58th INTERNATIONAL

CHEMISTRY OLYMPIAD

2026

UK Round One

STUDENT QUESTION BOOKLET

THE QUESTION BOOKLET MUST BE COLLECTED AFTER THE EXAM

* * * * *

- **The time allowed is two hours.**
- **Attempt all 5 questions.**
- **Write your answers in the student answer booklet.**
- **Write only the essential steps of your calculations in the answer booklet.**
- **Always give the appropriate unit and number of significant figures.**
- **A copy of the periodic table and some useful physical constants and formulae are provided as a separate document.**
- **Do *NOT* write anything in the right-hand margin of the answer booklet.**
- **The marks available for each question are shown below. These may be helpful when dividing your time between questions.**

Question	1	2	3	4	5	**Total**
Marks Available	8	18	19	26	13	**84**

Some of the questions will contain material you will not be familiar with. However, you should be able to work through the problems by applying the skills you have learnt as a chemist. There are different ways to approach the tasks – even if you cannot complete certain parts of a question, you may find later parts straightforward.

Q1 This question is about pee in the pool

Swimmer Michael Phelps, who has won the most Olympic gold medals, famously said, *"Everybody pees in the pool… chlorine kills it, so it's not bad."*

Swimming pools are commonly disinfected with chlorine. Chlorine reacts with water to form several disinfectant species, and the process must be carefully controlled to prevent the release of Cl_2 gas.

Chlorine reacts with water as follows:

$$Cl_2 + H_2O \rightarrow HOCl + HCl$$

(a) State the oxidation numbers of chlorine in each of these species: Cl_2, HOCl, and HCl.

On its own, this reaction would make the pool too acidic, and so other compounds such as Na_2CO_3 are added. This removes H^+ ions and prevents the backwards reaction reforming Cl_2.

(b) Write the equation for the reaction between sodium carbonate and hypochlorous acid (chloric(I) acid, HOCl).

Poor pool management can lead to a build-up of chlorate(V) ions (ClO_3^-). This is due to the slow disproportionation of chlorate(I) ions (OCl^-) into ClO_3^- and Cl^-.

(c) **(i)** Write the ionic equation for the disproportionation of chlorate(I) ions.

(ii) Name the shape of the ClO_3^- ion.

Urea, $(NH_2)_2CO$, found in urine, undergoes hydrolysis to form ammonia and carbon dioxide.

(d) Write the equation for this reaction.

Chloric(I) acid, HOCl, can react with this ammonia to form monochloramine (NH_2Cl), dichloramine ($NHCl_2$), and trichloramine (NCl_3).

(e) Draw a dot-and-cross diagram for the structure of NH_2Cl.

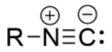
Trichloramine, NCl_3, is volatile and causes the characteristic 'chlorine smell' in swimming pools.

Henry's law states that the dissolved concentration of a gas is proportional to its partial pressure above the liquid. The constant of proportionality is called the Henry's law constant. For trichloramine in pool water, the Henry's law constant is 435 mol dm^{-3} atm^{-1}.

(f) For a concentration of NCl_3 of 5.0×10^{-4} mol dm^{-3} in the water, calculate the equilibrium partial pressure of NCl_3 above the pool (in atm).

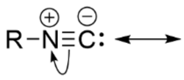
Q2 This question is about isocyanides

Isocyanides are organic molecules with extremely unpleasant odours. Chemists have described them as "horrible", "extremely distressing", and even "the Godzilla of smells". Despite this, isocyanides are important intermediates in many organic reactions.

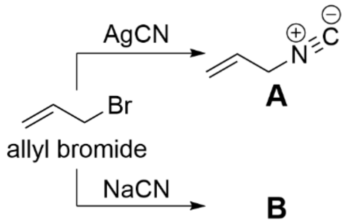


an isocyanide

(a) Draw the resonance structure for the isocyanide indicated by the arrow shown to the right. Indicate all lone pairs.



Isocyanides can be prepared by nucleophilic substitution. When AgCN is added to allyl bromide, the products are compound **A** and a cream-coloured precipitate. Repeating the reaction using NaCN instead of AgCN gives product **B**.



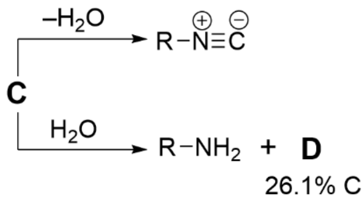
(b) **(i)** Draw the structure of compound **B**.

(ii) Identify the cream-coloured precipitate.

The threshold concentration at which an isocyanide can be detected by smell is 8.0×10^{-8} mol dm^{-3}.

(c) Calculate the number of molecules present at this detection limit in a room of volume 50 m^3.

Isocyanides can also be produced by dehydration of compound **C**. Compound **C** can be hydrolysed to give amine $R\text{-}NH_2$ and compound **D**. Elemental analysis shows **D** is 26.1% carbon by mass, independent of the identity of R.



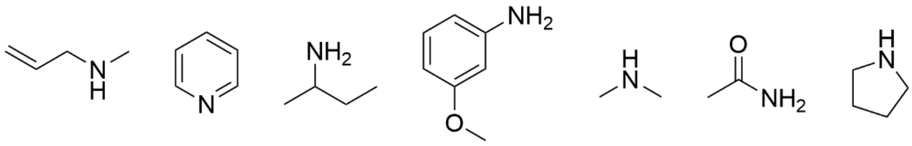
(d) **(i)** Draw the structure of compound **C**.

(ii) Draw the structure of compound **D**.

Amines can react with trichloromethane and sodium hydroxide to form isocyanides. This is known as Zaytsev's test. A positive result is indicated by the smell of isocyanide. Only some amines give a positive result; amides do not.

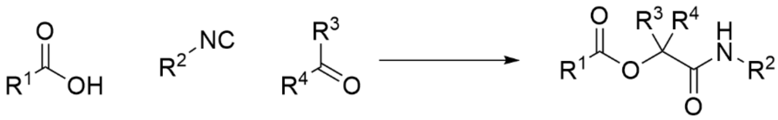
An amine with formula $C_3H_5NH_2$ gives a positive result and forms isocyanide **A** shown above, without producing any other organic products.

(e) Write the equation for this reaction to form isocyanide **A**. Write all species as molecular formulae.

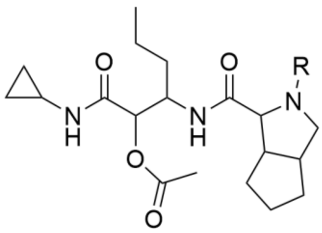


(f) In the answer booklet, circle which of the above compounds will give a positive Zaytsev's test result.

Isocyanides can react with a carboxylic acid and an aldehyde or ketone in one step to form a single product. This is called the Passerini reaction. R^1-R^4 indicate variable substituent groups.



A key intermediate in the synthesis of antiviral drug telaprevir, compound **E**, is formed using a Passerini reaction (where R represents the rest of the molecule).

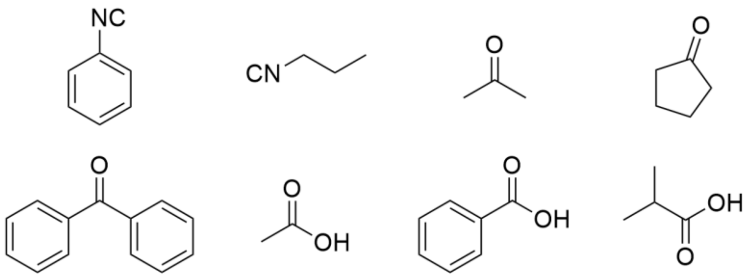


E

(g) Draw the three molecules that react to give compound **E** in the Passerini reaction. You do not need to consider stereochemistry for this part.

By combining multiple different isocyanides, carboxylic acids, and aldehydes/ketones, many products can be made.

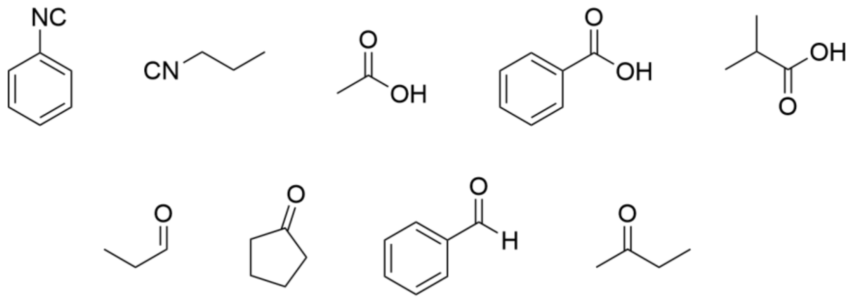
Chemist Isobel has the following compounds in her cupboard.



(h) Calculate the number of possible Passerini reaction products Isobel could make.

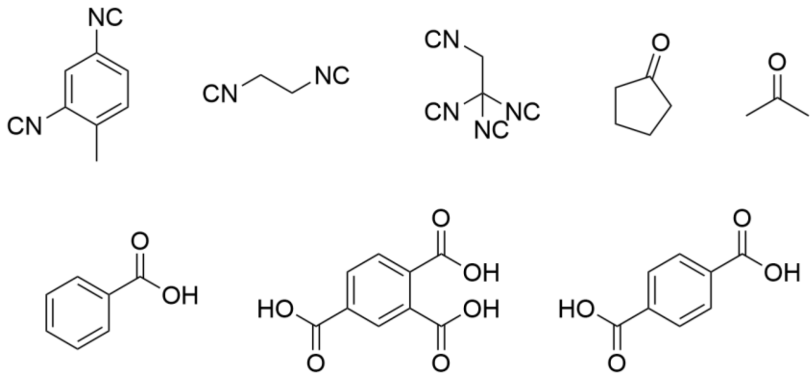
(i) On the general structure of the Passerini product in the answer booklet, indicate with a * which carbon atom has the potential to be a stereocentre.

Chemist Cynthia has the following compounds in her cupboard.



(j) Calculate the number of possible Passerini reaction products Cynthia could make. Count each enantiomer as a unique product.

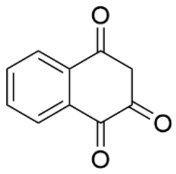
Chemist Galvin has the following compounds in his cupboard.



(k) Calculate the number of possible reaction products Galvin could make. Assume that each product results from the combination of only three of the molecules above (one isocyanide, one carboxylic acid, and one ketone).

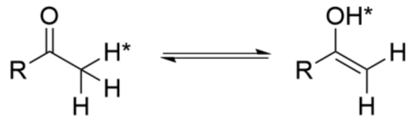
Q3 This question is about compounds in henna tattoos

Henna tattoos contain a compound called lawsone, which reacts with keratin in the skin to form a coloured product. Lawsone has three ketone groups and is an example of a molecule that undergoes tautomerism.



lawsone

Certain ketones exist in equilibrium with an alternative isomer called an enol. The keto and enol forms interconvert rapidly as a hydrogen atom (marked with *) and a double bond change position. These pairs of isomers are called tautomers, and their equilibrium is described by an equilibrium constant.



keto form enol form

(a) At equilibrium, a particular ketone exists in 99.997% of keto form, **A**, and in 0.003% of enol form, **B**. Calculate the equilibrium constant, K_1.

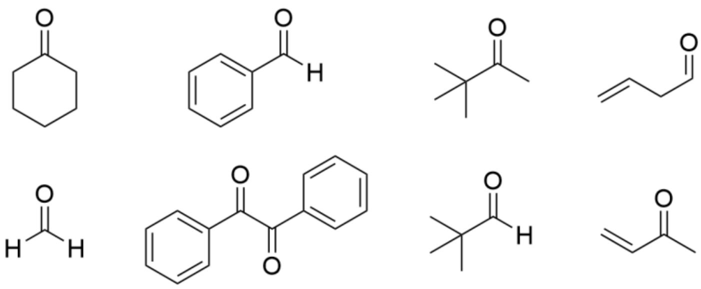
$$K_1 = \frac{[\mathbf{B}]}{[\mathbf{A}]}$$

(b) The equilibrium constant, K_2, between the keto form, **C**, and the enol form, **D**, of another ketone is 0.23. Calculate the percentage of **C** and **D** present at equilibrium.

$$K_2 = \frac{[\mathbf{D}]}{[\mathbf{C}]}$$

Enols can also be formed from aldehydes. However, to form an enol, the carbon atom next to the carbon of the C=O group must have a hydrogen atom which can be removed.

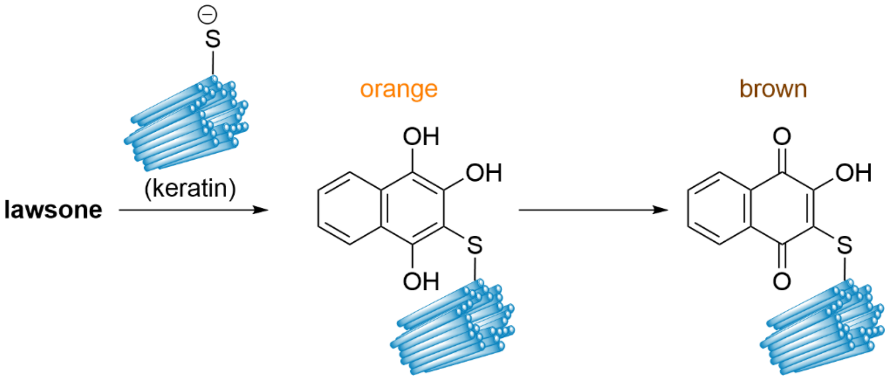
(c) Circle in the answer booklet which of the following aldehydes and ketones can form tautomers.



(d) **(i)** Lawsone can form two different enol isomers. Draw the structure of **both** enol forms.

(ii) One enol isomer is stabilised by an intramolecular hydrogen bond. Add this hydrogen bond to your drawing in part **(d)(i)** using a dotted line.

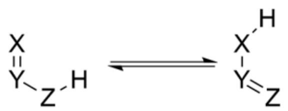
Upon addition to the skin, the lawsone in henna reacts with thiolate anions present in the side chain of keratin proteins in the skin. This gives the skin an orange colour. Over time, a chemical reaction takes place and the colour changes to brown.



(e) Classify the reaction that causes the colour change from orange to brown. Tick the correct answer in the answer booklet.

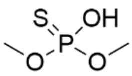
electrophilic aromatic substitution	nucleophilic aromatic substitution	reduction	oxidation	hydrolysis

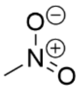
Tautomerism is observed with a wide range of functional groups. It can be represented by the following general equation:



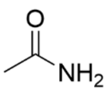
X, Y, and Z represent atoms that may or may not be the same and they may or may not have further atoms attached. Tautomerisation typically takes place when atom X is highly electronegative (*e.g.*, X = O or N), making the X=Y bond strongly polarised and the X–H and Z–H bonds relatively acidic.

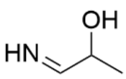
(f) Draw the tautomer of the following compounds.

(i) 

(ii) 

(g) Draw **all possible** tautomers of the following compounds. You do not need to consider stereochemistry.

(i) 

(ii) 

The standard enthalpy change, $\Delta_r H^\ominus$, for a tautomerisation of a ketone to an enol in the gas phase can be estimated from average bond enthalpies.

Bond	Bond enthalpy $\Delta H^\ominus$ / kJ mol^{-1}	Bond	Bond enthalpy $\Delta H^\ominus$ / kJ mol^{-1}
C–C	348	C–O	360
C=C	612	C=O	743
C–H	412	O–H	463

(h) Calculate $\Delta_r H^\ominus$ for a typical ketone to enol tautomerisation.

In lawsone the contribution from the hydrogen bond (and other factors) should also be considered. In the gas phase, the $\Delta_r H^\ominus$ for the ketone to enol tautomerisation of the preferred tautomer of lawsone is −32.58 kJ mol^{-1}. The standard entropy change, $\Delta_r S^\ominus$, for this reaction is −11.48 J K^{-1} mol^{-1}.

(i) Calculate the equilibrium constant, K_{gas}, for this ketone to enol tautomerisation of lawsone in the gas phase at 298 K.

If you do not get an answer for ***(i)****, assume the answer is 3.05 × 10^6.*

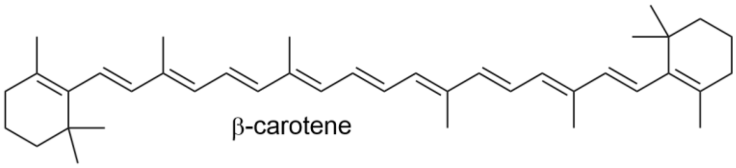
The Gibbs free energy change of solvation, $\Delta_{sol} G^\ominus$, differs between the keto and enol forms of lawsone. $\Delta_{sol} G^\ominus_{keto}$ = −126.0 kJ mol^{-1}; $\Delta_{sol} G^\ominus_{enol}$ = −109.2 kJ mol^{-1}.

Gibbs free energies can be summed in a cycle similar to a Hess's Law cycle used for enthalpy changes.

(j) Calculate the equilibrium constant, K_{water}, for the ketone to enol tautomerisation of lawsone in water at 298 K.

Q4 This question is about rice, spice, and mice

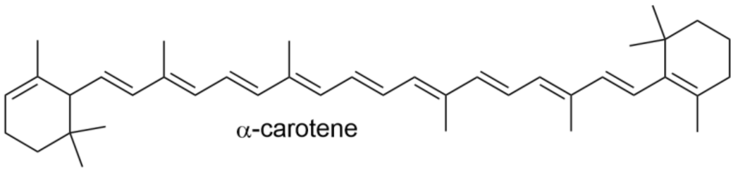
The national dish of Uzbekistan, host nation for the 2026 International Chemistry Olympiad, is called pilaf. Pilaf is a rice dish, typically containing lamb, carrots, and spices. Its characteristic colour comes from the carotene pigment found in carrots, which has several different isomers.



β-Carotene contains 40 carbon atoms, 11 C=C bonds, and two rings.

(a) Write the molecular formula for β-carotene.

The colours in carotenes come from their long chains of alternating C=C and C–C bonds. We say C=C bonds in these types of chains (*e.g.*, -C=C–C=C-) are conjugated. α-Carotene has a more yellow colour and β-carotene a more orange colour due to different numbers of conjugated C=C bonds.



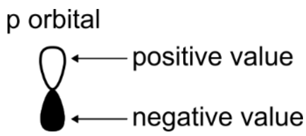
(b) Write the number of conjugated C=C bonds in:

(i) α-carotene

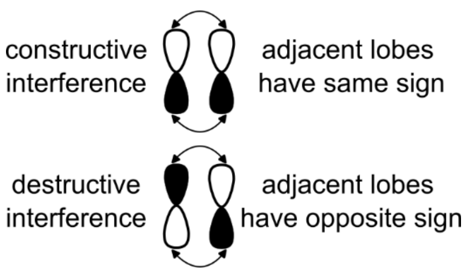
(ii) β-carotene

Molecular orbitals help us understand why molecules with conjugated C=C bonds absorb visible light. Molecular orbitals give information about the location of electrons in a molecule.

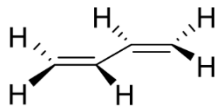
The shapes of orbitals are derived from mathematical functions called wavefunctions. In any region of space, the value of a wavefunction can be positive or negative. We represent the regions of an orbital where the wavefunction is negative by shading them black. p orbitals, for example, always have one region where the wavefunction is negative, and one region where it's positive.



Molecular orbitals for conjugated systems can be generated by considering the interference between p orbitals. In ethene, for example, the two p orbitals involved in the pi bond interfere to make two molecular orbitals.

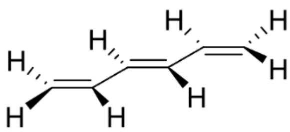


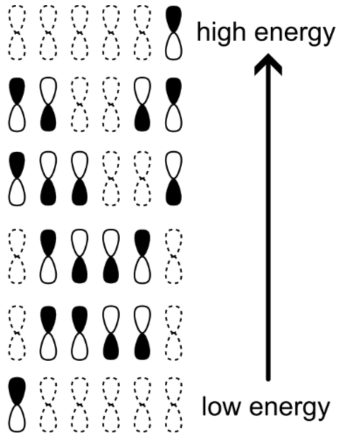
In butadiene, the four p orbitals in the conjugated C=C bonds interfere to form four molecular orbitals.



(c) By considering the amount of constructive and destructive interference between neighbouring p orbitals, order these molecular orbitals from lowest to highest in energy.

In hexatriene the six p orbitals involved in the conjugated C=C bonds interfere to form six molecular orbitals.





(d) In the answer booklet, complete the diagram of molecular orbitals for hexatriene by shading in the correct parts of the p orbitals.

Conjugated alkenes absorb light whose wavelength corresponds to the energy gap between two of these molecular orbitals. We can approximate the energy gap using this equation:

$$\Delta E = 4\beta \sin\left(\frac{90°}{N+1}\right)$$

N = number of p orbitals in conjugated system

β (hexatriene) = 6.85×10^{-19} J

(e) **(i)** Calculate the energy gap in hexatriene.

(ii) Calculate the wavelength of light absorbed by hexatriene. Give your answer in nanometres to the nearest whole number.

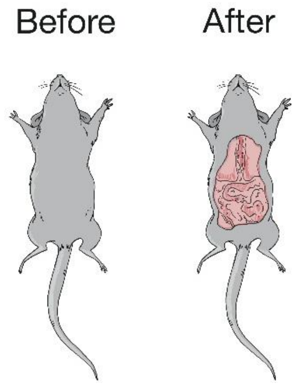
If you do not get an answer for ***(e)(ii)****, assume the answer is 200 nm.*

Visible light has wavelengths between 380 nm (violet) and 720 nm (red).

(f) Based on your answer to **(e)(ii)**, tick in the answer booklet whether hexatriene absorbs visible light or not.

(g) In the answer booklet, tick what happens to the wavelength of light absorbed as the number of conjugated C=C bonds increases. Assume that the value of β does not change.

it decreases	it stays the same	it increases



Tartrazine is a food dye. It is best known for giving *Nacho Cheese Doritos*® their distinctive yellow-orange colour, but now it has got a much more unusual application.

Mouse skin isn't normally transparent because it contains regions with different refractive indices. Spreading a tartrazine solution onto mice makes their skin temporarily transparent. This allows the study of blood vessels, muscles, and internal organs without invasive surgery.

aqueous regions, refractive index = 1.33 fatty regions, refractive index = 1.45

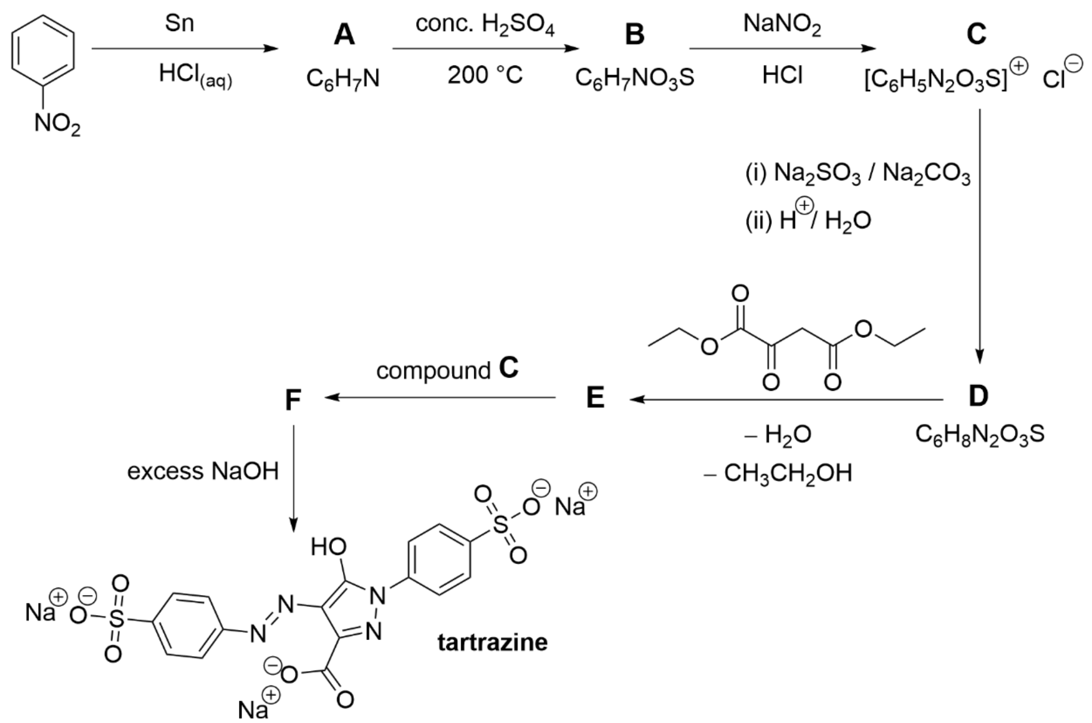
When tartrazine dissolves into the aqueous regions, it changes their refractive index, n. The change in refractive index is related to the concentration of tartrazine (in mol dm^{-3}) in the aqueous region, c_t, as follows:

$$\Delta n = 0.143c_t$$

When the refractive index of the aqueous regions is equal to the refractive index of the fatty regions, the mouse's skin becomes transparent. M_r(tartrazine) = 534.4 g mol^{-1}.

(h) Assume the total volume of aqueous regions in a mouse's skin is 8.50 cm^3. Calculate the minimum mass of tartrazine required to make this mouse's skin transparent.

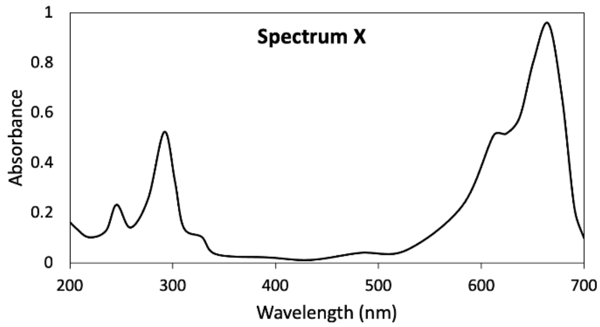
The synthesis of tartrazine from nitrobenzene is shown below.



(i) Draw the structures of compounds **A**-**F**.

Hint: Na_2SO_3 is a reducing agent.

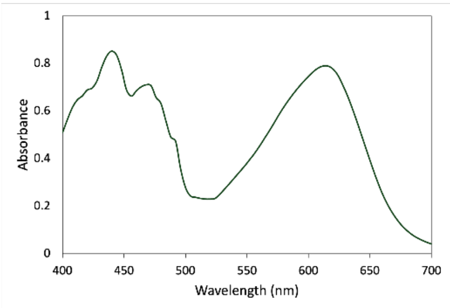
One way of differentiating between β-carotene and tartrazine is by investigating which wavelengths of light they absorb using UV-vis spectroscopy. The wavelengths of UV and visible light that the sample absorbs are used to produce a spectrum.

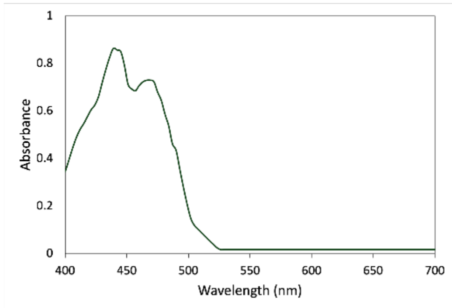


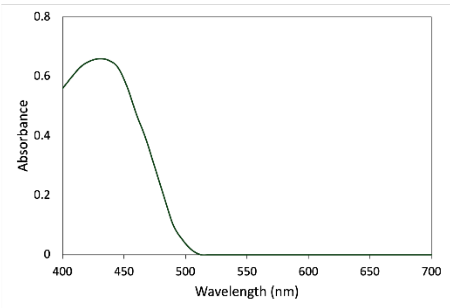
(j) Suggest the colour of substance **X** based on its UV-vis spectrum above.

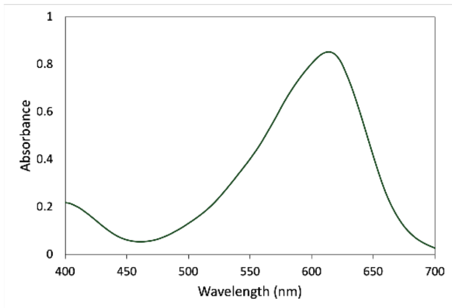
blue	yellow	orange	red

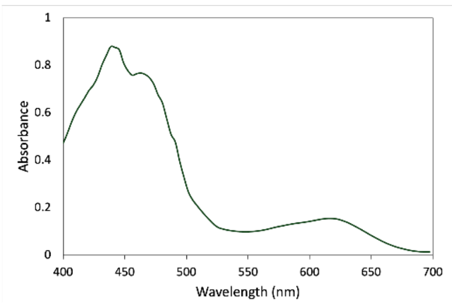
A sample containing tartrazine, β-carotene, and a pH indicator was added to diethyl ether. Aqueous HCl was added, the mixture shaken, and the layers were left to separate. The aqueous layer gave spectrum **1** and the organic layer gave spectrum **2**. A base was then added to the organic layer, which caused a colour change. The organic layer now gave spectrum **3**. The diethyl ether was then evaporated from the organic layer and ethanol was added to the residue. Any undissolved solids were filtered off and dissolved in hexane. The ethanol solution gave spectrum **4**, and the hexane solution gave spectrum **5**.









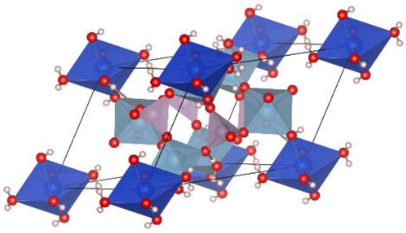


(k) In the answer booklet, label these spectra as **spectra 1-5**.

Q5 This question is about minerals

The 10th Century chemist, al-Bīrūnī, was born in Uzbekistan. Al-Bīrūnī developed tests for distinguishing similar-looking minerals from each other, and so is known as one of the earliest scientific mineralogists. He studied turquoise, a valuable blue-green gemstone.

Turquoise has an idealised formula of $CuAl_6(PO_4)_4(OH)_x{\cdot}yH_2O$. The oxidation state of copper in this mineral is 2+.



(a) Determine the number of hydroxide ions, x, present in this formula.

If you do not get an answer for ***(a)****, assume the answer is x = 10.*

A simple way to identify a gemstone is destructive analysis to determine the elemental content. The water content of turquoise is variable and y can range from 2 to 8. This water can be removed by heating in a kiln. Elemental analysis was carried out on a sample of dehydrated pure turquoise.

(b) Determine the percentage copper by mass in this dehydrated sample to three significant figures.

Libethenite, Cu_2PO_4OH, is blue-green copper-containing mineral similar in appearance to turquoise. Six mineral samples were analysed.

Sample	A	B	C	D	E	F
% Cu by mass	0%	7%	11%	17%	46%	53%

(c) Calculate which sample from the table was pure libethenite and which was pure turquoise.

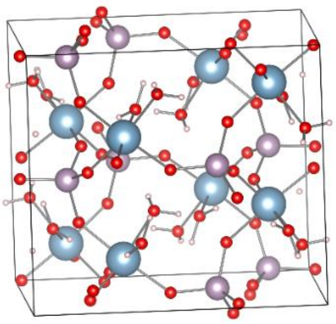
Turquoise is intermediate in composition between libethenite and another blue-green mineral, variscite, $AlPO_4{\cdot}2H_2O$. These minerals can be easily distinguished by chemical analysis.

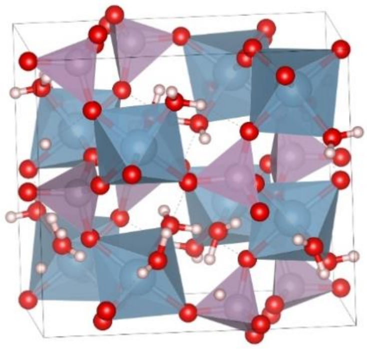
Al-Bīrūnī only had access to simple chemical analysis. He had to rely on other measurements such as the comparison of mineral densities. Densities can be calculated from the size and composition of the crystal unit cell. The unit cell is the periodically repeating unit making up the crystal.

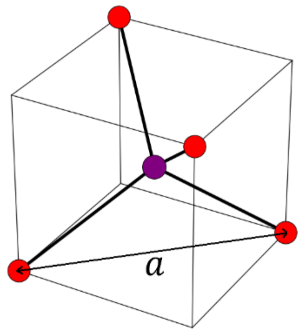
The unit cell of variscite is shown. It consists of eight formula units.

Within the unit cell we can see 'AlO_6' octahedra, where an Al^{3+} is surrounded by six oxygens in an octahedral shape. Two of these oxygens are part of water molecules. The others can be considered as O^{2-} ions. There are also 'PO_4' tetrahedra, where a P(V) centre is surrounded by a tetrahedron of four oxygens (like the phosphate anion). These can be considered as O^{2-} ions.

All O^{2-} ions are shared between two polyhedra (octahedra or tetrahedra).







A regular tetrahedral molecule is shown drawn inside a cube. The volume of a regular tetrahedron, V_{tet}, of edge length, a, is:

$$V_{\text{tet}} = \frac{1}{6\sqrt{2}} a^3$$

(d) Determine the volume of the PO_4 tetrahedron in Å^3. The P–O bond length is 1.54 Å.

If you do not get an answer for ***(d)****, assume the answer is 1.50 Å^3.*

The volume of the unit cell can be approximated as the sum of the volume of the octahedra, tetrahedra, water molecules, and empty spaces. Each water molecule contributes an extra 20 Å^3 volume. The AlO_6 octahedron has a volume of 9.00 Å^3.

(e) **(i)** Calculate the volume of the unit cell of variscite in Å^3. Assume the cell is 50% filled by tetrahedra, octahedra, and water.

If you do not get an answer for ***(e)(i)****, assume the answer is 969 Å^3.*

(ii) Calculate the density of variscite in g cm^{-3}.

Turquoise, consists of six 'AlO_6' octahedra, one 'CuO_6' octahedron, and some 'PO_4' phosphate tetrahedra. The Cu–O bond length is 2.29 Å. The Al–O bond length is 1.89 Å and the P–O bond length is 1.54 Å (both the same as in variscite). The volume of a regular octahedron, V_{oct}, of edge length, a, is:

$$V_{\text{oct}} = \frac{\sqrt{2}}{3} a^3$$

Assume that turquoise contains six molecules of water of crystallisation in the formula unit (y = 6) and the cell is 70% filled by tetrahedra, octahedra, and water/hydroxide. Like water, each hydroxide also contributes an extra 20 Å^3 volume.

(f) **(i)** Calculate the volume of the unit cell of turquoise in Å^3.

If you do not get an answer for ***(f)(i)****, assume the answer is 444 Å^3.*

(ii) Determine the density of turquoise in g cm^{-3}.

Acknowledgements & References
References will be added to the version of the paper uploaded to the web later.

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