Efnafræðifélag Íslands
The Icelandic Chemical Society

20th General National Chemistry Competition

for high school students

Thursday February 25, 2021

Time: 8-10 (120 min)

HÁSKÓLI ÍSLANDS

TANDUR
- þegar hreinlæti skiptir máli

University of Iceland

Tandur hf

20TH GENERAL NATIONAL CHEMISTRY COMPETITION

FEBRUARY 25, 2021

Name: _____

Kennitala: _____

Phone number: _____

Email: _____

School: _____

General instructions

1. This booklet contains 21 questions on 16 numbered pages, as well as a cover page, a formula sheet and the periodic table. Make sure that you have all of 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. Your results and answers must be written on the exam papers (this booklet). Answers on scratch papers will not be graded.

3. There will be no point deduction for wrong answers.

4. The only support materials allowed are a non-programmable calculator and the next two pages, which include formulas, constants and the periodic table. You may tear the formula sheets from the booklet.

5. There is only one correct answer in each multiple choice questions.

6. Some of the questions are in several parts. If any part is answered incorrectly and the answer is used in subsequent parts, no points will be deducted for the later parts as long as the calculations are correct.

Some formulas and constants

$\Delta G = \Delta H - T\Delta S$

$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$

$\Delta G = \Delta G^\circ + RT\ln Q$

$k = Ae^{-\frac{E_a}{RT}}$

$\ln\left(\frac{k_1}{k_2}\right) = -\frac{E_a}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$

$E = E^\circ - \frac{RT}{nF}\ln Q$

$\Delta G^\circ = -RT\ln K = -nFE^\circ$

$q = C\Delta T$

$q = mc\Delta T$

$pH = -\log[\mathrm{H_3O^+}]$

$pK_a = -\log K_a$

$pH = pK_a + \log\frac{[A^-]}{[HA]}$

$A = \epsilon bc$

$PV = nRT$

$E = \frac{hc}{\lambda}$

$N_A = 6{,}0223 \cdot 10^{23}\mathrm{mól}^{-1}$

$F = 96485\frac{\mathrm{C}}{\mathrm{mól}\ e^-}$

$T_K = T_{^\circ\mathrm{C}} + 273{,}15$

$1\mathrm{atm} = 760\mathrm{torr} = 101325\mathrm{Pa}$

$K_w = 1{,}00 \cdot 10^{-14}$

$1\mathrm{bar} = 10^5\mathrm{Pa} = 0{,}9869\mathrm{atm}$

$h = 6{,}626 \cdot 10^{-34}\mathrm{J}\cdot\mathrm{s}$

$c = 3 \cdot 10^8\mathrm{m/s}$

$R = 8{,}3144\frac{\mathrm{J}}{\mathrm{K}\cdot\mathrm{mól}} = 0{,}08206\frac{\mathrm{L}\cdot\mathrm{atm}}{\mathrm{K}\cdot\mathrm{mól}}$

$A = A_0 \cdot e^{-kt}$

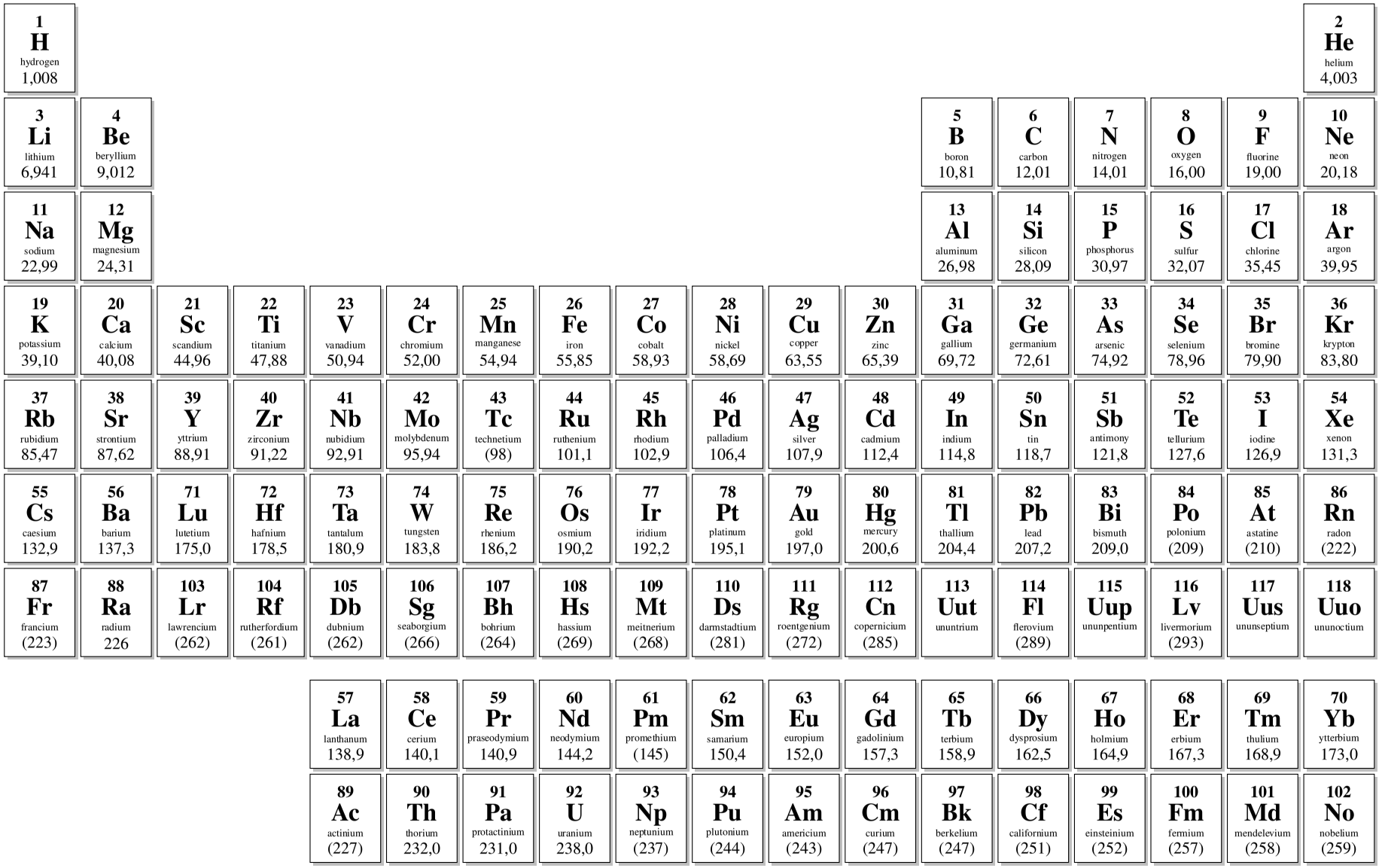
$1\mathrm{J} = 1\mathrm{kg}\cdot\mathrm{m}^2\cdot\mathrm{s}^{-2}$

1 kaloría $= 4{,}184\mathrm{J}$

$ax^2 + bx + c = 0 \Rightarrow x = \frac{-b \pm \sqrt{b^2-4ac}}{2a}$

$I = \frac{Q}{t}$

$\pi = icRT$


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 of the following is **NOT** a chemical mixture?

- [ ] Petrol
- [ ] Sea Water
- [ ] Iron
- [ ] Air
- [ ] Sand

Question 2

Which element has the electron configuration [Ar]$4s^2 3d^3$?

- [ ] Calcium (Ca)
- [ ] Arsenic (As)
- [ ] Niobium (Nb)
- [ ] Scandium (Sc)
- [ ] Vanadium (V)

Question 3

A chemist needs to measure 25.00 mL of a certain solution. Which apparatus should they use for the measurement?

- [ ] Graduated cylinder
- [ ] Beaker
- [ ] Erlenmeyer flask
- [ ] Separatory funnel
- [ ] Pipette

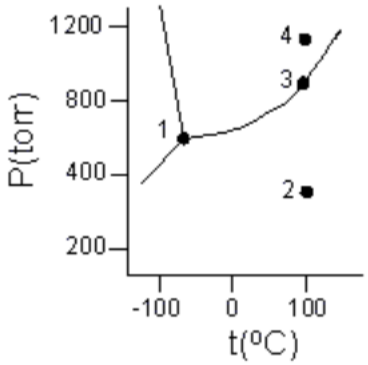
Question 4

According to the VSEPR model, what is the molecular geometry of NH_3?

- ☐ Seesaw
- ☐ Trigonal Pyramid
- ☐ T-shaped
- ☐ Octahedral
- ☐ Trigonal Planar

Question 5

A phase diagram for substance **Y** can be seen below. Which of the statements below is correct?



- ☐ At 0 °C and 1200 torr, **Y** is a solid.
- ☐ At point 1, **Y**(*s*) will convert to **Y**(*g*) and no **Y**(*l*) is present.
- ☐ At point 2, the phase equilibrium **Y**(*l*) ⇌ **Y**(*g*) exists.
- ☐ At point 3, the phase equilibrium **Y**(*l*) ⇌ **Y**(*g*) exists.
- ☐ At point 4, the phase equilibrium **Y**(*l*) ⇌ **Y**(*g*) exists.

Question 6

What is the chemical formula for pent-3-en-1-yne?

- ☐ C_4H_8
- ☐ C_5H_6
- ☐ C_5H_{12}
- ☐ C_6H_{12}
- ☐ C_6H_{14}

Question 7

The following chemical equilibrium is given:

$$2HF(g) \rightleftharpoons H_2(g) + F_2(g)$$

If 5 moles of HF(g) and 2 moles of $F_2(g)$ are mixed in a 1.00 L container, which of the following statements is correct?

- ☐ HF will form from H_2 and F_2 until the system reaches equilibrium.
- ☐ These amounts of moles in 1.00 L give equilibrium concentrations and therefore nothing happens.
- ☐ HF will react and form H_2 and F_2 until the system reaches equilibrum.
- ☐ There is not sufficient information given to be able to determine what happens in the reaction.
- ☐ All of the statements above are wrong.

Question 8

Aluminium reacts with chrome(II)oxide according to the following chemical equation:

$$Cr_2O_3 + 2Al \rightarrow 2Cr + Al_2O_3$$

10.8 g of aluminium is reacted with excess chrome(II)oxide. What is the maximum mass of chrome that could be formed by this reaction?

- ☐ 30.4 g
- ☐ 1.00 g
- ☐ 0.400 g
- ☐ 20.8 g
- ☐ 10.8 g

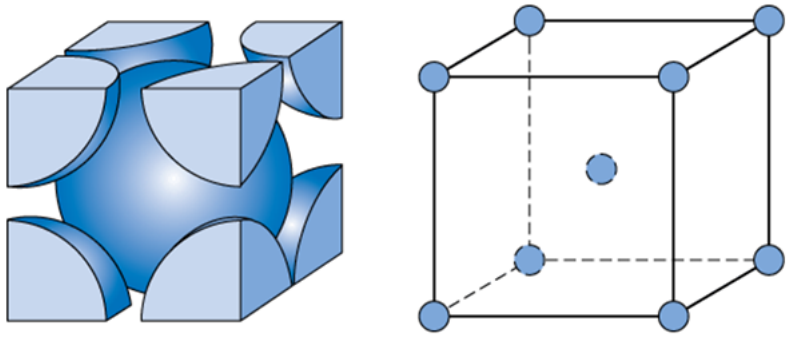
Question 9

Arrange the following species in order of increasing size: Ar, K^+, Cl^-, S^{2-}.

- ☐ $Ar < K^+ < Cl^- < S^{2-}$
- ☐ $S^{2-} < Cl^- < Ar < K^+$
- ☐ $K^+ < Ar < Cl^- < S^{2-}$
- ☐ $Cl^- < S^{2-} < Ar < K^+$
- ☐ $S^{2-} < K^+ < Cl^- < Ar$

Question 10

The figure below demonstrates a body-centered cubic (bcc) unit cell. How many ions are inside one such unit cell?



- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 6
- ☐ 9

Part II - 5 point questions

Question 11

Electrolysis is used to apply chrome to an antique car's bumper. The bumper is placed in a solution that contains Cr^{3+} and the solution then electolyzed with 200 A current. How long does it take to apply 95 g of chrome onto the bumper?

- ☐ 5.0 min
- ☐ 15 min
- ☐ 44 min
- ☐ 56 min
- ☐ 79 min

Question 12

25.00 g sample of industrial waste was analyzed in regards of chloride content. The sample was dissolved in water and the chlorine precipitated as silver chloride. The dried precipitate weighed 15.523 g. What was the mass percentage of chlorine in the initial sample?

- ☐ 15.36%
- ☐ 1.536%
- ☐ 1.083%
- ☐ 3.840%
- ☐ 2.191%

Question 13

12.2 g of $I_2(s)$ is placed in a 15.0 L vacuum sealed vessel and heated until the temperature reached 100 °C. At that temperature all the iodine has sublimated. What will the pressure be inside the vessel?

- ☐ 0.0981 torr
- ☐ 19.9 torr
- ☐ 74.5 torr
- ☐ 137 torr
- ☐ 373 torr

Question 14

A sample which contains *only* $SrCO_3$ and $BaCO_3$ weighs 0.800 g. When it is dissolved in excess acid, 0.211 g CO_2 is released. What mass-percentage of SrCO3 did the sample contain? Assume all the carbon originally present is converted to CO_2.

- ☐ 42.8%
- ☐ 45.8%
- ☐ 54.2%
- ☐ 66.9%
- ☐ 71.3%

Question 15

Balance the equation for the following redox reaction in an acidic medium:

$$Cr_2O_7^{2-} + C_2O_4^{2-} \rightarrow Cr^{3+} + CO_2$$

Balanced equation:_____

Question 16

a) A buffer solution is 0.30 M NH_3 and 0.36 M NH_4Cl ($pK_a = 9.25$). What is the pH of this solution?

pH = _____

b) 20.0 mL of 0.050 M NaOH was then added to 80.0 mL of the buffer solution. What will the pH become after this addition?

pH = _____

Question 17

The element M is in the 2nd group of the periodic table. A saturated solution of the insoluble salt MX_2 has the osmotic pressure 0.0979 atm at 25 °C. What is the solubility product (K_{sp}) of MX_2? (Assume that the salt splits completely into its ions).

$K_{sp}[MX_2]$ = _____

Question 18

Glucose ($C_6H_{12}O_6$) is one of the main energy source for animals. The following unbalanced chemical reaction describes the burning of glucose in oxygen:

$$C_6H_{12}O_6(s) + O_2(g) \rightarrow CO_2(g) + H_2O(l)$$

The standard heats formation (ΔH_f^o) for some of the reactants and products can be seen in the table below:

Compound	ΔH_f^o [kJ/mol]
$CO_2(g)$	-393.5
$H_2O(l)$	-285.8
$C_6H_{12}O_6(s)$	-1273.3

a) What is the standard enthalpy for the reaction of glucose burning, ΔH_{rxn}^o?

ΔH_{rxn}^o = _____ $\frac{\text{kJ}}{\text{mol}}$

b) What will be the enthalpy change when 5.00 g of glucose is burned?

ΔH = _____ kJ

Part III - 10 point questions

Question 19 Solubility product

Þórir the chemist has a solution which contains $8.88 \cdot 10^{-3}$ M Pb^{2+} and $1.46 \cdot 10^{-2}$ M Zn^{2+}. He needs to seperate the lead and zinc in the solution and for that he plans to use the different solubilities of lead phosphate and zinc phosphate. The solubility product for these insoluble salts are as follows:

$$K_{sp}[Pb_3(PO_4)_2] = 3.0 \cdot 10^{-44}$$
$$K_{sp}[Zn_3(PO_4)_2] = 9.1 \cdot 10^{-33}$$

Þórir then proceeds to add $Na_3PO_4(s)$ slowly into the solution until he sees precipitation form in the solution.

a) Which insoluble salt will precipitate first? (Provide reasoning with calculations).

The salt that precipitates first is _____

b) What is the concentration of PO_4^{3-} in the solution when the more insoluble compound starts to precipitate?

$[PO_4^{3-}]$ = _____ M

c) What is the concentration of the more insoluble compound's cation when the more soluble compound starts to precipitate?

Cation's concentration = _____ M

d) Seperation is deemed sufficient if it is possible to remove one of the ions in such a way that less then 1/1000 of the original concentration remains in the solution. Is it possible to seperate lead and zinc in sufficient fashion in this case? Provide reasoning with calculations.

Question 20 Kinetics

The solvation of aspirin ($C_9H_8O_4$) in water can be described as follows:

$$C_9H_8O_4(s) \rightarrow C_9H_8O_4(aq)$$

In this question, spectroscopic measurements will be used to determine the rate of solvation of aspirin.

a) 1.00 mL of an aspirin solution with an unknown concentration was diluted to 100.0 mL and the absorption measured at 274 nm in a 1.00 cm cuvette. The absorption was measured as $A = 0.3031$. What was the molarity of aspirin in the original solution? The molar absorptivity of aspirin at 274 nm is 1100 $\frac{\text{L}}{\text{mol}\cdot\text{cm}}$.

c_{aspirin} = _____M

b) Now an aspirin tablet was put into 1 L of deionized water and allowed to dissolve under constant stirring. Every five minutes a sample of the solution was measured and the concentration determined with a spectroscopic measurement. The results from these tests can be seen in the table below:

Time (min)	Concentration (mM)
5	0.0835
10	0.170
15	0.249
20	0.334

What is the order of the solvation according to these measurements? (Provide reasoning)

The order of the solvation is _____

c) What is the rate constant of the solvation?

$k =$ _____ $\frac{\text{mM}}{\text{min}}$

d) The solvation of aspirin is faster at higher temperatures. The rate constants at different temperatures can be seen in the table below:

Temperature (°C)	k (mM/min)
40	$2.22 \cdot 10^{-2}$
50	$4.44 \cdot 10^{-2}$
60	$8.67 \cdot 10^{-2}$

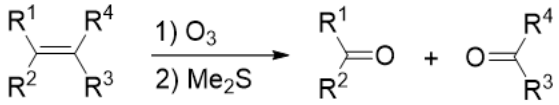
What is the activation energy of the solvation?

$E_a =$ _____ $\frac{\text{kJ}}{\text{mol}}$

Question 21 Organic Chemistry

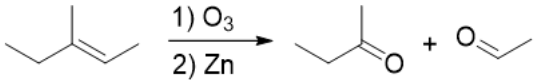
Ozonolysis is an organic reaction in which ozone is used to cleave carbon – carbon double bonds and form two carbonyl groups instead. Ozone is a strong oxidant and this type of a reaction is called oxidative cleavage since it cleaves the double bond oxidatively. Most often the oxidative cleavage is followed by a reductive workup with reducing agents such as zinc (Zn) and dimethyl sulfide (Me_2S).

A general reaction scheme for an ozonolysis is shown below.



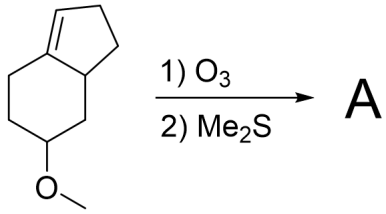
In this scheme, R can be an alkyl group, an aryl group or a hydrogen atom.

An example of this is the formation of ethanal and butanone from 3-methylpent-2-ene:

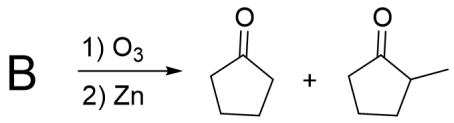


As can be seen above, the groups bound to the double bond remain unchanged.

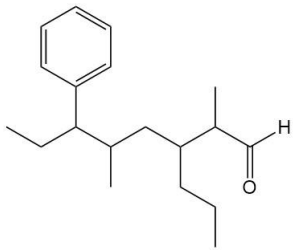
a) Draw the structure of product **A** in the reaction here below.



b) In the reaction shown below, a double bond has been cleaved to form cyclopentanone and 2-methylcyclopentanone. Draw the structure of the starting material, compound **B**, which was used in the reaction below.



c) What is the IUPAC name of the compound shown below. Write your answer on the line.



IUPAC name:_____

d) Draw circles around all the stereocenters (chiral centers) in the compound below.