

General Instructions

- This examination has **10 problems**.
- Each signal is given by the ringing of a cowbell.
- You may begin working as soon as the **START** command is given. You will then have **5 hours** to complete the exam.
- All results must be written in the appropriate answer boxes with pen on the **answer sheets**. Use the back of the question sheets if you need scratch paper. Remember that answers written outside the answer boxes will not be graded.
- Write relevant calculations in the appropriate boxes when necessary. Full marks will be given for correct answers only when your work is shown.
- For the multiple choice questions, **if you want to change your answer**, fill the tick box completely and then make a **new box next to it**.
- Use only the pen and calculator provided.
- The official English version of this examination is available on request for clarification only.
- The supervisors will announce a **30-minute** warning before the **STOP** command.
- You **must stop** working when the **STOP** command is given. Failure to stop writing can lead to the nullification of your examination.
- After the supervisor tells you to do so, put **all sheets with the cover sheet on top** back into the envelope. **Do not** seal the envelope.
- You are not allowed to leave your working place without permission. If you need any assistance, raise the corresponding nonverbal communication card (see table below for meanings).
- **Do not** draw anything into or close to the QR codes.


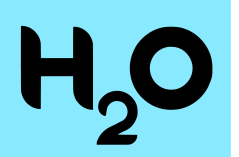

Theory



55TH INTERNATIONAL
CHEMISTRY OLYMPIAD
SWITZERLAND 2023

G0-2

English (Official)

		
I need to use the toilet, grab a snack, or take a break	I need my water bottle refilled	I need to see the official English version for clarification

Meanings of the non-verbal communication cards.

GOOD LUCK!

DELEGATION PRINT

Problems and Grading Information

	Title	Question Pages	Answer Pages	Total Score	Percentage
1	Molecular Imaging	3	4	22	5
2	Electrochemical CO ₂ Reduction	4	5	33	5
3	Artificial Photosynthesis	4	6	29	6
4	Fluorinated and Hypervalent Compounds	6	4	34	6
5	Hydrodesulfurization	3	4	34.5	7
6	Direct Conversion of Methane to Methanol	3	5	32	7
7	Enzyme Kinetics	3	5	34	7
8	Nazarov Reaction	3	3	31	5
9	Electrolysis in Organic Synthesis	6	5	29	6
10	Switzerland - The Country of Pharmaceuticals	6	4	39	6
Total					60

Physical Constants and Equations

Constants

Planck constant	$h = 6.626 \cdot 10^{-34} \text{ J s}$
Boltzmann constant	$k_B = 1.381 \cdot 10^{-23} \text{ kg m}^2 \text{ s}^{-2} \text{ K}^{-1}$
Speed of Light	$c = 2.998 \cdot 10^8 \text{ m s}^{-1}$
Elementary charge	$e = 1.602 \cdot 10^{-19} \text{ C}$
Avogadro constant	$N_A = 6.022 \cdot 10^{23} \text{ mol}^{-1}$
Universal gas constant	$R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$
Faraday constant	$F = 96485 \text{ C mol}^{-1}$
Standard pressure	$p_0 = 1 \cdot 10^5 \text{ Pa} = 1 \text{ bar}$
SHE:	Standard Hydrogen Electrode ($p = 1 \text{ bar}$)
Electronvolt	$1 \text{ eV} = 1.602 \cdot 10^{-19} \text{ J}$
Electric Charge & Current	$1 \text{ C} = 1 \text{ A} \cdot 1 \text{ s}$
Absolute zero	$0 \text{ K} = -273.15 \text{ }^\circ\text{C}$
Ångstrom	$1 \text{ Å} = 10^{-10} \text{ m}$
pico (p)	10^{-12}
nano (n)	10^{-9}
micro (μ)	10^{-6}
milli (m)	10^{-3}
centi (c)	10^{-2}
deci (d)	10^{-1}
kilo (k)	10^3
mega (M)	10^6
giga (G)	10^9
tera (T)	10^{12}
Pi (π)	$\pi = 3.141592 \dots$
Euler's number	$e = 2.718281 \dots$

Equations

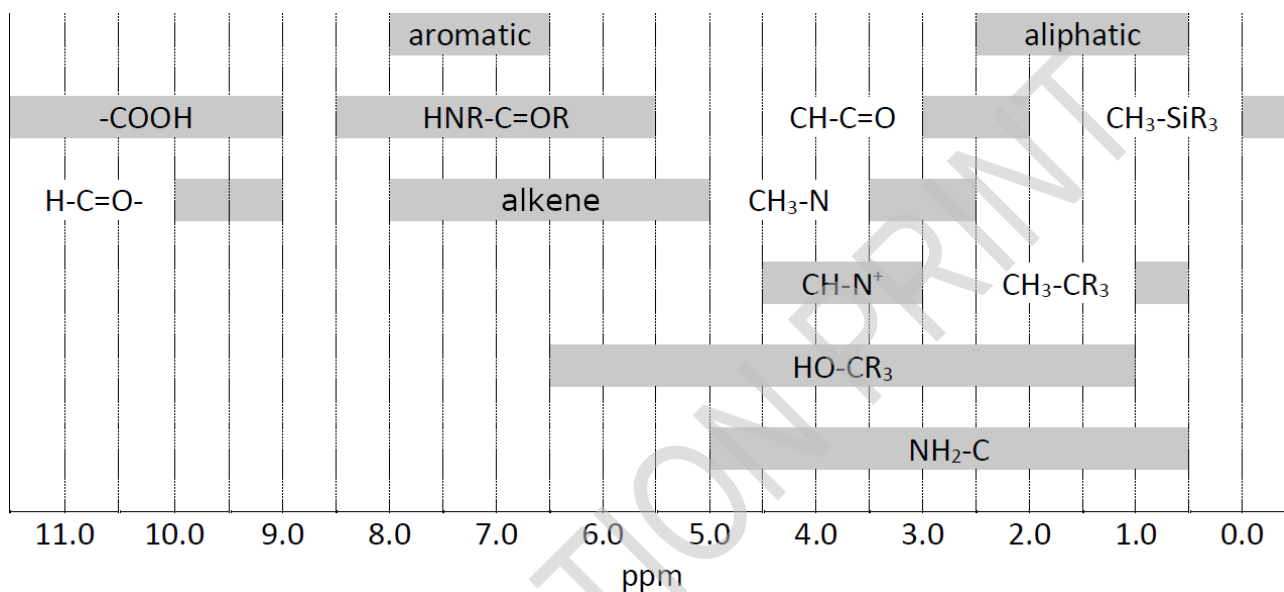
Ideal gas law	$pV = nRT = Nk_B T$
Gibbs free energy	$\Delta G = \Delta H - T\Delta S$ $\Delta G^\circ = -RT \ln K^\circ$ $\Delta_r G^\circ = -nFE_{cell}^\circ$ where n is the number of electrons $\Delta_r G = \Delta_r G^\circ + RT \ln Q$
Reaction quotient Q for reaction: $aA + bB \rightleftharpoons cC + dD$	$Q = \frac{[C]^c [D]^d}{[A]^a [B]^b}$
Nernst equation	$E = E_0 - \frac{RT}{nF} \ln Q$
Electric current	$I = Q/t$
Faraday equation	$I \cdot t = n \cdot z \cdot F$
Energy of charge q in electric field	$E = k \frac{q_1 q_2}{d}$
Arrhenius law	$k = A \exp\left(\frac{-E_A}{RT}\right)$
Lambert Beer equation	$A = \log(I_0/I_1) = \varepsilon \cdot l \cdot c$
Henderson-Hasselbalch equation	$\text{pH} = \text{pK}_a + \log\left(\frac{[A^-]}{[HA]}\right)$
Energy of a photon	$E = h\nu = \frac{hc}{\lambda}$
Integrated rate laws for ...	
... zeroth order	$[A] = [A]_0 - kt$
... first order	$\ln[A] = \ln[A]_0 - kt$
... second order	$\frac{1}{[A]} = \frac{1}{[A]_0} + kt$
Half life for a first order reaction	$t_{1/2} = \frac{\ln 2}{k}$
Half life for a second order process	$t_{1/2} = \frac{1}{[A]_0 k}$
Radioactivity	$A = k \cdot N$
Surface area of a sphere with radius R	$A = 4\pi R^2$
Volume of a sphere with radius R	$V = \frac{4\pi}{3} R^3$

Periodic Table of the Elements

1 H 1.008																	2 He 4.003
3 Li 6.94																	9 F 19.00
4 Be 9.01																	8 O 16.00
11 Na 22.99																	17 Cl 35.45
12 Mg 24.31																	16 S 32.06
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.63	33 As 74.92	34 Se 78.97	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.95	43 Tc [98]	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
55 Cs 132.91	56 Ba 137.33	57-71 La [226]	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po [209]	85 At [210]	86 Rn [212]
87 Fr [223]	88 Ra [226]	89-103 Ac [227]	104 Rf [267]	105 Db [268]	106 Sg [269]	107 Bh [270]	108 Hs [270]	109 Mt [278]	110 Ds [281]	111 Rg [282]	112 Cn [285]	113 Nh [286]	114 Fl [289]	115 Mc [290]	116 Lv [293]	117 Ts [294]	118 Og [294]
57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 140.24	61 Pm [145]	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.05	71 Lu 174.97			
89 Ac [227]	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np [237]	94 Pu [244]	95 Am [243]	96 Cm [247]	97 Bk [247]	98 Cf [251]	99 Es [252]	100 Fm [257]	101 Md [258]	102 No [259]	103 Lr [266]			

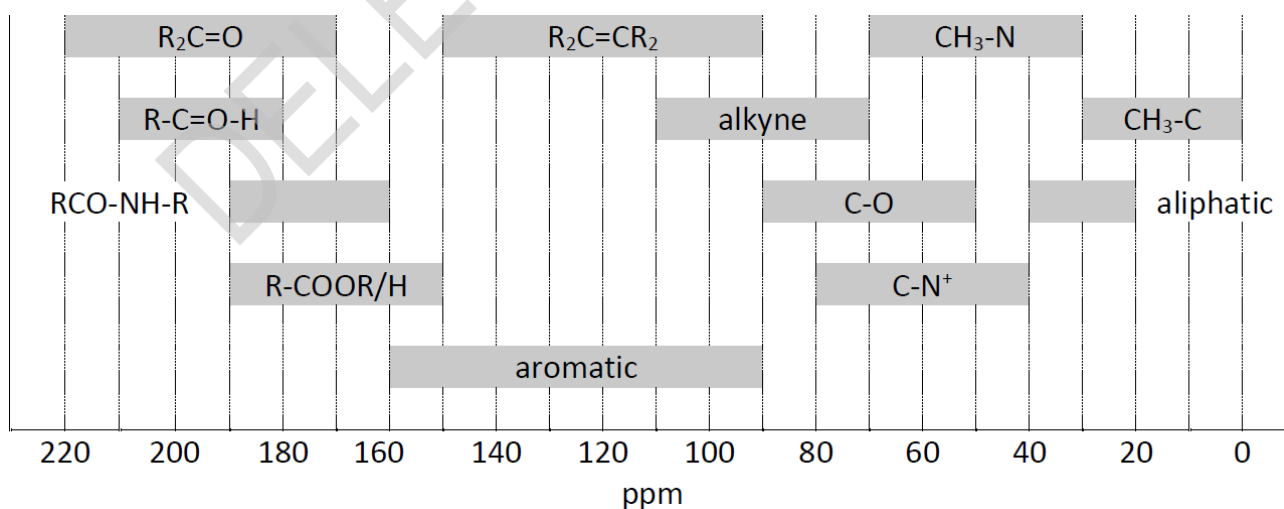
Table of NMR Chemical Shifts

¹H NMR Chemical Shifts



Possible translation for aromatic, aliphatic and alkyne

¹³C NMR Chemical Shifts

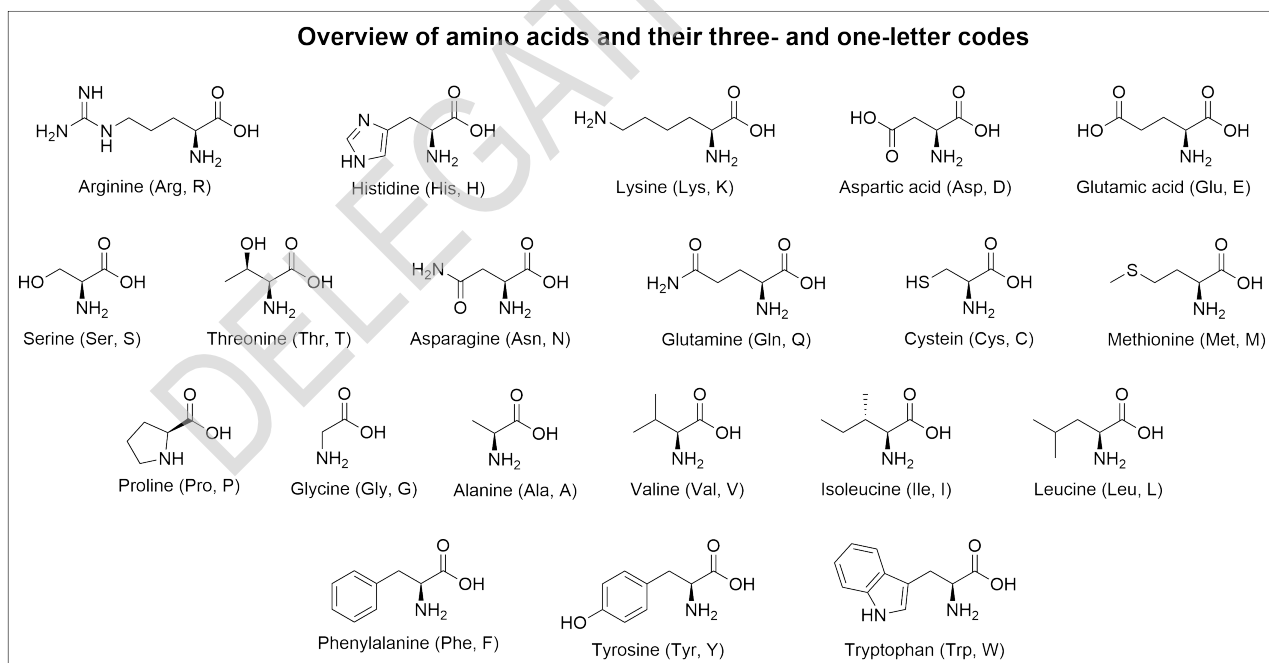


Possible translation for aromatic, aliphatic and alkyne

¹H NMR Coupling Constants

Type of hydrogen	$ J_{ab} $ (Hz)
$R_2CH_aH_b$	4-20
$R_2CH_a-CR_2H_b$	2-12
$R_2CH_a-CR_2-CR_2H_b$	If rotation free: < 0.1 Otherwise (fixed): 1-8
$RH_aC=CRH_b$	<i>cis</i> : 7-12 <i>trans</i> : 12-18
$R_2C=CH_aH_b$	0.5-3
$RH_aC=CR-CR_2H_b$	0.5-2.5

List of Amino Acids



Possible translations for the English expressions in the figure above.