SwissChO Central Exam 2026

CHEMISTRY.
OLYMPIAD.CH
CHEMIE-OLYMPIADE
OLYMPIADES DE CHIMIE
OLIMPIADI DELLA CHIMICA

G0-1

English (Official)

General Information

Instructions

- You have three hours to solve the problems. Wait for the **START** signal before you begin.
- Write all necessary calculations, ideas and explanations legibly.
- Write only in pen.
- Put your pages into the provided envelope at the end of the exam. Do not seal the envelope.
- Finish your work immediately when the **STOP** signal is given.
- Leave your seat only when allowed to do so.
- Only **answers written in the given spaces** can be considered.
- The points of every exercise are weighted according to weights that can be found on the score sheet to give the final result.
- This exam has **9** problems.

Viel Erfolg!

Bonne chance!

Buona fortuna!

Good luck!

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Physical Constants and Formulae

Constants

Planck constant	$h = 6.626 \times 10^{-34}\,\mathrm{J\,s}$
Boltzmann constant	$k_B = 1.381 \times 10^{-23}\,\mathrm{J\,K^{-1}}$
Speed of light	$c = 2.997 \times 10^{8}\,\mathrm{m\,s^{-1}}$
Elementary charge	$e = 1.602 \times 10^{-19}\,\mathrm{C}$
Avogadro's constant	$N_A = 6.022 \times 10^{23}\,\mathrm{mol^{-1}}$
Universal gas constant	$R = 8.314\,\mathrm{J\,mol^{-1}\,K^{-1}}$
Faraday constant	$F = 9.648 \times 10^{4}\,\mathrm{C\,mol^{-1}}$
Standard pressure	$p_0 = 1 \times 10^{5}\,\mathrm{Pa}$
Electronvolt	$1\,\mathrm{eV} = 1.602 \times 10^{-19}\,\mathrm{J}$
Absolute zero	$0\,\mathrm{K} = -273.15\,^{\circ}\mathrm{C}$
Ångstrom	$1\,\text{Å} = 1 \times 10^{-10}\,\mathrm{m}$
Pi (π)	$\pi \approx 3.141592$
Euler's number	$e \approx 2.718281$

For the calculation of equilibrium constants and all concentrations, refer to the standard concentration $1\,\mathrm{mol\,dm^{-3}} = 1\,\mathrm{mol\,L^{-1}}$. If not stated otherwise in a task, consider all gases ideal throughout this exam.

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Formulae and Equations

Ideal gas law	$pV = nRT = Nk_BT$
Gibbs free energy	$\Delta G = \Delta H - T\Delta S$
Relation between ΔG° and K	$\Delta G^\circ = -RT \ln(K)$
Relationship between ΔG and ΔE_{cell}	$\Delta G = -zF\Delta E_{\text{cell}}$
Nonstandard ΔG	$\Delta_r G = \Delta_r G^\circ + RT \ln(Q)$
Reaction quotient Q for reaction $\mathrm{aA} + \mathrm{bB} \rightleftharpoons \mathrm{cC} + \mathrm{dD}$	$Q = \frac{[\mathrm{C}]^c \cdot [\mathrm{D}]^d}{[\mathrm{A}]^a \cdot [\mathrm{B}]^b}$
Nernst equation	$E = E^\circ - \frac{RT}{zF} \ln(Q)$
Arrhenius law	$k = Ae^{-\frac{E_a}{RT}}$
Electric current	$I = \frac{q}{t}$
Lambert-Beer law	$A = \epsilon L c = \log\left(\frac{I_0}{I}\right)$
Buffer equation	$\mathrm{pH} = \mathrm{pK_a} + \log\left(\frac{[\mathrm{A^-}]}{[\mathrm{HA}]}\right)$
Definition of $\mathrm{pK_a}$	$\mathrm{pK_a} = -\log\left(\frac{[\mathrm{H^+}]\cdot[\mathrm{A^-}]}{[\mathrm{HA}]}\right)$
Energy of a photon	$E = h\nu = \frac{hc}{\lambda}$
Half life of a first-order reaction	$t_{\frac{1}{2}} = \frac{\ln(2)}{k}$
Activity of a radioactive sample	$A = kN$
Surface area of a sphere	$A = 4\pi R^2$
Volume of a sphere	$V = \frac{4}{3}\pi R^3$

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Periodic Table of Elements

1																		2
H																		He
1.008																		4.003
3	4												5	6	7	8	9	10
Li	Be												B	C	N	O	F	Ne
6.94	9.01												10.81	12.01	14.01	16.00	19.00	20.18
11	12												13	14	15	16	17	18
Na	Mg												Al	Si	P	S	Cl	Ar
22.99	24.31												26.98	28.09	30.97	32.06	35.45	39.95
19	20	21	22	23	24	25	26	27	28	29	30		31	32	33	34	35	36
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn		Ga	Ge	As	Se	Br	Kr
39.10	40.08	44.96	47.87	50.94	52.00	54.94	55.85	58.93	58.69	63.55	65.38		69.72	72.63	74.92	78.97	79.90	83.80
37	38	39	40	41	42	43	44	45	46	47	48		49	50	51	52	53	54
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd		In	Sn	Sb	Te	I	Xe
85.47	87.62	88.91	91.22	92.91	95.95	[98]	101.07	102.91	106.42	107.87	112.41		114.82	118.71	121.76	127.60	126.90	131.29
55	56		72	73	74	75	76	77	78	79	80		81	82	83	84	85	86
Cs	Ba	57–71	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg		Tl	Pb	Bi	Po	At	Rn
132.91	137.33		178.49	180.95	183.84	186.21	190.23	192.22	195.08	196.97	200.59		204.38	207.2	208.98	[209]	[210]	[212]
87	88		104	105	106	107	108	109	110	111	112		113	114	115	116	117	118
Fr	Ra	89–103	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn		Nh	Fl	Mc	Lv	Ts	Og
[223]	[226]		[267]	[268]	[269]	[270]	[270]	[278]	[281]	[282]	[285]		[286]	[289]	[290]	[293]	[294]	[294]

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
138.91	140.12	140.91	140.24	[145]	150.36	151.96	157.25	158.93	162.50	164.93	167.26	168.93	173.05	174.97
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
[227]	232.04	231.04	238.03	[237]	[244]	[243]	[247]	[247]	[251]	[252]	[257]	[258]	[259]	[266]

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Score Sheet

Not to be filled in by the student.

Student's name: _____

Q	Title	Points	Weight
1	Basics of Chemistry?	18.5	8%
2	Acids: From Filthy Foul to Fruitily Fragrant	14.0	9%
3	Redox Chemistry with $KMnO_4$	13.5	11%
4	Iodine: Quiet or Explosive	17.0	13%
5	Luminol Literally Lighting Labs	13.0	10%
6	Carbon Clock: Archeology and *in vivo* Imaging	16.0	15%
7	Gaslighting and Lighting Gasses	12.5	11%
8	Tasting the Right (and Left) Sugars	16.0	11%
9	Organic Reactions	13.0	9%
Σ	**TOTAL**		100%

Basics of Chemistry? (18.5 pts, 8%)

1.1 **Indicate** whether the following processes include chemical reactions. 2.0 pt

Charging your phone	☐ Yes	☐ No
Boiling salt water	☐ Yes	☐ No
Electromagnets lifting iron	☐ Yes	☐ No
Baking cookies	☐ Yes	☐ No

1.2 **Indicate**, for the following four properties, whether the trend follows $I > Br > Cl > F$. 2.0 pt

Electronegativity	☐ Yes	☐ No
Atomic radius	☐ Yes	☐ No
Acidity (of HX)	☐ Yes	☐ No
Boiling point (of X_2)	☐ Yes	☐ No

1.3 **Select** the element with the highest atomic mass. 1.0 pt

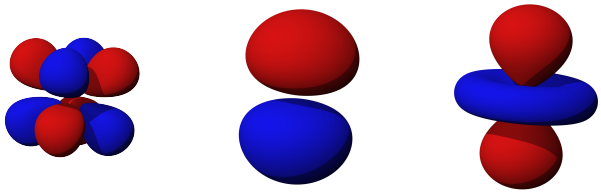
☐ Samarium (Sm) ☐ Curium (Cm) ☐ Hafnium (Hf) ☐ Meitnerium (Mt)

1.4 **Select** the number of oxygen atoms in one mole of tris(oxalato)chromate(III) $[Cr(C_2O_4)_3]^{3-}$. 1.0 pt

☐ 2.409×10^{24} ☐ 7.227×10^{24} ☐ 1.807×10^{24} ☐ 6.022×10^{23}

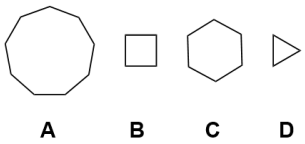
1.5 **Select** the orbital type of each illustration. 3.0 pt

☐ s	☐ s	☐ s
☐ p	☐ p	☐ p
☐ d	☐ d	☐ d
☐ f	☐ f	☐ f



☐ s	☐ s	☐ s
☐ p	☐ p	☐ p
☐ d	☐ d	☐ d
☐ f	☐ f	☐ f

1.6 **Order** the following cycloalkanes **A**-**D** with increasing ring strain (from least to most strained). 1.0 pt

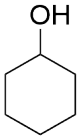


☐ **D<B<A<C** ☐ **A<C<B<D** ☐ **C<A<B<D** ☐ **B<D<A<C**

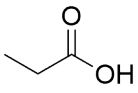
1.7 **Draw** a stable Lewis formula of the following sum formulae and **determine** the oxidation states of all atoms. 4.5 pt

H_3PO_4	C_3H_6	H_2CO_2

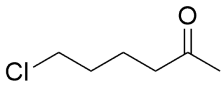
1.8 **Complete** the structures according to IUPAC nomenclature. 4.0 pt



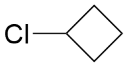
Benzene-1,2-diol ($C_6H_6O_2$)



2-Amino-3-hydroxypropanoic acid ($C_3H_7O_3N$)



4,6-Dichlorohex-5-en-2-one
($C_6H_8OCl_2$)

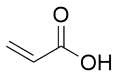


3-Bromo-3-chlorocyclobutane-1-carboxylic acid
($C_5H_6O_2ClBr$)

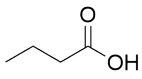
Acids: From Filthy Foul to Fruitily Fragrant (14.0 pts, 9%)

Carboxylic acids appear commonly in everyday life. Many of these short-chained carboxylic acids have unique tastes or odours. Let us first discuss three such carboxylic acids: acetic acid H**A** (smells like vinegar), acrylic acid H**B** (smells like acrid, burnt oil) and butyric acid H**C** (smells like aged cheese or vomit). The strength of these acids is given by their pK_a value. For most carboxylic acids such these three, pK_a values hover around 4.50.

H**A**
$pK_a = 4.76$
$M_{HA} = 60\ g \cdot mol^{-1}$



H**B**
$pK_a = 4.25$
$M_{HB} = 72\ g \cdot mol^{-1}$



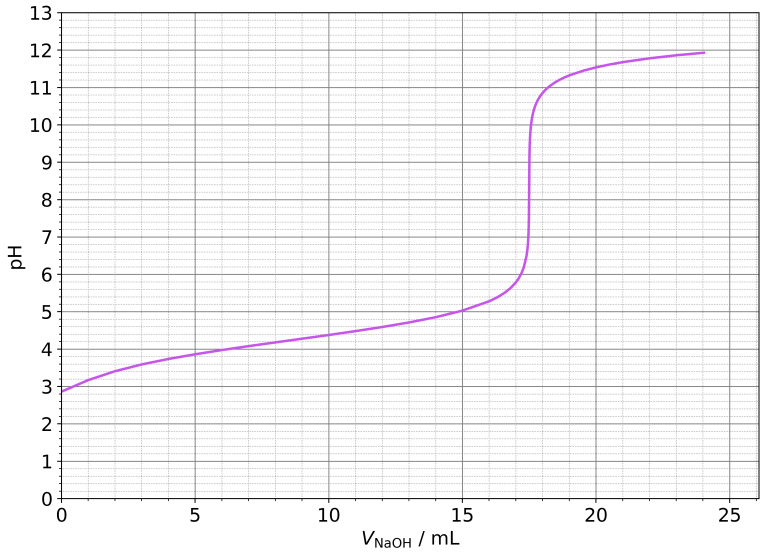
H**C**
$pK_a = 4.82$
$M_{HC} = 88\ g \cdot mol^{-1}$

2.1 **Give** the balanced equation for the deprotonation reaction of acetic acid H**A** with NaOH. **Use** the structural formula in your representation of H**A**. 1.0 pt

2.2 **Order** the acids H**A**, H**B**, and H**C** in order of increasing acid strength. 1.0 pt

_____ < _____ < _____

You find an unlabelled bottle in your lab that contains a solution of one of the three acids H**X** (either H**A**, H**B** or H**C**). With your trusty pH meter, you titrate a sample with a volume $V_{\text{sample}} = 50\,\text{mL}$ of the unknown solution of H**X** with NaOH ($c_{\text{NaOH}} = 0.100\,\text{mol L}^{-1}$) and get the following titration curve.



2.3 On the titration curve, **mark** a cross at the following points (no geometric determination/precision necessary): 2.0 pt

- Equivalence point (**mark** with "**1**")
- Half-equivalence point (**mark** with "**2**")

2.4 **Determine** the pK_a of the H**X** contained in the sample and **select** which one of the three acids was contained in your sample. 1.5 pt

pK_a = _____

☐H**A** ☐H**B** ☐H**C**

2.5 **Calculate** the mass $m_{\mathbf{HX}}$ in g of the unknown acid H**X** contained in your titrated sample. **Note:** If you could not determine what acid is contained in the sample in **2.4**, assume that $M'_{\mathbf{HX}} = 100\,\text{g mol}^{-1}$. 1.5 pt

$m_{\mathbf{HX}}$ = _____ g

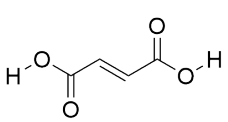
You find a different sample in your laboratory cabinet. It is a solution of H**A** with H**Y** (either H**B** or H**C**). You measure the ratio $\frac{[\mathbf{HA}]}{[\mathbf{A}^-]} = 0.91$. From your measurements, you can also tell that H**Y** appears more in its protonated than in its deprotonated form.

2.6 **Determine** if H**Y** is either H**B** or H**C**. **Explain** your answer. 3.0 pt

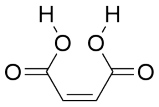
☐H**B** ☐H**C**

Explanation:

Lastly, let us consider two acids that taste fruity, tart and sweet: Fumaric acid H_2**D** and maleic acid H_2**E**. These two isomers only differ in the configuration of the central double bond, with H_2**D** being *trans*-configured, whereas H_2**E** is *cis*-configured. The differences in their pK_a values are remarkable. H_2**D** has pK_a values that are similar to other carboxylic acids. H_2**E** on the other hand, has a $pK_{a1} = 1.90$, which is significantly lower than most carboxylic acids. Its second $pK_{a2} = 6.07$ is significantly higher than expected.



H_2**D**
pK_{a1} = 3.03
pK_{a2} = 4.04



H_2**E**
pK_{a1} = 1.90
pK_{a2} = 6.07

2.7 **Explain** these findings for H_2**E** by considering the structure of the singly and doubly charged species $H\mathbf{E}^-$ and $\mathbf{E}^{2-}$ and listing stabilising and destabilising factors. 4.0 pt

Redox Chemistry with $KMnO_4$ (13.5 pts, 11%)

As an aspiring scientist, you step into the lab and notice a vibrant purple solution — potassium permanganate ($KMnO_4$). Curious of its oxidizing potential, you conduct some experiments.

Half Reaction	Standard Reduction Potential (E°/V)
$Au^{3+} + 3\,e^- \longrightarrow Au$	1.50
$MnO_4^- + 8\,H^+ + 5\,e^- \longrightarrow Mn^{2+} + 4\,H_2O$	1.49
$Cl_2 + 2\,e^- \longrightarrow 2\,Cl^-$	1.36
$MnO_2 + 4\,H^+ + 2\,e^- \longrightarrow Mn^{2+} + 2\,H_2O$	1.23
$Pt^{2+} + 2\,e^- \longrightarrow Pt$	1.22
$2\,IO_3^- + 12\,H^+ + 10\,e^- \longrightarrow I_2 + 6\,H_2O$	1.21
$Ag^+ + e^- \longrightarrow Ag$	0.80
$Mn^{2+} + 2\,e^- \longrightarrow Mn$	−1.18

3.1 **Provide** the oxidation state of the underlined Mn atom in the following compounds: 3.5 pt

$K_2\underline{Mn}O_4$ _____ $\underline{Mn}_2O_7$ _____ $\underline{Mn}SO_4$ _____

$(H_3O)_2\underline{Mn}(MnO_4)_6$ _____ $\underline{Mn}_2(CO)_{10}$ _____

Potassium permangante's redox behaviour depends on the pH. In an acidic medium, it reacts as follows:

$$MnO_4^- + 8\,H^+ + 5\,e^- \longrightarrow Mn^{2+} + 4\,H_2O$$

3.2 **Balance** the reduction of MnO_4^- in basic medium: 1.0 pt

_____ MnO_4^- + _____ H_2O + _____ e^- ⟶ _____ MnO_2 + _____ OH^-

Because you are a responsible chemist, you have read the safety instructions, so you know what happens when you mix concentrated hydrochloric acid with $KMnO_4$.

3.3 **Give** the balanced reaction between $KMnO_4$ and hydrochloric acid. 2.0 pt

3.4 **Name** the produced molecule and **explain** why it is more dangerous than $KMnO_4$. 1.0 pt

3.5 **Select** for the following solids if they react with $KMnO_4$ in an acidic solution and under standard condition. 1.5 pt

Au	☐ Reaction	☐ No reaction
Pt^{2+}	☐ Reaction	☐ No reaction
Ag	☐ Reaction	☐ No reaction

In the following, we want to find out what happens to the reduction potential, if we change the pH value and the concentration of $KMnO_4$. For this, you will need the Nernst equation for a half-cell:

$$E = E^\circ - \frac{RT}{zF} \cdot \ln(Q)$$

3.6 **Provide** the reaction quotient Q for the reduction of $KMnO_4$ in acidic medium. 0.5 pt
Note: Because the reaction happens in water, $[H_2O] = 1$.

$Q =$ _____

You have some $KMnO_4$ solution **A** with unknown ratio of Mn^{2+} and MnO_4^- ions. You put a few drops of solution **A** onto Pt, but nothing happens. Then you add some I_2 into the solution **A**, and you see that a reaction takes place. The experiments were conducted at $T = 25\,°C$.

3.7 **Calculate** the ratio $\frac{[Mn^{2+}]}{[MnO_4^-]}$ at pH = 3 of solution **A** using the Nernst equation. 4.0 pt

$\frac{[Mn^{2+}]}{[MnO_4^-]} =$ _____

Iodine: Quiet or Explosive (17.0 pts, 13%)

Iodine is a vital trace element with significant biological, chemical, and industrial importance, discovered in 1811 by French chemist Bernard Courtois. It is most commonly recognized for its role in human health, particularly in the synthesis of thyroid hormones, which regulate metabolism, growth, and development.

4.1 **Identify** the most stable oxidation state of iodine. 2.0 pt

Write the election configuration for iodine both in its elementary state and in its most stable oxidation state.

Explain why this oxidation state is considered the most stable one.

There are two beakers with liquid in front of you. One contains water, the other cyclohexane. To identify them, you added some iodine to each beaker.

4.2 **Predict** the colour of each solution after adding iodine. 3.0 pt

In water: _____ In cyclohexane: _____

State, whether iodine be well dissolved in both solvents.

Iodine dissolves well in water.	☐ True	☐ False
Iodine dissolves well in cyclohexane.	☐ True	☐ False

Explain your thinking.

You take a new beaker with 100 mL water. 0.254 g I_2 and 0.166 g KI are now added to the beaker. **Note**: I_2 and I^- combine to give the triiodide anion I_3^-.

4.3 **Predict** if you will get a clear liquid phase without precipitation and **explain** your reasoning. 2.0 pt

The phase will be clear. ☐ True ☐ False

Explanation:

4.4 **Draw** the three-dimensional geometric structure of I_3^- clearly, including all electron pairs. 1.0 pt

Iodine can form a variety of interesting and useful compounds due to its versatile chemical behaviour. An explosive example is NI_3.

4.5 **Draw** the three-dimensional geometric structure of NI_3 clearly, including all electron pairs. 1.0 pt

Reaction/Name	**Value**
$N_2(s) \longrightarrow N_2(l)$	$\Delta_{fus}H^\circ(N_2) = 0.7\,kJ\,mol^{-1}$
$N_2(l) \longrightarrow N_2(g)$	$\Delta_{vap}H^\circ(N_2) = 5.6\,kJ\,mol^{-1}$
$I_2(s) \longrightarrow I_2(l)$	$\Delta_{fus}H^\circ(I_2) = 15.6\,kJ\,mol^{-1}$
$I_2(l) \longrightarrow I_2(g)$	$\Delta_{vap}H^\circ(I_2) = 41.8\,kJ\,mol^{-1}$
$N(g) \longrightarrow N(g)^+ + e^-$	$IE(N) = 1402.3\,kJ\,mol^{-1}$
$N(g) + e^- \longrightarrow N^-(g)$	$EA(N) = -6.8\,kJ\,mol^{-1}$
$I(g) \longrightarrow I^+(g) + e^-$	$IE(I) = 1008.4\,kJ\,mol^{-1}$
$I(g) + e^- \longrightarrow I^-(g)$	$EA(I) = 295.0\,kJ\,mol^{-1}$
$N_2(g) \longrightarrow 2\,N(g)$	$BDE(N_2) = 945\,kJ\,mol^{-1}$
$I_2(g) \longrightarrow 2\,I(g)$	$BDE(I_2) = 151\,kJ\,mol^{-1}$
$NI_3(g) \longrightarrow N(g) + 3\,I(g)$	$BDE(NI_3) = 169\,kJ\,mol^{-1}$ **(per bond)**
Standard molar entropy of $N_2(g)$	$\Delta S^\circ(N_2(g)) = 191.6\,J\,mol^{-1}\,K^{-1}$
Standard molar entropy of $I_2(s)$	$\Delta S^\circ(I_2(s)) = 260.7\,J\,mol^{-1}\,K^{-1}$
Standard molar entropy of $NI_3(g)$	$\Delta S^\circ(NI_3(g)) = 344.3\,J\,mol^{-1}\,K^{-1}$

This table includes entries for various thermodynamic quantities concerning nitrogen, iodine and nitrogen triiodide.

4.6 Based on the data and reactions in the table, **determine** the molar formation enthalpy $\Delta_f H^\circ$ of gaseous NI_3 from $I_2(s)$ and $N_2(g)$ in $kJ\,mol^{-1}$. 4.0 pt

$\Delta_f H^\circ(NI_3(g)) =$ _____ $kJ\,mol^{-1}$

4.7 **Show** that the explosion reaction of nitrogen triiodide: 4.0 pt

$$2\,NI_3(g) \longrightarrow N_2(g) + 3\,I_2(s)$$

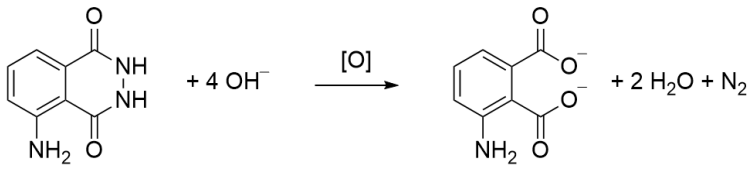
is spontaneous at $T = 298\,K$. **Note**: If you could not calculate $\Delta_f H^\circ(NI_3(g))$ in **4.6**, use $\Delta_f H^\circ(NI_3(g))' = 300\,kJ\,mol^{-1}$ instead.

Mark the correct driving force(s) for the reaction.

☐ enthalpy-driven
☐ entropy-driven
☐ both of the above
☐ none of the above

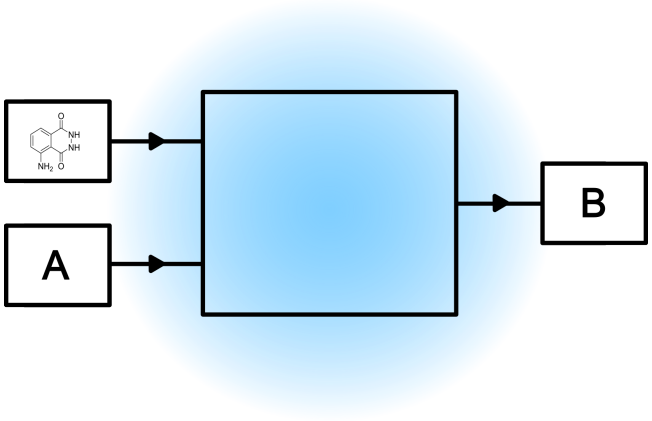
Luminol Literally Lighting Labs (11.0 pts, 13%)

Let's consider the following reaction:



In this reaction, luminol is oxidised to a 3-aminophthalate dianion. Under ideal conditions, the quantum yield of the reaction is approximately 0.01 so each molecule of luminol that reacts and enters an excited state has a $p = 1\,\%$ chance that a photon will be emitted. The wavelength of the emitted photon is $\lambda = 425\,\text{nm}$. We assume that the energy released in this oxidation of one molecule of luminol is either all lost as light or all lost as heat.

For the following exercise, we will be working with a reactor that allows us to control exactly how many moles of luminol are *reacting* inside the reactor per second. To achieve this, all reactants except for luminol (coming from **A**) are kept in large excess and luminol is gradualllly added to the reactor to keep the rate ($\text{mol}\,\text{s}^{-1}$) at which luminol is reacting constant. The products then flow into **B**.



We start our reactor and place solar cells all around the reactor to capture all the photons that are emitted. We measure that our solar cells are continually converting $P = 0.1\,\text{W}$ of light into electricity. We assume the efficiency of the solar cells is $100\,\%$ and that they are insensitive to infrared light.

5.1 **Calculate** the reaction enthalpy $\Delta_r H$ in kJ mol^{-1} and the rate r_1 in mol s^{-1} at which luminol is consumed in this reaction. 4.0 pt

$\Delta_r H =$ _____ kJ mol^{-1} $r_1 =$ _____ mol s^{-1}

Our lab experiences a power outage that does not affect our reactor. We want to replace the light bulb at the ceiling with our reactor (emits the same number of photons). The light bulb has an efficiency $\eta = 10\,\%$, emits light at $\lambda = 589$ nm and runs on a power $P = 60$ W.

5.2 **Calculate** the reaction rate r_2 in mol s^{-1} we need to replace the light bulb. 4.0 pt

$r_2 =$ _____ mol s^{-1}

Now we switch off our reactor. After 15 seconds, we measure the rate of emitted photons to be $\frac{N_{15}}{N_0} = 0.333$, where N_{15} is the rate measured after 15 s and N_0 is the rate measured while running the reactor at the conditions of task **5.2**. **Hint**: With all other reagents in vast excess, the reaction becomes first order in luminol concentration.

5.3 **Calculate** the value of $\frac{N_{42}}{N_0}$ at $t = 42$ s after switching off the reactor. 3.0 pt

$\frac{N_{42}}{N_0} =$ _____

5.4 **List** four reasons why illuminating your lab with a luminol reactor is a terrible idea. 2.0 pt

Carbon Clock: Archeology and *in vivo* Imaging (16.0 pts, 15%)

Radiocarbon dating uses the ^{14}C isotope to estimate the age of carbon-bearing material. This radioactive carbon isotope decays into ^{14}N.

6.1 **Choose** the particle emitted upon radioactive decay of ^{14}C. 1.0 pt

☐ α ☐ β^+ ☐ β^-

6.2 **Give** the kinetic order of radioactive decay. 1.0 pt

Order: _____

The use of ^{14}C isotope for archaeological age determination was proposed by Libby in 1949. For this purpose, however, the half-life of ^{14}C first needed to be determined. Libby found that a contemporary tree sample emits around 12.5 particles per minute per gram of carbon. For his research, he also measured the activity of one archaeological sample, which was 2928 years old at the time, and found that it emitted only 8.78 particles per minute per gram of carbon.

6.3 **Determine** the rate constant k in year^{-1} for the decay of ^{14}C. 2.5 pt

Assumptions:

- The level of ^{14}C in the atmosphere remains constant over time due to continuous synthesis in the upper atmosphere.
- Living organisms actively exchange carbon with their surroundings and maintain a constant ^{14}C-level.

k = _____ year^{-1}

6.4 **Determine** the half-life of ^{14}C in years. **Note**: If you could not determine k in **6.3**, use $k' = 1.00 \times 10^{-4}$ year^{-1} instead. 1.5 pt

$t_{\frac{1}{2}} =$ _____ years

6.5 **Propose** two coordinates, $f(r)$ and $g(t)$, such that any data obtained about the ^{14}C emission rate r and age t will plot as a single straight line. 1.0 pt

$f(r) =$ _____ $g(t) =$ _____

6.6 **Determine** the natural level of ^{14}C in contemporary carbon in parts per trillion (ppt). **Hint**: 1 ppt $= \frac{1\,\text{g}}{1 \times 10^{12}\,\text{g}}$. 2.5 pt

Level: _____ ppt

Another radioactive isotope of carbon, isotope **X**, forms ^{11}B upon decay (α, β^+, or β^-).

6.7 **Identify** the carbon isotope **X**, the decay type, and provide the corresponding nuclear reaction. 2.0 pt

X: _____

Emitted particle: ☐ α ☐ β^+ ☐ β^-

Equation:

Isotope **X** is used in drug discovery and medicine for *in vivo* imaging. The binary compound **A** ($w(\mathrm{O}) = 74.37\%$), which contains isotope **X**, is obtained directly from a cyclotron. Compound **A**, upon reduction with $LiAlH_4$ without quenching, yields compound **B** ($w(\mathrm{O}) = 43.27\%$). A subsequent reaction with HI then produces compound **C** ($w(\mathrm{I}) = 90.08\%$). Compound **C** is a key intermediate that can be used in nucleophilic substitution reactions to rapidly introduce isotope **X** into organic molecules. Notably, each of these chemical steps requires just 5 minutes. Chemical steps are automated and one happens immediately after the other.

6.8 **Identify** **A**, **B**, and **C**. Providing calculations is optional. 3.0 pt

A: _____ **B**: _____ **C**: _____

Typical activity of compound **A**, as obtained from cyclotron, is 300 MBq.

6.9 **Calculate** the activity $A_{\mathbf{C}}$ of the obtained sample of compound **C** (in MBq) immediately after the second step, assuming all synthesis steps are quantitative (100% yield). The half-life of isotope **X** is 20 minutes. 1.5 pt

$A_{\mathbf{C}} =$ _____ MBq

Gaslighting and Lighting Gasses (12.5 pts, 11%)

You find two gas cylinders in an old, dusty corner of your laboratory, neither of which are labelled with their contents. You are, however, sure, that both of them contain a single type of molecule. One of the cylinders contains substance **A**, whereas the other contains substance **B**.

In order to pass the next safety inspection, we must now figure out what the contents of the cylinder are and label them accordingly! First, we will gain some insight using density and masses. Then, we shall explore some reactions and try to light them on fire!

You fill gas **A** into a balloon. Once filled, the radius of the balloon measures $r = 12\,\text{cm}$.

7.1 **Calculate** the volume V_{balloon} in L filled with **A**, assuming the balloon to be a sphere. 1.0 pt

$V_{\text{balloon}} =$ _____ L

With some tricks, you determine the mass of the filled ballon to be $m_{\text{balloon+A}} = 14.203\,\text{g}$ under ambient conditions ($p = 1 \times 10^5\,\text{Pa}$, $T = 25\,°\text{C}$). Under the same conditions, a balloon inflated to the same radius with air, reads $m_{\text{balloon+air}} = 9.773\,\text{g}$. Air is a composition of 79% N_2 and 21% O_2 by mass.

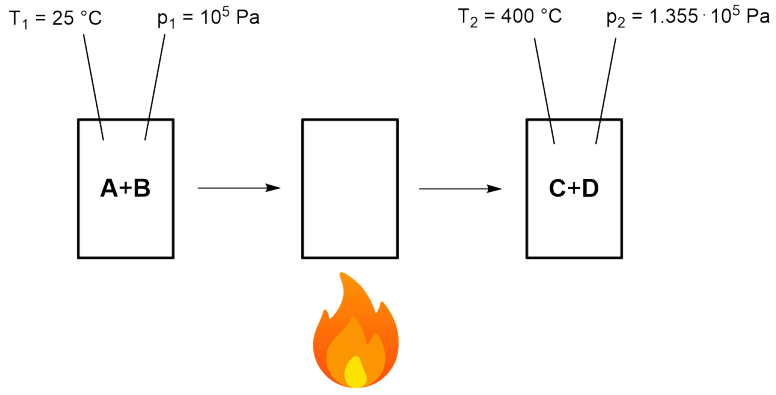
7.2 **Calculate** the mass of the empty balloon m_{balloon} in g. **Note**: If you could not calculate V_{balloon} in **7.1**, use $V'_{\text{balloon}} = 7.50\,\text{L}$ instead. 2.5 pt

$m_{\text{balloon}} =$ _____ g

7.3 **Calculate** the molar mass $M_{\mathbf{A}}$ of molecule **A** in g mol^{-1}. **Note**: If you could not calculate m_{balloon} in **7.2**, use $m'_{\text{balloon}} = 1.40$ g instead. 2.0 pt

$M_{\mathbf{A}} =$ _____ g mol^{-1}

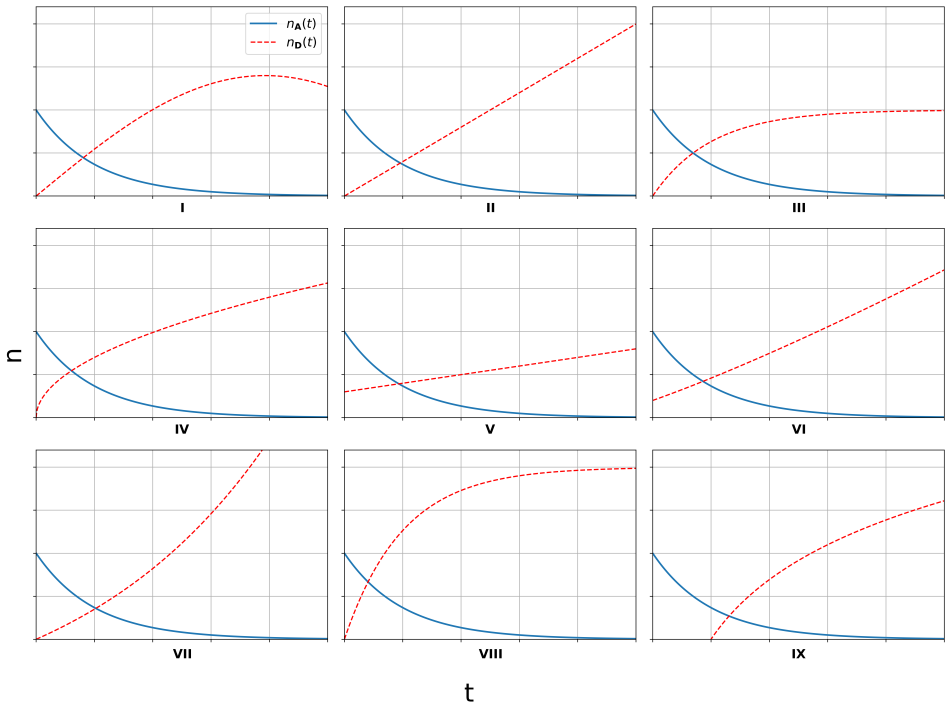
You experiment around with the gasses. Your reaction vessel with a constant volume $V_{\text{vessel}} = 5$ L is filled with 1 L of **A** with 4 L of **B** at $T_1 = 25$ °C. The mixture is then heated to $T_2 = 400$ °C. Once T_2 is reached, your pressure gauge shows a continuous drop in pressure at a constant temperature. Once the pressure has stabilised to $p_2 = 1.355 \times 10^5$ Pa at $T_2 = 400$ °C, you obtain a mixture of only two products, **C** and **D**.



7.4 **Explain** the reason why the pressure is dropping during this process. 1.0 pt

You then cool the mixture to room temperature and open the vessel. Product **D** is obtained as a colourless liquid with density $\rho_{\mathbf{D}} = 1\,\text{g mL}^{-1}$ with $m_{\mathbf{D}} = 1.45\,\text{g}$.

7.5 **Circle** the graph that correctly describes the amount of **D** $n_{\mathbf{D}}(t)$ over time, given the amount of **A** $n_{\mathbf{A}}(t)$. 2.0 pt



Lastly, you perform some experiments using fire and find the following:

- **A** extinguishes the flame.
- **B** explodes and reacts to **D**.
- **C** explodes and reacts to **A** & **D**.
- **D** extinguishes the flame.

7.6 **Assign** a chemical formula to all substances (**A**, **B**, **C** & **D**). **Balance** the reaction equation transforming **A** and **B** into **C** and **D**. 4.0 pt

A: _____ **B**: _____ **C**: _____ **D**: _____

_____ **A** + _____ **B** $\longrightarrow$ _____ **C** + _____ **D**

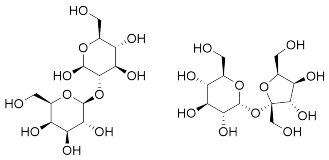
Tasting the Right (and Left) Sugars (16.0 pts, 11%)

Sugars are a group of structurally related molecules consisting of polyhydroxy aldehydes or ketones. Despite their structural similarities, sugars exhibit unique properties depending on their stereochemistry and oxidation states. In this exercise, we will be looking at various types of sugars, their similarities and differences, as well as a practical way to differentiate between them in the lab.

Isomers are molecules with the same chemical formula but different connectivity or spatial arrangement of atoms. Isomers can have vastly different properties, for example, while starch, a polymer of α-glucose, is digestible by humans and fundamental for our survival, cellulose, a polymer of β-glucose, is found in cell walls and is indigestible by humans.

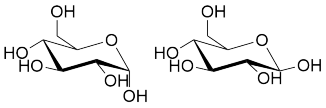
8.1 **Determine** the relationship between the following pairs of molecules by ticking the correct box. 6.0 pt

A



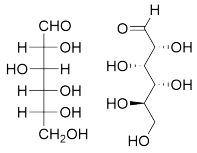
☐ identical
☐ enantiomers
☐ diastereomers
☐ constitutional isomers
☐ none of the above

B



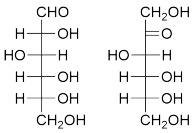
☐ identical
☐ enantiomers
☐ diastereomers
☐ constitutional isomers
☐ none of the above

C



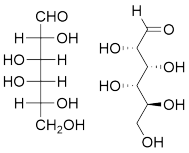
☐ identical
☐ enantiomers
☐ diastereomers
☐ constitutional isomers
☐ none of the above

D



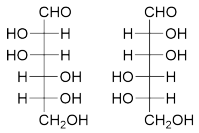
☐ identical
☐ enantiomers
☐ diastereomers
☐ constitutional isomers
☐ none of the above

E



☐ identical
☐ enantiomers
☐ diastereomers
☐ constitutional isomers
☐ none of the above

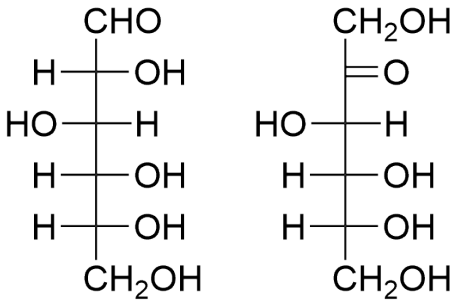
F



☐ identical
☐ enantiomers
☐ diastereomers
☐ constitutional isomers
☐ none of the above

8.2 **Circle** the stereogenic centres in the molecules from **D** and **determine** *R/S.* 2.0 pt

D



All simple sugars either contain an aldehyde or a ketone in their open form, and chemists have developed a simple test to distinguish between the two types. The reagent is prepared by mixing silver nitrate, sodium hydroxide and ammonia. In the presence of an aldehyde, silver will precipitate and form a "silver mirror" inside the glassware (positive test). In the case of a ketone, no reaction will take place, as ketones cannot be further oxidized (negative test).

8.3 **Provide** the name of this test. 1.0 pt

8.4 **Determine** the oxidation state of Ag in $[Ag(NH_3)_2]^+$ and $Ag(s)$. 1.0 pt

$[\underline{Ag}(NH_3)_2]^+$ _____

$\underline{Ag}(s)$ _____

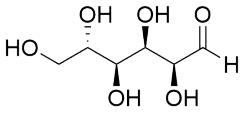
8.5 **Write down** the half-reaction and overall reaction between your sugar RCHO and the silver reagent $[Ag(NH_3)_2]^+$. 5.0 pt

Oxidation:

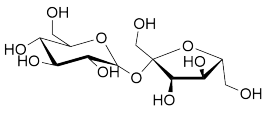
Reduction:

Overall reaction:

8.6 **Mark** which of the following sugars will produce a silver mirror, as described above. 1.0 pt



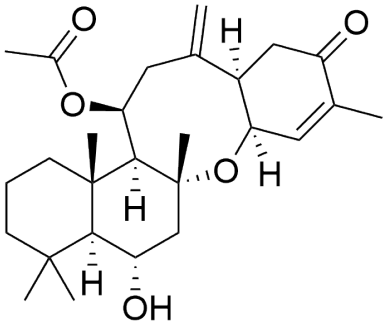
☐ positive test
☐ negative test



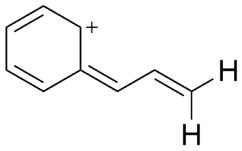
☐ positive test
☐ negative test

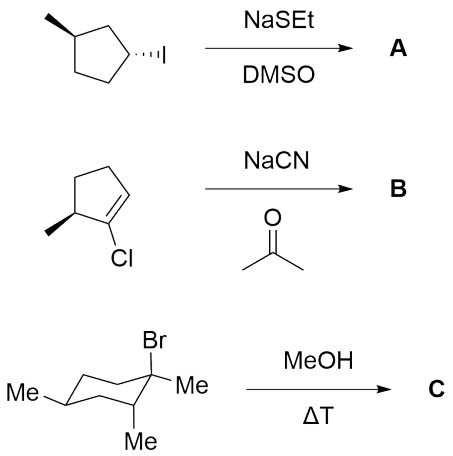
Organic Reactions (13.0 pts, 9%)

9.1 **Circle** all the stereogenic centres in the following molecule. 4.0 pt



9.2 **Draw** all the resonable possible resonance structures of the carbocation below. 3.0 pt





9.3 For the reactions provided above, **determine** which of the following reactions take place: 1.5 pt
S_N1, S_N2, E1, E2, $E1_{cb}$, S_NAr, no reaction

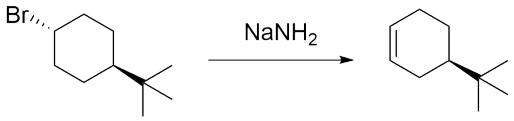
A: _____ **B**: _____ **C**: _____

9.4 **Draw** the major products **A**–**C**. If no reaction takes place, **place** a cross (×). 1.5 pt

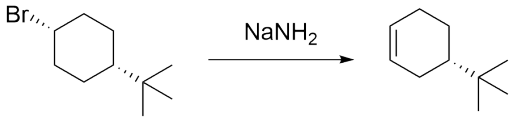
A	B	C

9.5 The two following eliminations (**1** & **2**) occur at different rates. **Explain** which of the two is faster and why using diagrams and drawings. 3.0 pt

1



2



Faster reaction: ☐ **1** ☐ **2**

Explanation: