Efnafræðifélag Íslands
The Icelandic Chemical Society

21th General National Chemistry Competition

for high school students

Thursday March 3, 2022

Time: 8-10 (120 min)

HÁSKÓLI ÍSLANDS

ICELAND

University of Iceland

21TH GENERAL NATIONAL CHEMISTRY COMPETITION

MARCH 3, 2022

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

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

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

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

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

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

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

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

$q = C\Delta T$

$q = mc\Delta T$

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

$pK_a = -\log K_a$

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

$A = \epsilon bc$

$PV = nRT$

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

$N_A = 6.0223 \cdot 10^{23}\mathrm{mól}^{-1}$

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

$T_K = T_{^\circ\mathrm{C}} + 273.15$

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

$K_w = 1.00 \cdot 10^{-14}$

$1\mathrm{bar} = 10^5\mathrm{Pa} = 0.9869\mathrm{atm}$

$h = 6.626 \cdot 10^{-34}\mathrm{J} \cdot \mathrm{s}$

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

$R = 8.3144 \frac{\mathrm{J}}{\mathrm{K \cdot mól}} = 0.08206 \frac{\mathrm{L \cdot atm}}{\mathrm{K \cdot mól}}$

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

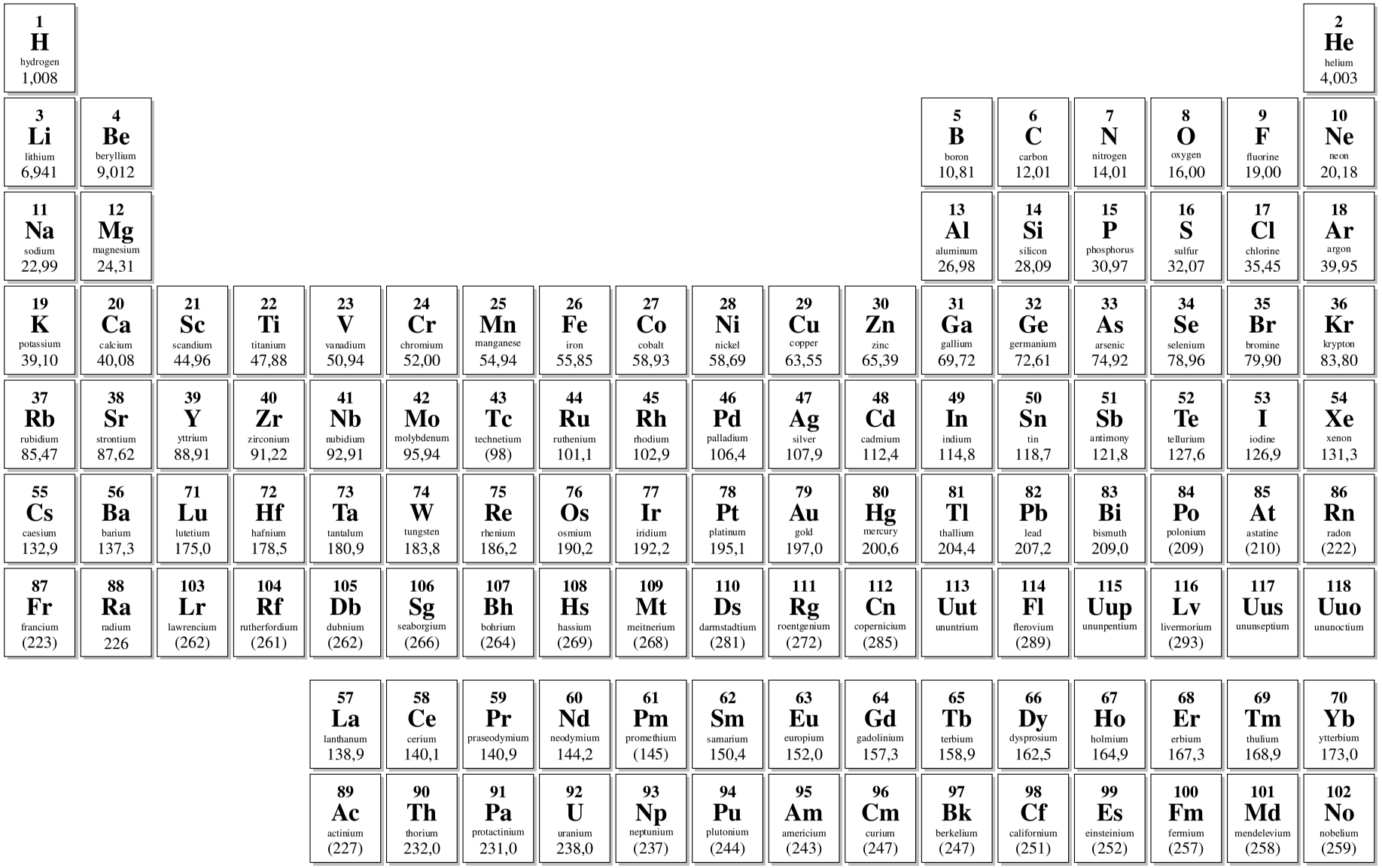
$1\mathrm{J} = 1\mathrm{kg} \cdot \mathrm{m}^2 \cdot \mathrm{s}^{-2}$

1 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 elements is a transition metal?

- [ ] Ni
- [ ] Mg
- [ ] Al
- [ ] Pb
- [ ] Na

Question 2

Identify the conjugate base of HSO_4^-.

- [ ] SO_4^{2-}
- [ ] H_2O
- [ ] H_2SO_4
- [ ] H_2SO_3
- [ ] OH^-

Question 3

What does $^{57}Fe^{3+}$ have many protons (p), neutrons (n) and electrons (e)?

- [ ] 26p, 31n, 23e
- [ ] 26p, 29n, 29e
- [ ] 57p, 31n, 23e
- [ ] 26p, 31n, 29e
- [ ] 31p, 26n, 29e

Question 4

How many significant figures are there in the answer to the following calculations?

$$\frac{2.531}{4.1} - \frac{0.380}{0.723} =$$

- [ ] 1
- [ ] 2
- [ ] 3
- [ ] 4
- [ ] 5

Question 5

How many atoms are there in 1.00 ng of magnesium (Mg)?

- [ ] 4.11×10^{-11} atoms
- [ ] 2.48×10^{13} atoms
- [ ] 6.83×10^{-35} atoms
- [ ] 6.02×10^{14} atoms
- [ ] 1.46×10^{34} atoms

Question 6

The following reaction is exothermic:

$$CO(g) + 2\,H_2(g) \rightleftharpoons CH_3OH(g)$$

Which of the following statements about the reaction is true?

- [ ] Spontaneous at all temperatures
- [ ] Non-spontaneous at all temperatures
- [ ] Sponaneous above certain temperature
- [ ] Spontaneous below certain temperature
- [ ] Nothing can be said about its spontaneity

Question 7

For the reaction:

$$NH_4OCONH_2(s) \rightleftharpoons 2\,NH_3(g) + CO_2(g) \qquad K_p = 2.9 \times 10^{-3} \text{ at } 25°C$$

In an experiment, $NH_4OCONH_2(s)$ is placed in an evacuated container and allowed to come to equilibrium at 25°C. What is the total pressure in the container at equilibrium?

- ☐ 0.27 atm
- ☐ 2.9×10^{-3} atm
- ☐ 0.090 atm
- ☐ 0.18 atm
- ☐ 0.43 atm

Question 8

A gas sample in a 225 mL container at 30 °C has a pressure of 625 torr. If the sample is transferred to a 400 mL container and heated to 40 °C, what will the pressure be?

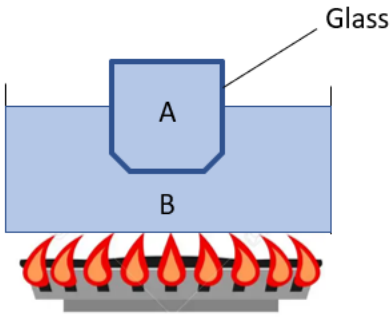
- ☐ 363 torr
- ☐ 869 torr
- ☐ 1.15×10^3 torr
- ☐ 593 torr
- ☐ 486 torr

Question 9

What is the molar volume of Ne gas under the conditions of temperature and pressure where its density is 0.429 g/L?

- ☐ 47.0 L/mol
- ☐ 8.66 L/mol
- ☐ 2.13×10^{-2} L/mol
- ☐ 24.5 L/mol
- ☐ 35.7 L/mol

Question 10



Water A, in a container made of glass, is placed in a pot full of water B, which is then heated on a stove. The glass does neither touch the bottom nor the sides of the pot. Which of the following statements is correct for water A?

- ☐ Water A will boil after water B.
- ☐ Water A will boil before water B.
- ☐ Water A and water B will boil simultaneously.
- ☐ Water A will never boil.
- ☐ Water A will boil as soon as the glass touches water B.

Part II - 5 point questions

Question 11

Gasoline with lead as an additive was banned due to the number of untimely deaths it caused. At a certain time the concentration of lead (Pb) in an air sample was 3.01 μg/m^3. How many atoms of lead would be precent in 0.500 L of this air sample (average breath volume of a grown-up person)?

- ☐ 4.37×10^{18} atoms
- ☐ 4.37×10^{12} atoms
- ☐ 8.74×10^{12} atoms
- ☐ 6.52×10^{18} atoms
- ☐ 8.74×10^{21} atoms

Question 12

Electrolysis of an alkaline earth metal chloride, MCl_2 using a current of 5.00 A for 748 s deposits 0.777 g of M(s) at the cathode. Identify the metal M.

- ☐ Be
- ☐ Mg
- ☐ Ca
- ☐ Sr
- ☐ Ba

Question 13

The complete combustion of ethylene (C_2H_4) produces water and carbon dioxide. Calculate, using average bond energies (BE), how much energy is released when burning one mole of ethylene.

Bond	BE (kJ/mol)
C=C	614
C−H	413
O=O	495
O−H	467
C=O	799

- ☐ 1313 kJ
- ☐ 1323 kJ
- ☐ 266 kJ
- ☐ 1345 kJ
- ☐ 2798 kJ

Question 14

Back-titration is a process where an analyte is reacted with an excess of reagent and the unreacted reagent is then (*back*-)titrated to an end point.

In this problem, back-titration is used to determine the mass percent of $BaCl_2 \cdot 2H_2O$ in a 0.7170 g sample.

The sample was dissolved in water and 20.16 mL of 1.777×10^{-3} M $AgNO_3$ added to the solution. $AgNO_3$ reacts with $BaCl_2$ according to:

$$BaCl_2 + 2AgNO_3 \rightarrow 2AgCl(s) + Ba(NO_3)_2$$

The unreacted $AgNO_3$ was titrated with 7.56 mL of 1.704×10^{-3} M KSCN solution:

$$AgNO_3 + KSCN \rightarrow AgSCN(s) + KNO_3$$

What was the mass percent of $BaCl_2 \cdot 2H_2O$ in the sample?

- ☐ 1.345%
- ☐ 0.272%
- ☐ 0.333%
- ☐ 0.782%
- ☐ 0.391%

Question 15

Balance the following redox reaction (in acidic solution) with the lowest possible integer coefficients:

$$CN^- + MnO_4^- \rightarrow CNO^- + MnO_2$$

Balanced equation:_____

Question 16

The reaction of potassium metal with water is very exothermic:

$$K(s) + 2\,H_2O(l) \rightarrow 2\,KOH(aq) + H_2(g) \qquad \Delta H^\circ = -390\ \text{kJ/mol}$$

A 7.00 g chunk of potassium is dropped into 1.00 kg of water at 25.0 °C. What is the final temperature of the water after the preceeding reaction occurs? Assume that all the heat is used to raise the temperature of the water. ($s_{water} = 4.18\ \text{J/g°C}$)

$T_{water,final}$ = _____ °C

Question 17

a) 25.0 mL of 0.200 M NaOH solution, 35.0 mL of 0.050 M KOH solution and 50.0 mL of 0.100 M HCl solution are mixed together. Let's call this mixture solution A. What is the pH of solution A?

pH = _____

b) 20.0 mL of 0.050 M CH_3COOH solution ($K_a = 1.8 \times 10^{-5}$) is added to solution A and results in solution B. What is the pH of solution B?

pH = _____

18. dæmi

Antimony trifluoride, SbF_3, is used in dyeing and as a reactant in organic synthesis. It is possible to oxidise SbF_3 with F_2 to yield antimony pentafluoride, SbF_5. The reaction is as follows:

$$SbF_3 + F_2 \rightarrow SbF_5$$

If SbF_5 is mixed with HF, a solution called fluoroantimonic acid will form, which includes among other things the ions H_2F^+ and SbF_6^-. Fluoroantimonic acid is a super acid, which can be more than 10^{15} times stronger than sulfuric acid. Answer the following questions in the appropriate field in the table below.

a) Draw a Lewis structure for SbF_3, SbF_5 and SbF_6^-.

b) Use the VSEPR model to predict the geometry of these molecular structures and draw a 3D representation of them.

c) What is the geometry of the molecular structure called?

Substance	a) Lewis structure	b) 3D representation	c) Name of geometry
SbF_3			
SbF_5			
SbF_6^-			

Part III - 10 point questions

Question 19 Mass Percentage

A 6.495 g sample contains $MgCl_2 \cdot 6H_2O$ and NaCl.

In order to determine the mass percentage of $MgCl_2 \cdot 6H_2O$ and NaCl in the sample, the sample was dissolved in water to get 500.0 mL solution. Then, two 50.0 mL aliquotes of this solution were analyzed:

Experiment 1: All the Mg^{2+} ions from one of the aliquotes were precipitated as $MgNH_3PO_4(s)$, which then was converted to $Mg_2P_2O_7(s)$. The $Mg_2P_2O_7(s)$ weighted 0.1769 g.

Experiment 2: All the Cl^- ions form the other aliquote were precipitated as AgCl. The AgCl precipitate weighted 0.5923 g.

a) What are the molar masses of $Mg_2P_2O_7$ and AgCl?

$M_{Mg_2P_2O_7}$ = _____ g/mol

M_{AgCl} = _____ g/mol

b) Experiment 1: What is the number of moles of Mg^{2+} ions in the 50.0 mL solution?

$n_{Mg^{2+}}$ = _____ mol

c) Experiment 2: What is the number of moles of Cl^- in the 50.0 mL solution?

n_{Cl^-} = _____ mol

d) What was the number of moles of $MgCl_2 \cdot 6H_2O$ in the sample?

$n_{MgCl_2 \cdot 6H_2O}$= _____ mol

e) What was the number of moles of NaCl in the sample?

n_{NaCl}= _____ mol

f) What was the mass percentage of $MgCl_2 \cdot 6H_2O$ in the sample?

Mass percentage $MgCl_2 \cdot 6H_2O$ = _____%

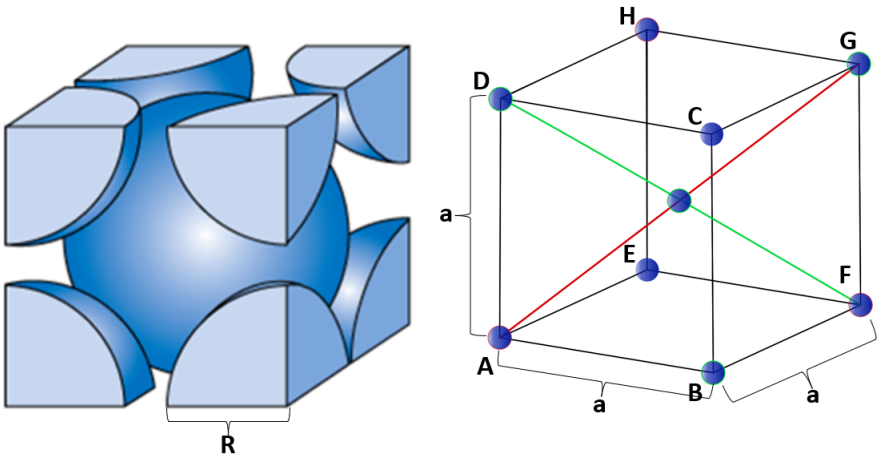
g) What was the mass percentage of NaCl in the sample?

Mass percentage NaCl = _____%

Question 19 Density from crystal structure

In this problem, the theoretical density of chrome (Cr) will be determined based on the crystal structure.

Chrome has body-centered cubic (BCC) crystal structe. The figure below shows how a unit cell with corners ABCDEFGH in a BCC crystal structure looks like:



a) How many chrome atoms are there inside one unit cell?

n = _____atom/cell

b) Write an equation for density of chrome as a function of the unit cell length (a), number of atoms inside one unit cell (n), molar mass of chrome (M) and Avagadro's Number (N_A). Take note that the unit cell length, a, equals the length $||AB||$ in the figure above.

ρ = _____

c) What is the longer diagonal line $||AG||$ (red line in the figure) equal to many atom radii (R)?

$||AG|| =$ _____ R

d) Write the longer diagonal line $||AG||$ as a function of the unit cell length a.

$||AG|| =$ _____ a

e) Write an equation for the relationship between the unit cell length, a, and the radius of the chrome atom, R.

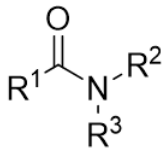
$a =$ _____ R

f) What is the density of chrome based on the equation in part-b if it is known that the molar mass of chrome is $M = 52.00$ g/mol and the atomic radius $R = 0.125$ nm. Answer in the unit g/cm^3.

$\rho =$ _____ g/cm^3

21. dæmi Organic Chemistry

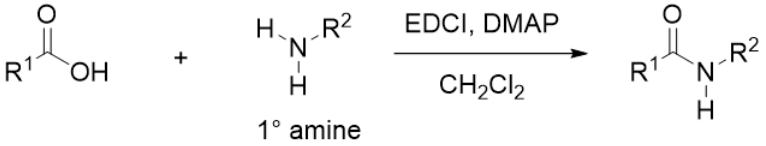
Amide is an organic functional group with the chemical formula $-CONR_2$ (see figure below) where R can be organic groups or hydrogen.



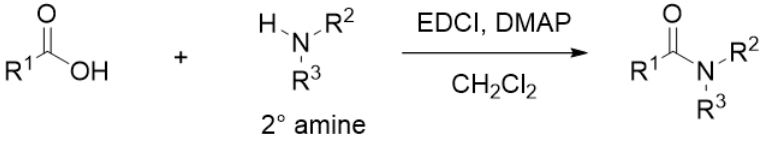
Amides are common in nature, especially in proteins. Amides are also common in a variety of plastics, for example nylons. Furthermore amides can be found in many drugs, such as paracetamol and penicillin.

There are many ways to synthesize amides.

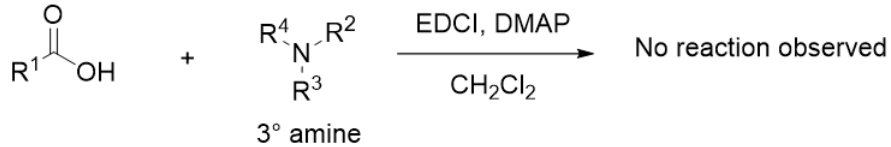
One way is to react a carboxylic acid with an amine in the presence of EDCI and DMAP



1° amine



2° amine

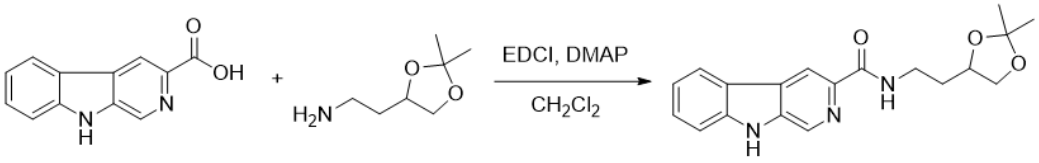


3° amine

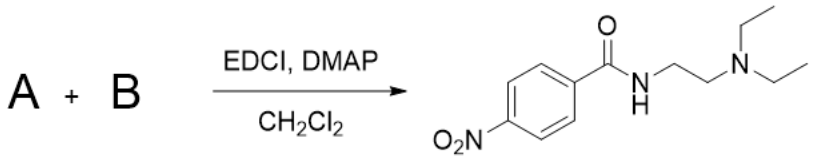
In these reactions, R stands for organic groups.

This reaction only works for 1° and 2° amine. If 3° amine is used no reaction is observed.

An example of an amide synthesis from a carboxylic acid and amine with the help of EDCI and DMAP can be seen below.



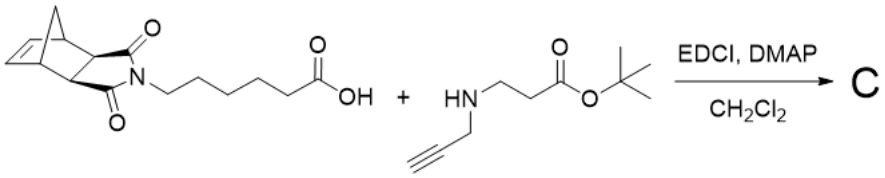
a) Draw the structure of the carboxylic acid **A** and the amine **B** in the reaction below inside the boxes.



Carboxylic acid A

Amine B

b) Draw the structure of compound **C** in the reaction below.



c) Draw a circle around, and name all the functional groups in compound **D**.

D