SEMI-FINAL: Problems

Dear students,

We congratulate you on your participation in the Chemistry Olympiad and wish you every success in this second round, as well as in your studies and all your future endeavours. We also congratulate you on passing the first round, which has allowed you to move on to the 'Problems' test today. **Before starting this exam, please read the following carefully.**

You will find 4 problems attached. The subjects covered by these questions are: thermochemistry, redox reactions, quantum chemistry, general chemistry, stoichiometry and organic chemistry.

You have **two hours** (120 minutes) to answer the questions. You may use a non-programmable calculator, but you must not carry any personal documents.

Indicate your name and school name at the top of **each** question. Answer each question on the sheet of paper (front and back, if necessary) where the question appears. **Clearly show your reasoning and calculations. Justify your answers and indicate the units in your final answers.** The last sheet is a draft sheet that will not be taken into consideration for the assessment.

Following the assessment of this second test, the 12 best students will be invited to participate in a **training day**, which will take place on **Saturday, 28 March 2026** at the University of Luxembourg laboratories (Belval site), from 09h00 to 17h00. Further information will be provided to the finalists in due course. The **final (practical) exam** will take place on **Saturday, 25 April 2026** at the University of Luxembourg laboratories (Belval site). This final exam will select the four winners of the National Chemistry Olympiad, who will also form the Luxembourg team for the 58th IChO, which will be hosted by Uzbekistan from 10 to 19 July 2026 in Tashkent. More information is available on our website https://chimie.olympiades.lu/.

The results of this second round will be taken into account for the ranking of the four finalists!!!

We wish you all the best of luck and send you our warmest regards,

The Chemistry Olympiad organisers

Periodic table

I	II											III	IV	V	VI	VII	VIII	
1,0 H 1																	4,0 He 2	1
6,9 Li 3	9,0 Be 4											10,8 B 5	12,0 C 6	14,0 N 7	16,0 O 8	19,0 F 9	20,2 Ne 10	2
23,0 Na 11	24,3 Mg 12											27,0 Al 13	28,1 Si 14	31,0 P 15	32,1 S 16	35,5 Cl 17	39,9 Ar 18	3
39,1 K 19	40,1 Ca 20	45,0 Sc 21	47,9 Ti 22	50,9 V 23	52,0 Cr 24	54,9 Mn 25	55,8 Fe 26	58,9 Co 27	58,7 Ni 28	63,5 Cu 29	65,4 Zn 30	69,7 Ga 31	72,6 Ge 32	74,9 As 33	79,0 Se 34	79,9 Br 35	83,8 Kr 36	4
85,5 Rb 37	87,6 Sr 38	88,9 Y 39	91,2 Zr 40	92,9 Nb 41	95,9 Mo 42	(97) Tc 43	101,1 Ru 44	102,9 Rh 45	106,5 Pd 46	107,9 Ag 47	112,4 Cd 48	114,8 In 49	118,7 Sn 50	121,8 Sb 51	127,6 Te 52	126,9 I 53	131,3 Xe 54	5
132,9 Cs 55	137,3 Ba 56	57-71	178,5 Hf 72	180,9 Ta 73	183,8 W 74	186,2 Re 75	190,2 Os 76	192,2 Ir 77	195,1 Pt 78	197,0 Au 79	200,6 Hg 80	204,4 Tl 81	207,2 Pb 82	209,0 Bi 83	(209) Po 84	(210) At 85	(222) Rn 86	6
223 Fr 87	226 Ra 88	89-103	(267) Rf 104	(268) Db 105	(269) Sg 106	(270) Bh 107	(269) Hs 108	(278) Mt 109	(281) Ds 110	(282) Rg 111	(285) Cn 112	(286) Nh 113	(289) Fl 114	(290) Mc 115	(293) Lv 116	(294) Ts 117	(294) Og 118	7

Lanthanides	138,9 La 57	140,1 Ce 58	140,9 Pr 59	144,2 Nd 60	(145) Pm 61	150,4 Sm 62	152,0 Eu 63	157,3 Gd 64	158,9 Tb 65	162,5 Dy 66	164,9 Ho 67	167,3 Er 68	168,9 Tm 69	173,0 Yb 70	175,0 Lu 71
Actinides	(227) Ac 89	232,0 Th 90	231,0 Pa 91	238,0 U 92	(237) Np 93	(244) Pu 94	(243) Am 95	(247) Cm 96	(247) Bk 97	(251) Cf 98	(252) Es 99	(257) Fm 100	(258) Md 101	(259) No 102	(266) Lr 103

Constants:

R = 8,31 J·mol^{-1}·K^{-1}	1 F = 9,65 · 10^{4} C·mol^{-1}
R = 8,21 · 10^{-2} L·atm·mol^{-1}·K^{-1}	N_A = 6,022 · 10^{23} mol^{-1}
Volume of one mole of an ideal gas at 273 K and 101325 Pa: 22,4 dm^3·mol^{-1} (L·mol^{-1}).	
One year corresponds to 365 days.	

General chemistry:

The activity (*A*) in Becquerels (*Bq*) of a radioactive source is related to the number of nuclei (N) decaying and the half-life ($T_{1/2}$) of the radioisotope.

$$A = \frac{ln\,2}{T_{1/2}} \cdot N$$

The activity (A) at a given moment can be calculated using the initial activity (A_0) and its decay constant λ.

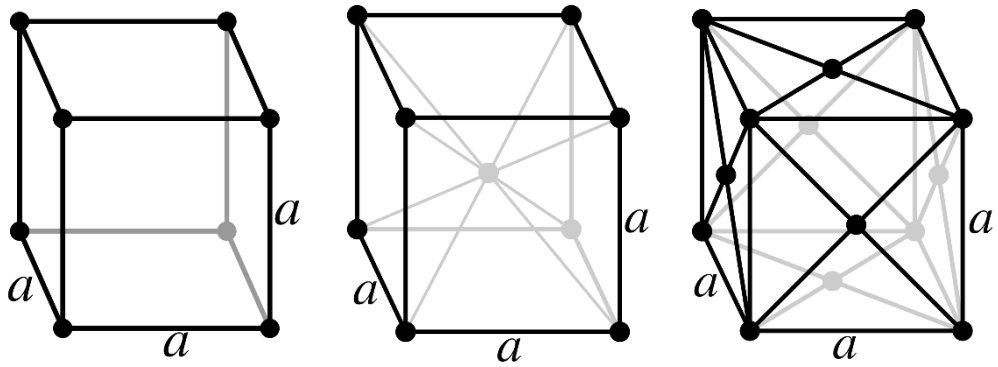
$$A = A_0 \cdot e^{-\lambda t}$$

$$\lambda = \frac{\ln 2}{T_{1/2}}$$

Faraday's law can be used to calculate the deposited mass m of a substance as a function of the current intensity I, the duration of electrolysis t, and the number of electrons exchanged during the redox reaction. M represents the molar mass of the substance in question and F corresponds to Faraday's constant.

$$m = \frac{M \cdot I \cdot t}{z \cdot F}$$

Cubic unit cells:



Name: _____

First Name: _____

School: _____

Problem I: Scintillating chemistry

1a	1b	1c	1d	1e	1f	1g	Total Problem I
2	4	5	3	3	3	4	24

Fireworks consist of a propulsion device (which carries the charge to altitude) and pellets (also called 'stars') that ignite in flight. It is the combustion of these pellets that causes the bang and releases the energy needed to excite the metal atoms, also contained in the pellets, to produce the colours visible from the ground.



Part A: combustion – heat – temperature – bang!

Let us assume that the fuel in the pellets consists of a cellulose monomer with the chemical formula $C_6H_{10}O_5$.

a) Write the equation for the complete combustion of cellulose.

A capsule typically contains 0.200 g of cellulose, whose enthalpy of formation at 25°C is $\Delta_f H^\circ = -1275\ \text{kJ} \cdot \text{mol}^{-1}$. In addition, the standard enthalpies of formation of CO_2 and H_2O gas are, at 25°C, -393.5 and $-241.8\ \text{kJ} \cdot \text{mol}^{-1}$ respectively.

b) Based on the above data, how much thermal energy will be released by the combustion of 0.200 g cellulose under standard pressure ($p = 1$ bar) and at 25°C ?

If combustion occurs adiabatically, i.e. all the combustion energy is used solely to heat the gaseous products formed by the reaction, it is possible to estimate the temperature of the gases after combustion. We will assume that the gases produced absorb all the thermal energy produced by combustion, that the temperature of the atmosphere around the capsule is initially 25°C, and that the pressure around the capsule is constant at standard pressure ($p = 1$ bar).



c) What temperature do the gases reach after combustion? The average molar heat capacities of CO_2 and H_2O gas are 50 and 36 $J \cdot mol^{-1} \cdot K^{-1}$ respectively and remain constant within the temperature range considered.



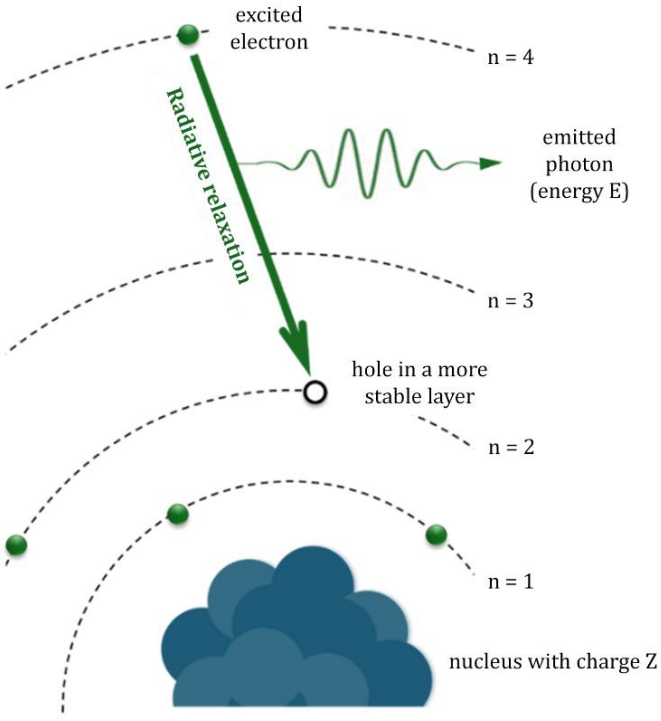
The shock wave caused by the instantaneous adiabatic expansion of the gases produced during explosive combustion in the atmosphere produces the characteristic bang of fireworks.

d) Calculate the final volume (in L), which will be occupied by the gases emitted during the combustion of 0.200 g cellulose. Assume that the gases produced behave like ideal gases and are instantly heated to the final temperature calculated in question C.

If you were unable to calculate the temperature in question C, use the value $T_{final} = 2000$ *K.*

Part B: radiative transitions

When pyrotechnic capsules explode, the metal atoms present in the charge are heated to high temperatures. Their electrons are then excited to unstable, high-energy energy levels (electron shells) called excited states (n_i), from which they will return to a more stable state (n_f). In doing so, they emit light: the energy is dissipated in the form of a photon with a specific energy *E* that is characteristic of each element.



It is possible to model these transitions based on Bohr's simplified model: the energy difference between two levels n_i and n_f corresponds to the energy of the emitted photon, E (*in eV*), according to the mathematical expression below.

$$E\ (in\ eV) = \frac{1240}{\lambda\ (in\ nm)} = 13.6 \cdot Z_{Eff}^2 \left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

where Z_{Eff} is the effective positive charge of the nucleus perceived by the electron in transition, taking into account the shielding effect of the core electrons.

e) Among the following statements, which one(s) is/are true?

	Core electrons are those furthest from the nucleus.
	Core electrons are those closest to the nucleus.
	Core electrons are the most stabilised in the atom.
	Core electrons are the least stabilised in the atom.
	Core electrons do not participate in chemical bonds.

Among the most common explosives used in pyrotechnics are chlorinated or nitrated salts of strontium, barium, copper and sodium, as well as aluminium powder, which produce red, green, blue, orange and white colours respectively.

f) In the case of Sr, the transition occurs between energy levels 5 and 4, and the electron involved is characterised by a Z_{Eff} of 2.50. What wavelength is associated with this transition and corresponds to a red photon?

g) The orange colour of sodium ($\lambda = 589$ nm) is produced by transitions of excited electrons in the n = 3 shell. Given that the electron involved has a Z_{Eff} of 1.06, to which energy level does it return to produce a photon with $\lambda = 589$ nm ?

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Problem II: Χρώμα

2a	2b	2c	2d	2e	Total Problem II
7	5	5	7	4	28

Chromium has a density of $\rho = 7{,}14\ \mathrm{g \cdot cm^{-3}}$. The atomic radius is 1,25 Å. Chromium crystallises in a cubic system, either body-centred or face-centred.

a) Determine in which of the two lattice types chromium crystallises and provide a clear calculation to support your conclusion.

Razor blades are made from an iron-chromium alloy. 0,1331 g of such a blade was dissolved in heated dilute sulphuric acid, forming iron(II) and chromium(III) ions. In the resulting solution, the iron was titrated with a permanganate solution ($c = 0{,}0205\ \mathrm{mol \cdot L^{-1}}$) forming iron(III) ions. The volume used was 20,08 $\mathrm{cm^3}$. The chromium(III) ions did not react under these conditions.

b) Provide the balanced ionic equations for the dissolution of iron, the dissolution of chromium and the titration reaction.

c) Calculate the mass fractions of iron and chromium in the alloy.

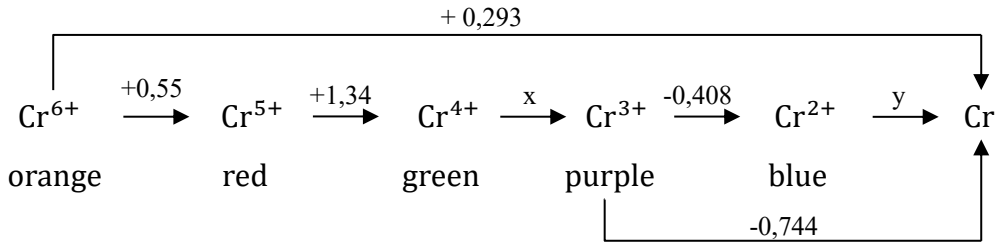
Chromium metal coatings can be produced by electrolysis. An electrolytic cell was filled with 100 L of an aqueous solution containing $230\,\mathrm{g}\cdot\mathrm{L}^{-1}$ anhydrous chromic acid (H_2CrO_4). Electrolysis was then carried out at a current of 1500 A for 10 hours. The chrome-plated objects served as the cathode, while the anode remained unaltered. The increase in mass at the cathode was 670 g.

d) Calculate the percentage yield for the process described.

Chromium compounds have a multicoloured appearance (Χρώμα = colour) depending on the degree of oxidation of the chromium.

The standard reduction potentials (at pH = 0) of these different ions can be represented in a Latimer diagram, where each arrow (going from left to right) represents the reduction potential $E°$ per electron gained.

Processes with positive potential occur spontaneously, while those with negative potential only occur under application of a voltage.



e) Calculate x and y using the diagram.

Name: _____

First Name: _____

School: _____

Problem III: Astatine monobromide

3a	3b	3c	3d	3e	3f	3g	3h	Total Problem III
2	5	2	1	2	2	2	5	21

The BrAt compound has a limited lifespan due to the radioactive decay of astatine. Astatine is the rarest naturally occurring element in the Earth's crust, with an estimated total mass of 30 g at any given time.

a) Estimate how many astatine atoms exist naturally on Earth at any given time. Assume that all astatine is the most stable naturally occurring isotope, ^{219}At.

Astatine can be synthesised from bismuth through a nuclear reaction. Bismuth is obtained as a by-product of lead refining. During purification, magnesium and calcium are added to form an alloy of lead and bismuth. Alloy A contains 7.91% Ca and 9.60% Mg by mass. There is no lead in alloy A.

b) Determine the empirical formula of alloy A**.**

Alloy A is separated from a second alloy, which contains lead, by reacting it with chlorine gas to form bismuth and two ionic compounds B and C in a 2:1 ratio.

c) Write the formulas for compounds B and C.

Astatine can be obtained by firing alpha particles at bismuth atoms. Alpha particles are high-energy ^{4}He nuclei emitted by a radioactive source. When an alpha particle collides with a bismuth nucleus, it forms an astatine isotope, ${}^{x}_{y}\mathrm{At}$, and two neutrons:

$$^{209}_{83}\mathrm{Bi} + \alpha \rightarrow {}^{x}_{y}\mathrm{At} + 2\ {}^{1}_{0}n$$

d) Write the mass and the atomic number of the astatine isotope, ${}^{x}_{y}\mathrm{At}$, that is formed.

Most bismuth atoms do not react and must be removed from the reaction mixture. After addition of concentrated nitric acid, bismuth reacts to form bismuth nitrate, a colourless gas with a molar mass of 30,01 g · mol^{-1}, and a third inorganic compound. Pure astatine, At_2, is isolated by extraction in an organic liquid with an organic solvent.

e) Write an equation for the reaction of bismuth with concentrated nitric acid.

BrAt can be synthesized from astatine in two steps. First, Br_2 reacts with D to form compound E. Compound E reacts with astatine to form BrAt. The mass spectrum of compound E shows two major peaks at m/z 205,82 and 207,82.

f) Give the formulas for D and E.

^{211}At is an alpha emitter used in targeted radiotherapy with a half-life of 432 minutes. A researcher prepares a radiopharmaceutical consisting of a monoclonal antibody labelled with ^{211}At. The injected dose contains 20 MBq ^{211}At. After injection, the antibody follows approximately exponential blood elimination kinetics with a biological half-life of 10 hours.

The effective half-life (T_{eff}) is the time required for the radioactivity of a substance in a living organism to be reduced by half, combining the physical radioactive decay (T_p) and biological decay (T_b):

$$\frac{1}{T_{eff}} = \frac{1}{T_p} + \frac{1}{T_b}$$

g) Calculate the effective half-life of the radiopharmaceutical in the blood.

h) Calculate the fraction of the injected activity that will remain in the blood after 12 hours.

Name: _____

First Name: _____

School: _____

Problem IV: Epoxides

4a	4b	4c	4d	4e	4f	4g	4h	Total Problem IV
1	2	2	2	4	4	6	6	27

Epoxy is a family of plastics that is extremely strong and chemically durable. It has a variety of applications, including high-strength adhesives, carbon fibre and decorative furniture.

Epoxy plastic is synthesised from epoxide molecules. An epoxide contains a three-atom ring with two carbon atoms and one oxygen atom. Epoxides are highly reactive due to the ring strain in the three-atom ring.

Examples of epoxides:

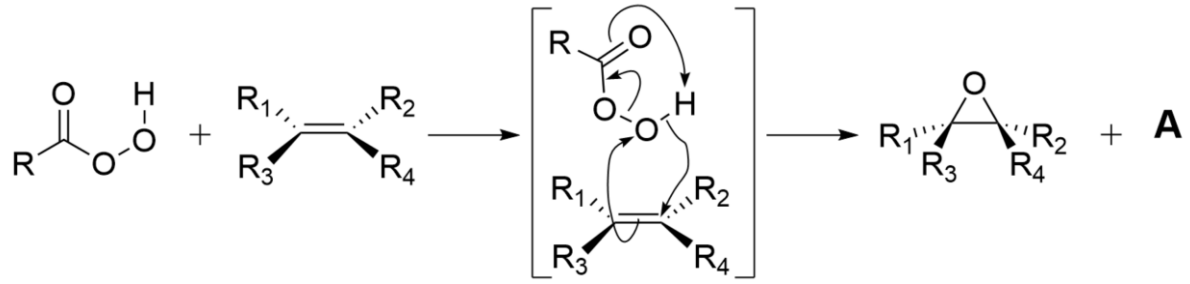


a) Indicate the general formula of an epoxide containing *n* carbon atoms.

b) Tick the approximate C – C – O bond angle for the following molecules:

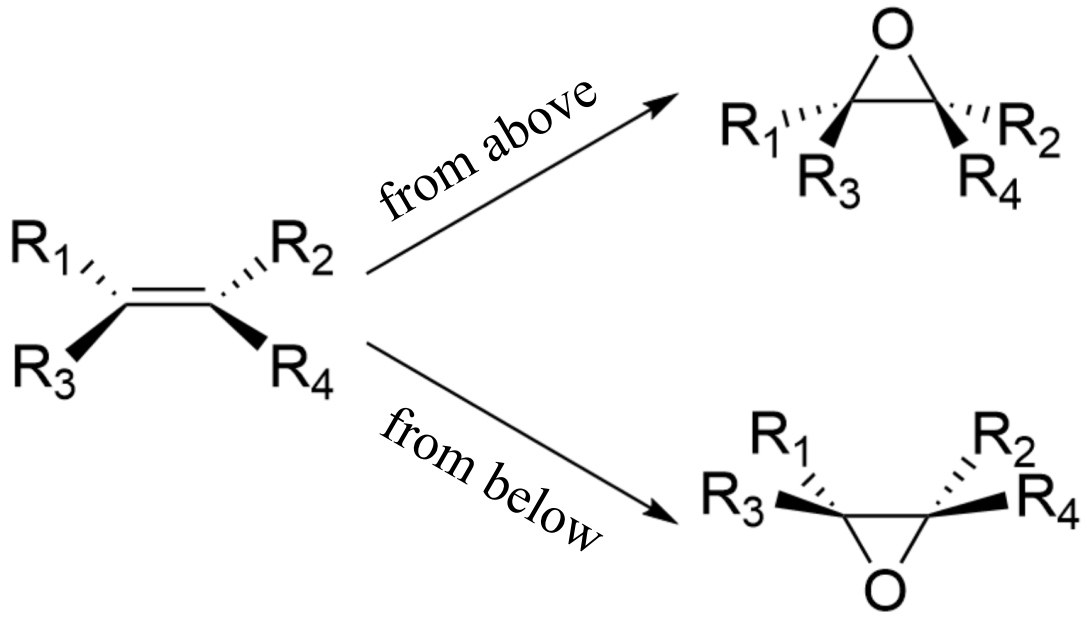
	60°	90°	104.5°	107°	109.5°	120°	180°
$C_2H_5OC_2H_5$							
							

A common method for forming epoxides is the reaction of alkenes with organic peracids. The mechanism of this reaction is illustrated below, with the transition state indicated in brackets.



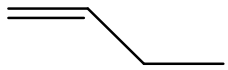
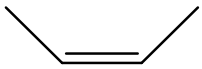
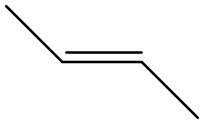
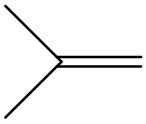
c) Draw the structure of compound **A**.

These peracids can add an oxygen atom either above or below the double bond, depending on the orientation of the approach. This can lead to the formation of stereoisomers.

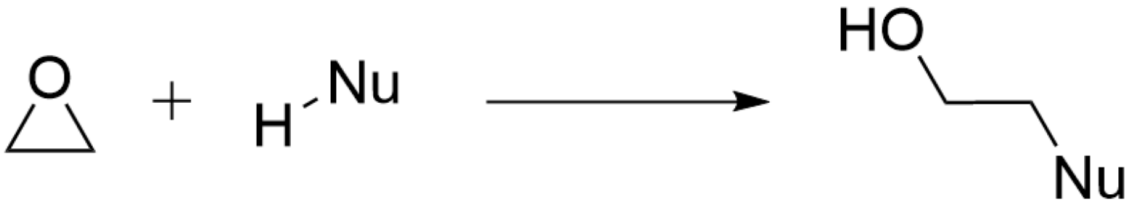


d) Draw the structures of the two stereoisomers formed when propene reacts with a peracid.

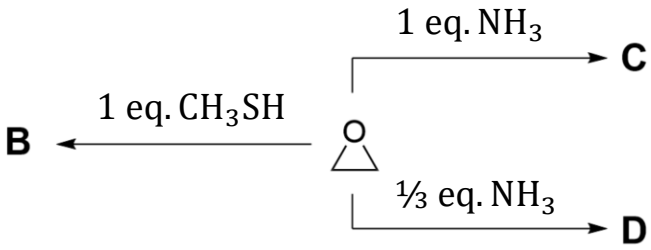
e) Tick the number of epoxide isomers that would be formed during the reaction of each of the C_4H_8 isomers with a peracid.

Isomer of C_4H_8	1	2	3	4
				
				
				
				

When epoxides react with a nucleophile, their three-atom ring is opened, as illustrated in the general scheme below.



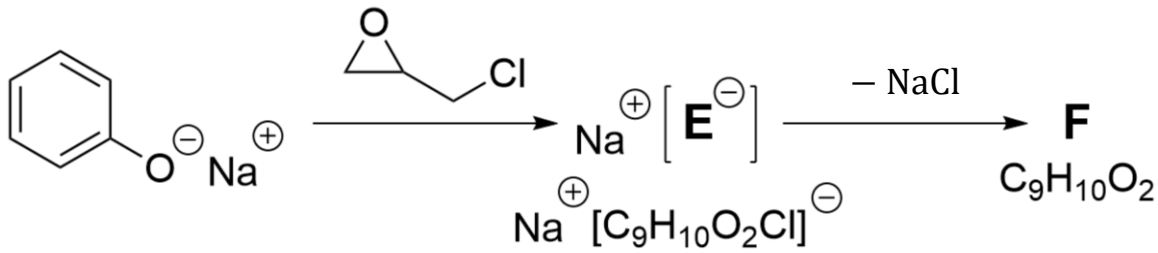
Consider the following reactions:



f) Draw the structures of compounds **B**, **C** and **D**.

B	**C**	**D**

A particularly versatile epoxide is epichlorohydrin (C_3H_5OCl). Sodium phenoxide reacts with epichlorohydrin to form the intermediate anion $\mathbf{E}^-$, which then cyclises to form epoxide **F**.



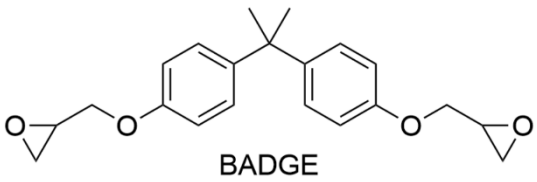
g) Draw the structures of the intermediate anion $\mathbf{E}^-$ and of compound **F**. Stereochemistry is not required.

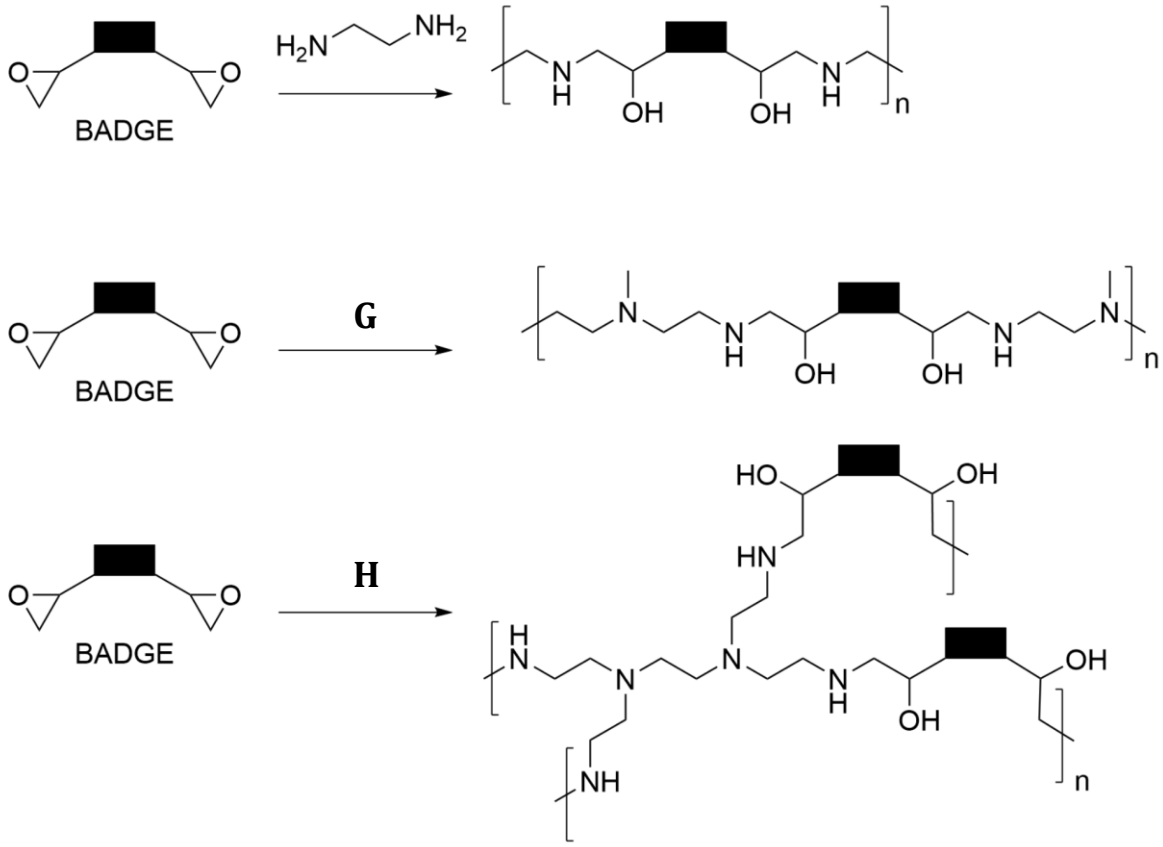
$\mathbf{E}^-$	**F**

To make epoxy plastic, an epoxy resin (which contains the epoxide) is mixed with a hardener (which contains the nucleophile).



A common ingredient in epoxy resin is bisphenol A diglycidyl ether, commonly known as **BADGE**. This reacts with a hardener to form epoxy. The repeating units of some epoxides are shown. The structure of BADGE has been simplified by a rectangular block.





h) Draw the structures of the hardeners **G** and **H**.

G	**H**

Draft sheet