + NO(g) \qquad K_c = ? \qquad (3)$$

a) Use the information given for equations (1) and (2) to determine the value of the equilibrium constant for reaction (3) at 25 °C.

$K_c$ = ______________________

b) $K_p$ and $K_c$ have a known relation of $K_p = K_c(RT)^{\Delta n}$, where $\Delta n$ is the change in number of gaseous molecules in the chemical equation. Calculate the equilibrium constant $K_p$ for reaction (3) at 25 °C. If you could not solve part a), then use the value $K_c = 10$.

$K_p$ = ______________________

c) $SO_2$ and $NO_2$ was put into an empty reaction vessel at 25 °C and allowed to reach equilibrium. At equilibrium the partial pressures of the substances were measured as follows:

| Substance | Partial pressure, $P_i$ |
|---|---|
| $SO_2$ | 0.2 atm |
| $NO_2$ | 0.15 atm |
| $SO_3$ | 0.3 atm |

Calculate the partial pressure of NO at equilibrium. If you could not solve part b), then use the value $K_p = 12$.

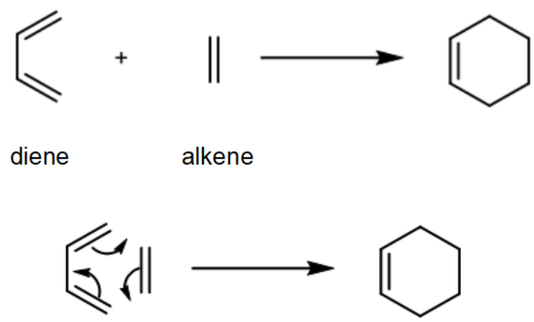
$P_{NO}$ = ____________________ atm

d) Again, $SO_2$ and $NO_2$, was put into an empty reaction vessel at 25 °C. The initial pressure of $SO_2$ was 0.20 atm and the initial pressure of $NO_2$ was 0.10 atm. Calculate the partial pressure of NO when the reaction has reached equilibrium. If you could not solve part b), then use the value $K_p = 12$.

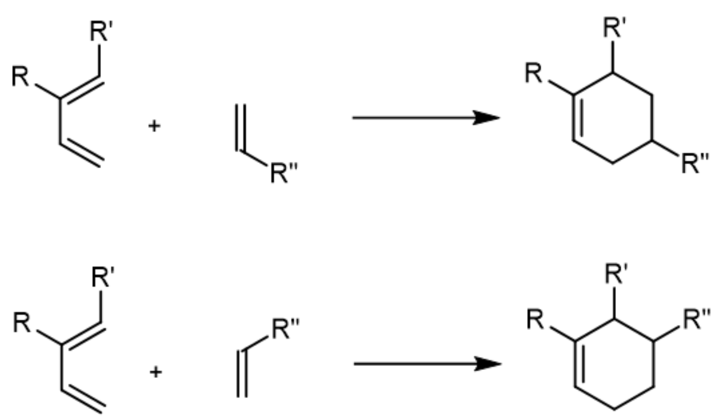
$P_{NO}$ = ____________________ atm

## Question 21 Organic Chemistry

In organic chemistry the Diels-Alder reaction is an important way to synthesize ring structures. One of the starting materials in the reaction is a diene, a chemical that has conjugated double bonds. The diene reacts with another double bond to form a ring. The mechanism for the reaction is shown below. The curved arrows show the movement of electrons during the reaction.

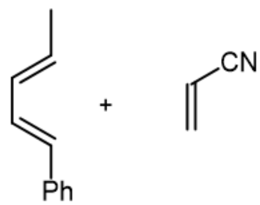



If the diene or the other alkene have any side groups (R) they stay relative to each other as shown below.

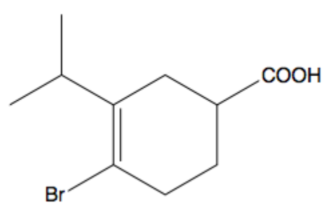



As you can see, the alkene can react with the diene in two possible ways, depending on how the alkene is flipped.

a) What two products can be formed when the following molecules react? Draw the products.




Compound **A** was synthesized with the Diels-Alder reaction.




**A**

b) Draw the two compounds that were used to synthesize compound **A**.

c) What is the name of compound **A** according to the IUPAC naming system?