SECTION A: MULTIPLE CHOICE
USE THE ANSWER SHEET PROVIDED

1. Which of the following molecules contains 36.86% nitrogen by mass?

   A. NO

   B. N_2O

   C. N_2O_3

   D. N_2O_4

   E. N_2O_5

2. Which of the following lists elements in order of increasing atomic radius?

   A. K, Se, Cl

   B. K, Cl, Se

   C. Se, Cl, K

   D. Se, K, Cl

   E. Cl, Se, K

   F. Cl, K, Se

3. What is the total number of valence electrons in the $S_4O_6^{2-}$ ion?

   A. 58

   B. 60

   C. 62

   D. 82

   E. 224

4. Which of the following has a bond angle closest to 120°?

   A. CO_2

   B. PCl_3

   C. SCl_2

   D. CCl_4

   E. BCl_3

5. Which of the following lists substances in order of increasing boiling point?

   A. Cl_2, SCl_2, $MgCl_2$

   B. Cl_2, SCl_2, $MgCl_2$

   C. $MgCl_2$, Cl_2, SCl_2

   D. SCl_2, Cl_2, $MgCl_2$

   E. SCl_2, $MgCl_2$, Cl_2

   F. Cl_2, $MgCl_2$, SCl_2

6. Limestone ($CaCO_3$) can be eroded by acids. What volume (in mL) of 11.5 mol L^{-1} nitric acid (HNO_3) is required for complete reaction with 24.7 g of limestone?

   A. 10.7 mL

   B. 11.5 mL

   C. 21.5 mL

   D. 42.9 mL

   E. 85.8 mL

Questions 7 relates to the following information.

Effusion refers to the process where a gas passes from a container, through a very small hole, into a vacuum. The rate at which different gases effuse is inversely proportional to the square roots of their relative molecular masses. Mathematically,

$$\frac{\text{rate of effusion of gas A}}{\text{rate of effusion of gas B}} = \sqrt{\frac{M_B}{M_A}}$$

where M_A and M_B are the relative molecular masses of A and B

7. A mixture containing equal amounts of S_2F_2 and SF_4 is allowed to effuse from a container, through a small hole, into a vacuum. What is the ratio of S_2F_2/SF_4 molecules present in the gas that first emerges?

   A. 0.89

   B. 0.95

   C. 0.97

   D. 1.03

   E. 1.06

   F. 1.12

8. The complete combustion of ethanamine ($C_2H_5NH_2$) produces carbon dioxide, nitrogen and water. What amount of oxygen is required for the complete combustion of 1.00 mol of ethanamine?

   A. 1.75

   B. 3.50

   C. 3.75

   D. 5.50

   E. 7.50

9. The reaction of ilmenite ($FeTiO_3$) with chlorine and carbon can be used in the industrial production of titanium from ilmenite:

$$2FeTiO_3 + 7Cl_2 + 6C \rightarrow 2TiCl_4 + 2FeCl_3 + 6CO$$

When 500 kg of $FeTiO_3$, 850 kg of Cl_2 and 125 kg of C are mixed, which of these reactants is present in excess? **Select all that apply.**

A. $FeTiO_3$

B. Cl_2

C. C

10. Iodine monochloride (ICl) reacts with carbon-carbon double bonds (one ICl per double bond). If 0.105 g of a molecule of molar mass 304.5 g mol-1 reacts with exactly 0.224 g of ICl, how many carbon-carbon double bonds are present in the molecule?

A. 2

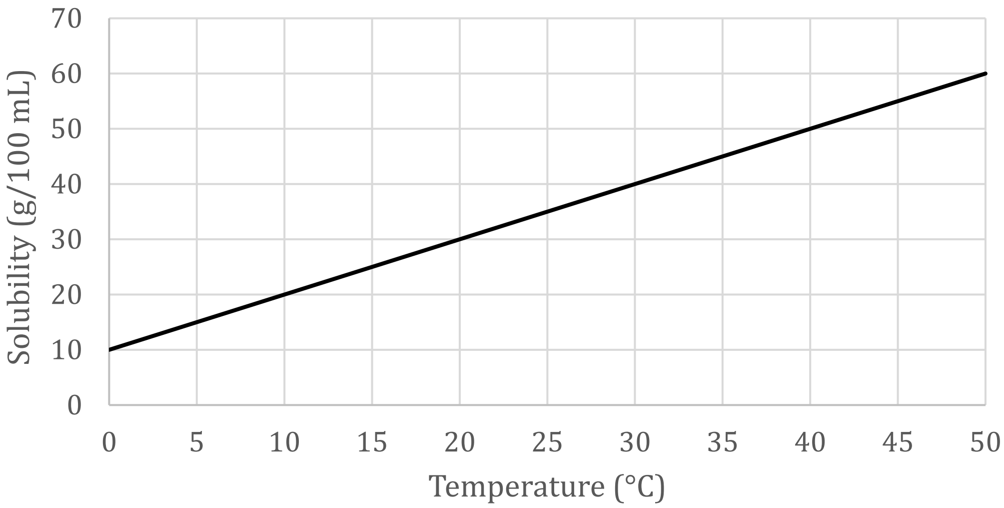
B. 3

C. 4

D. 5

E. 8

11. The following graph shows how the solubility of an unidentified substance changes with the temperature of the solution.



Using the graph, what mass of precipitate will be produced when 50 mL of a saturated solution at 40 °C is cooled to 10 °C?

A. 15 g

B. 20 g

C. 25 g

D. 30 g

E. 50 g

12. First ionisation energy is defined as the energy required to remove one mole of electrons from one mole of gaseous ions. Which of the following lists elements in order of increasing first ionisation energy?

A. He, O, F, N

B. N, O, F, He

C. He, N, O, F

D. O, N, F, He

E. He, F, O, N

13. What volume of 2.05 mol L^{-1} sodium chloride solution should be added to 1.06 L of 1.04 mol L^{-1} sodium chloride solution to make 2.22 L of 1.26 mol L^{-1} sodium chloride solution upon dilution to volume with water?

A. 0.49 L

B. 0.83 L

C. 0.96 L

D. 1.08 L

E. 1.16 L

14. A solid mixture of silver nitrate and an alkali metal nitrate was dissolved in a small volume of water. When an excess of an alkali metal halide was added to the solution, a silver halide precipitated from solution. After the precipitate was collected, weighed and dried, its mass was equal to the mass of the initial solid mixture.

Which of the following substances could be the alkali metal halide added? **Select all that apply.**

A. lithium fluoride

B. sodium chloride

C. potassium bromide

D. rubidium iodide

E. caesium chloride

15. A mineral has the formula $Na_2Ca_4X(PO_4)_3$, where **X** is an unspecified species. Which of the following could **X** be?

A. F^-

B. Ba^{2+}

C. Ag^+

D. SO_4^{2-}

E. AsO_4^{3-}

Question 16

(a) Balance the following equation:

$$P_4O_{10}(s) + 6\ H_2O(l) \rightarrow 4\ H_3PO_4(aq)$$

(b) When 4.585 g of P_4O_{10} reacts with water to produce 100 mL of H_3PO_4 solution, what concentration of H_3PO_4 (in mol L^{-1}) is this solution?

$n(P_4O_{10}) = \frac{4.585\ g}{283.88\ g\ mol^{-1}} = 0.01615\ mol$

$n(H_3PO_4) = 0.01615\ mol \times 4 = 0.06460\ mol$

$\therefore [H_3PO_4] = \frac{0.06460\ mol}{0.100\ L} = 0.646\ mol\ L^{-1}$.

(c) An aliquot of this H_3PO_4 solution is titrated with NaOH with using thymolphthalein as an indicator. 23.03 mL of 1.122 mol L^{-1} NaOH are required. What chemical amount of NaOH is required? Express your answer in mol or mmol.

$n(NaOH) = 1.122\ mmol\ mL^{-1} \times 23.03\ mL$

$= 25.84\ mmol$.

(d) If the aliquot of H_3PO_4 solution had a volume of 20.00 mL, how many moles of NaOH are required per mole of H_3PO_4?

$n(H_3PO_4) = 0.646\ mmol\ mL^{-1} \times 20.00\ mL$

$= 12.92\ mmol$

$\therefore n(NaOH\ per\ H_3PO_4) = \frac{25.84\ mmol}{12.92\ mmol} = 2$.

A sample of 2.684 g of phosphate (PO_4^{3-}) and phosphite (HPO_3^{2-}) containing fertiliser is dissolved in 30 mL of concentrated nitric acid (HNO_3) and 1 mL of concentrated hydrochloric acid (HCl). The nitric acid reacts with the phosphite in solution, converting it to phosphate. This solution is then made up to 250.0 mL in a volumetric flask. A 25.00 mL aliquot is then taken and excess sodium molybdate (Na_2MoO_4) is added, then quinolinium chloride ($C_9H_7NH^+ Cl^-$) is added until no more precipitate is formed. This precipitate has the formula $[C_9H_7NH]_3[PMo_{12}O_{40}]$.

This precipitate is then dissolved in exactly 50.00 mL of 0.5196 mol L^{-1} NaOH solution, which reacts with the precipitate in the following equation:

$[C_9H_7NH]_3[PMo_{12}O_{40}](s) + 26\ NaOH(aq) \rightarrow Na_2HPO_4(aq) + 12\ Na_2MoO_4(aq) +$
$3\ C_9H_7N(aq) + 14\ H_2O(l)$

The excess NaOH requires 21.27 mL of 0.5334 mol L^{-1} HCl for complete neutralisation.

(e) What chemical amount of HCl reacts with the excess NaOH? Express your answer in mol or mmol.

n(HCl) = 0.5334 mmol mL × 21.27 mL
= 11.35 mmol

(f) What chemical amount of NaOH reacts with the $[C_9H_7NH]_3[PMo_{12}O_{40}]$ precipitate? Express your answer in mol or mmol.

n (NaOH in excess) = 11.35 mmol
n (NaOH in total) = 0.5196 mmol mL^{-1} × 50.00 mL
= 25.98 mmol
n (NaOH reacting) = 25.98 − 11.35 mmol = 14.63 mmol

(g) What chemical amount of phosphorus does the original 2.684 g sample of fertiliser contain? Express your answer in mol or mmol.

n(P in 25 mL aliquot) = $\frac{14.63 \text{ mmol}}{26}$ = 0.5629 mmol
n(P in total) = 0.5629 mmol × $\frac{250}{25}$ = 5.629 mmol

(h) The phosphorus composition of fertilisers is often quoted as the equivalent percentage by mass of P_4O_{10} rather than the percentage by mass of phosphorus. What is the percentage by mass of P_4O_{10} in this fertiliser?

$m(P_4O_{10}) = \frac{5.629 \text{ mmol}}{4} \times 283.88 \text{ g mol}^{-1} = 0.3995 \text{ g}$

$\%(P_4O_{10}) = \frac{0.3995 \text{ g}}{2.684 \text{ g}} \times \frac{100}{1} = 14.88\%$

To determine the amount of phosphite (HPO_3^{2-}) in the fertiliser, 2.384 g of the same fertiliser is dissolved in 20 mL of water. The solution is then treated with excess LiOH solution; this precipitates Li_3PO_4, which is filtered out. Li_2HPO_3 stays in solution. Excess ethanoic acid and mercury(II) chloride ($HgCl_2$) are added to the resulting solution. The following reaction takes place (Li_3PO_4 does not precipitate under these conditions):

$2 \text{ HgCl}_2(aq) + H_3PO_3(aq) + H_2O(l) \rightarrow Hg_2Cl_2(s) + H_3PO_4(aq) + 2 \text{ HCl}(aq).$

1.069 g of Hg_2Cl_2 precipitates out.

(i) What is the percentage by mass of phosphite (HPO_3^{2-}) in the fertiliser?

$n(HPO_3^{2-}) = n(Hg_2Cl_2) = \frac{1.069 \text{ g}}{472.1 \text{ g mol}^{-1}} = 0.002264 \text{ mol}$

$m(HPO_3^{2-}) = 0.002264 \text{ mol} \times 79.978 \text{ g mol}^{-1} = 0.1811 \text{ g}$

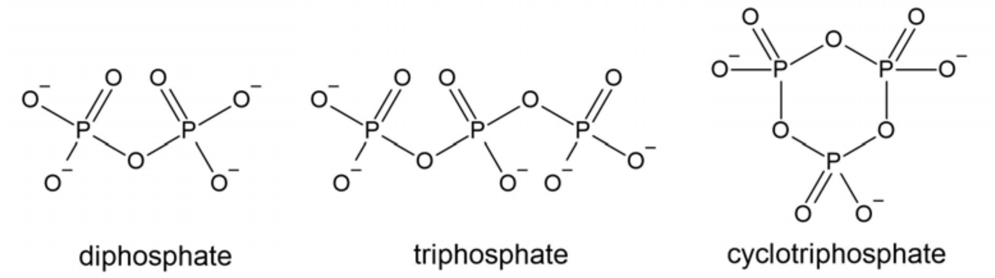
$\%(HPO_3^{2-}) = \frac{0.1811 \text{ g}}{2.384 \text{ g}} \times \frac{100}{1} = 7.596\%$

(j) Dissolved silicon dioxide in solution affects the determination of the concentration by forming a similar ion to $[PMo_{12}O_{40}]^{3-}$ with the phosphorus replaced by silicon. What is the charge on the corresponding silicon containing ion?

4−

Ion chromatography can be used to determine the anion content of a fertiliser. In ion chromatography, the solution to be analysed flows through a column that is coated with positively charged ions. Ions that are more negatively charged move through the column more slowly, as they interact with the positively charged column more strongly.

(k) In the following pairs of ions, which will move through the column **faster**?



I. phosphate or sulfate

II. diphosphate and triphosphate

III. triphosphate and cyclotriphosphate

In ion chromatography, the concentration of each ion of interest is measured from the area under the chromatogram curve (corresponding do a time, in µs). Conversion factors can be used to convert these times to concentrations; conversion factors and molar masses for phosphate, diphosphate and triphosphate given in the table below.

ion	conversion factor ($mg\ L^{-1}\ \mu s^{-1}$)	molar mass ($g\ mol^{-1}$)
phosphate	0.790	94.97
diphosphate	0.910	173.94
triphosphate	0.820	252.91

A 0.412 g sample of another fertiliser is dissolved in water and made up to 250.0 mL. The entire solution is subjected to ion chromatography to determine the phosphate, diphosphate and triphosphate content.

The first peak to elute has an area of 79.1 µs, the second peak to elute has an area of 58.5 µs and the third peak to elute has an area of 38.6 µs.

(l) Calculate the concentration of phosphate in the solution (in $mg\ L^{-1}$).

$[PO_4^{3-}] = 0.790\ mg\ L^{-1}\ \mu s^{-1} \times 79.1\ \mu s = 62.5\ mg\ L^{-1}$

(m) Calculate the amount of phosphate in the solution (in mmol).

$m(PO_4^{3-}) = 62.5\ mg\ L^{-1} \times 0.250\ L = 15.6\ mg$

$n(PO_4^{3-}) = \frac{15.6\ mg}{94.97\ g\ mol^{-1}} = 0.164\ mmol$

(n) Calculate the mass of P_4O_{10} (in mg) equivalent to the amount of phosphate in the solution.

$m(P_4O_{10}) = \frac{0.164\ mmol}{4} \times 283.88\ g\ mol^{-1}$

$= 11.7\ mg.$

(o) Calculate the total phosphorus composition of this fertiliser sample, by mass of phosphorus (expressed as the equivalent percentage by mass of P_4O_{10}).

Similarly,

$$n(\text{diphosphate}) = \frac{0.910\ \text{mg L}^{-1}\ \mu\text{s}^{-1} \times 58.5\ \mu\text{s} \times 0.250\ \text{L}}{173.94\ \text{g mol}^{-1}}$$

$$= 0.0765\ \text{mmol}$$

$$m(P_4O_{10}) = \frac{0.0765\ \text{mmol} \times 2}{4} \times 283.88\ \text{g mol}^{-1}$$

$$= 10.9\ \text{mg}$$

$$n(\text{triphosphate}) = \frac{0.820\ \text{mg L}^{-1}\ \mu\text{s}^{-1} \times 38.6\ \mu\text{s} \times 0.250\ \text{L}}{252.91\ \text{g mol}^{-1}}$$

$$= 0.0313\ \text{mmol}$$

$$m(P_4O_{10}) = \frac{0.0313\ \text{mmol} \times 3}{4} \times 283.88\ \text{g mol}^{-1}$$

$$= 6.66\ \text{mg}$$

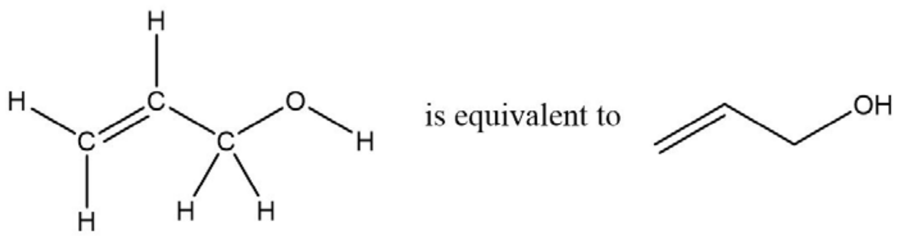
$$\therefore m(P_4O_{10}\ \text{total}) = 11.7 + 10.9 + 6.66 = 29.2\ \text{mg}$$

$$\therefore \%(P_4O_{10}) = \frac{29.2\ \text{mg}}{412\ \text{mg}} \times \frac{100}{1} = 7.09\ \%$$

Question 17

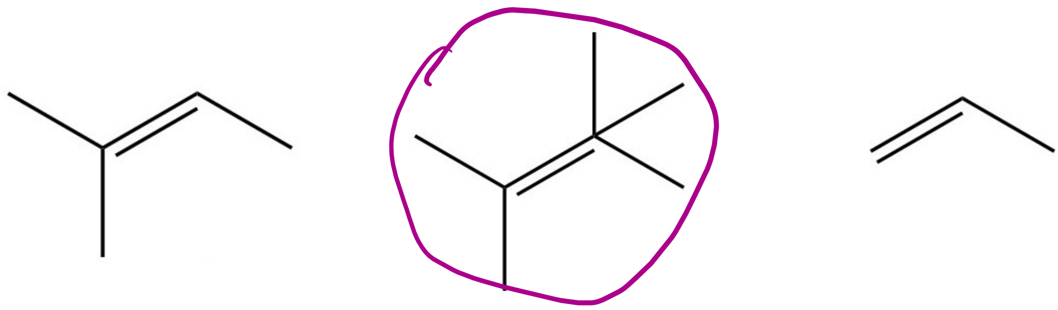
The field of organic chemistry (or carbon chemistry) involves the study of how to transform organic compounds into desired products. In organic chemistry, skeletal formula notation is often used to represent carbon backbones. In this notation, bonds are represented by lines, with carbon atoms located at the end of each line segment or meeting point of line segments. Hydrogen atoms connected to carbon atoms are implied rather than explicitly shown.

For example:

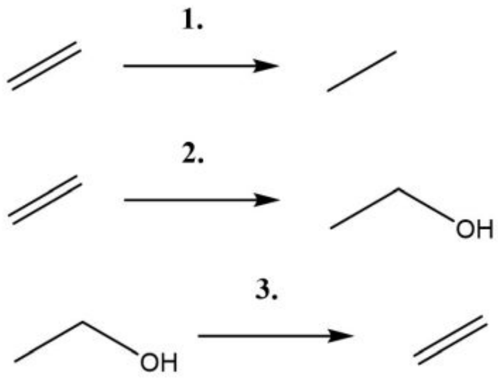


This question will explore the reactions involving carbon-carbon double bonds. Specific reaction conditions can be used to transform between different molecules. These reactions will be represented by numbers throughout this question.

(a) Which of the following molecules is an invalid structure?

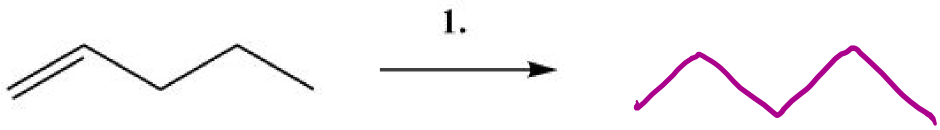


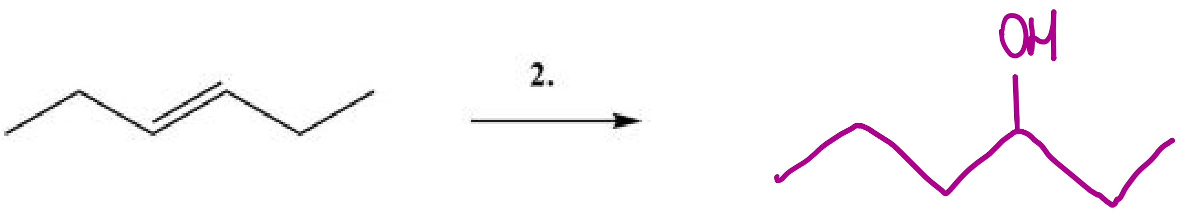
The first three reactions we will consider are presented below. These will be reproduced for you in the questions that follow, where relevant.

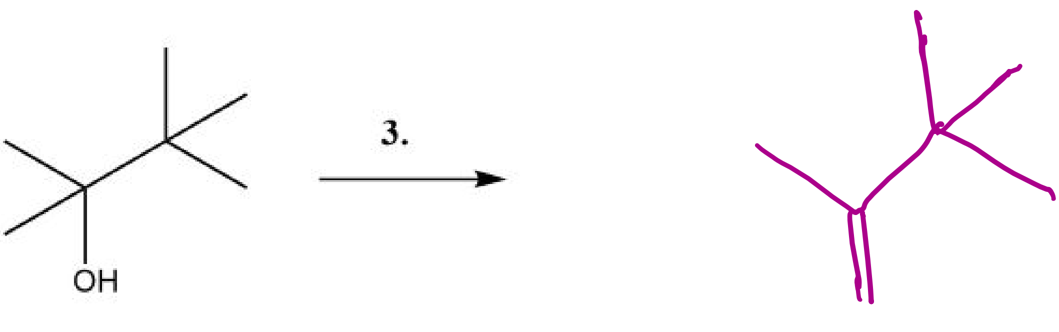


- Reaction **1** converts every carbon-carbon double bond in the molecule to a single bond, adding one hydrogen atom to each of the carbon atoms formerly involved in the double bond.
- Reaction **2** converts every carbon-carbon double bond to a single bond, adding a hydrogen atom to one of the carbon atoms and an OH group to the other.
- Reaction **3** removes an OH group from one carbon atom and a hydrogen atom from a neighbouring carbon atom, forming a carbon-carbon double bond.

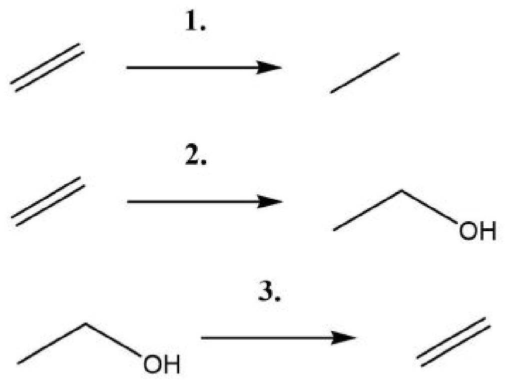
(b) Draw the product of the following reactions:





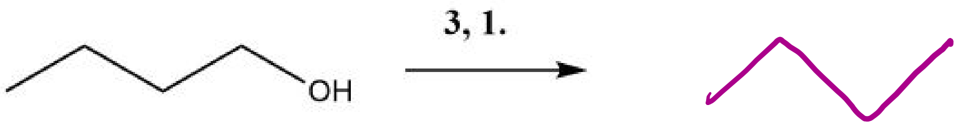


Recall reactions **1**, **2** and **3**:

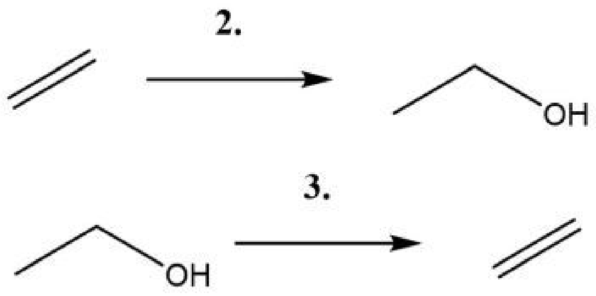


These reactions may be applied sequentially. For example, in the question below, "**3**, **1**" means take the reactant and perform reaction **3**, then take the product of this reaction and perform reaction **1** on it.

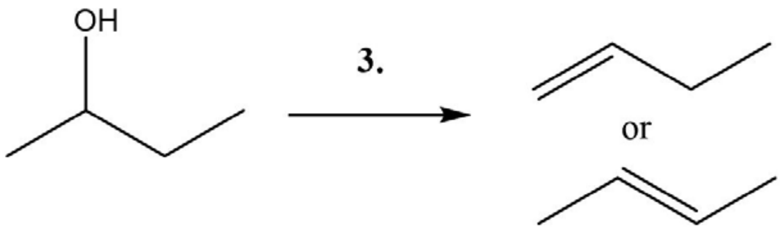
(c) Draw the product of the following reactions:



Recall reactions **2** and **3**:



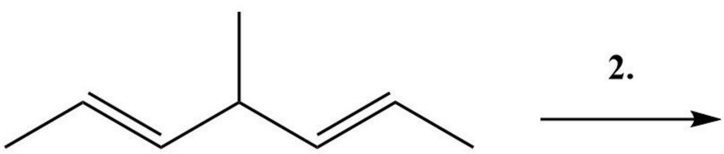
In reactions **2** and **3** as described above, there are some situations where the product is ambiguous, as shown in the example below.



For the purposes of this question, you should assume the following:

- There is an excess of the converting reagent present, ensuring complete conversion of all starting material to products.
- All possible products that are chemically valid will form, so that in the above reaction, both the top and the bottom products will be present after the reaction has taken place.

(d) How many different products will form in the following reaction?



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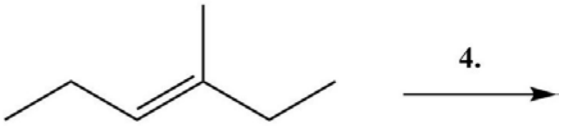
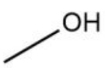
Consider a new reaction, reaction **4**. In this reaction, each double bond in the molecule is broken, and each carbon previously involved in the double bond is attached to an -OH group, pictured below.

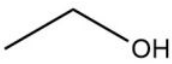
(e) Select **all** products of the following reaction:



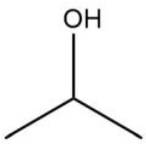
A.



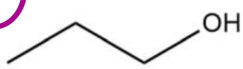
B.



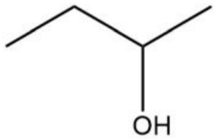
C.



D.

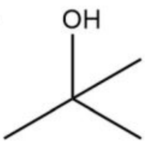


E.

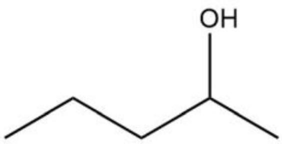


F.

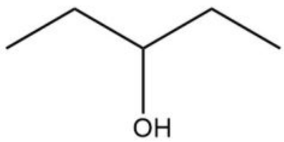
G.



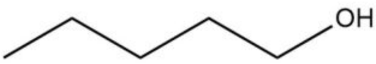
H.



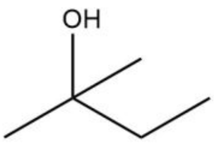
I.



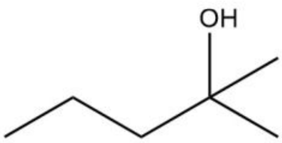
J.



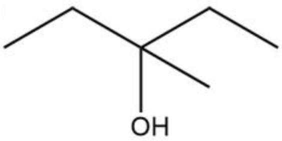
K.



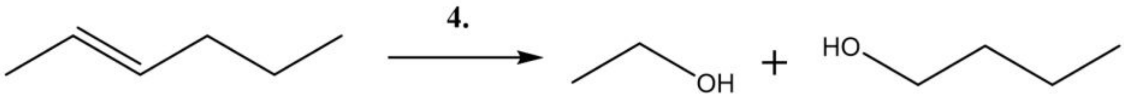
L.



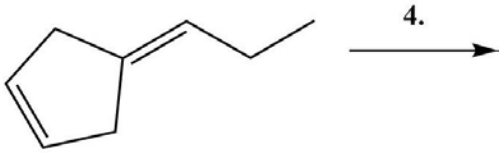
M.



Recall reaction **4**:

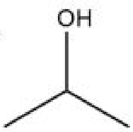


(f) Select **all** products of the following reaction:



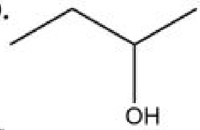
A.

B.



C.

D.



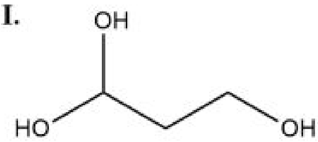
E.

F.

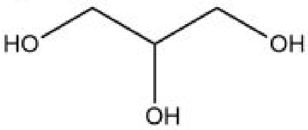
G.

H.

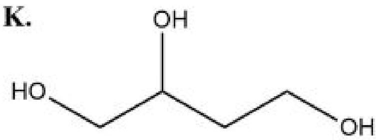
I.



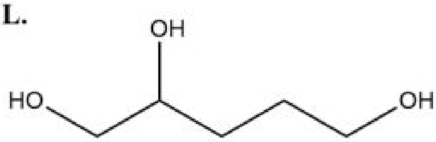
J.



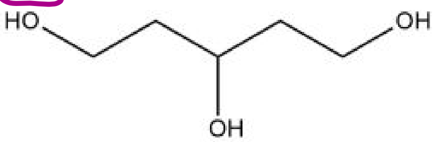
K.



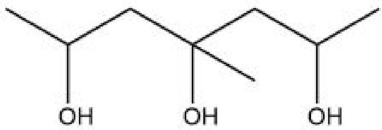
L.



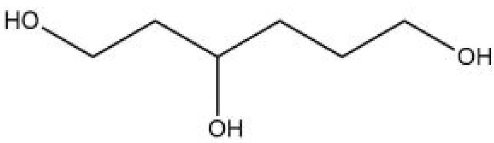
M.



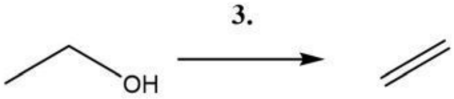
N.



O.

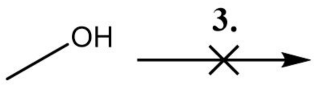


Recall reaction **3**:

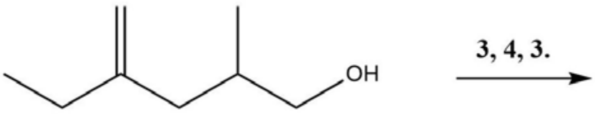


and reaction **4**:

When a molecule cannot form any valid product under a given reaction condition, it will not react. For example, the molecule below does not react under reaction condition **3** because the carbon-carbon double bond cannot form anywhere in the molecule.



(g) Select **all** possible products for the following sequence of reactions:



A.

B.

C.

D.

E.

F.

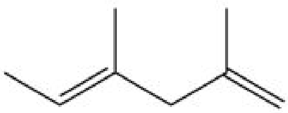
G.

H.

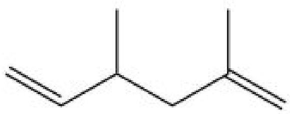
I.

J.

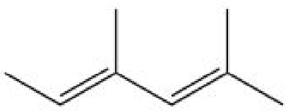
K.



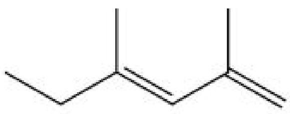
L.



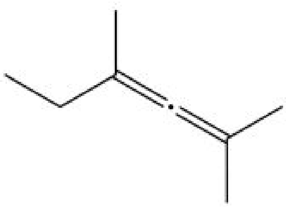
M.



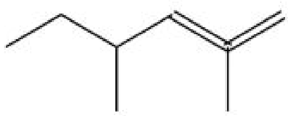
N.



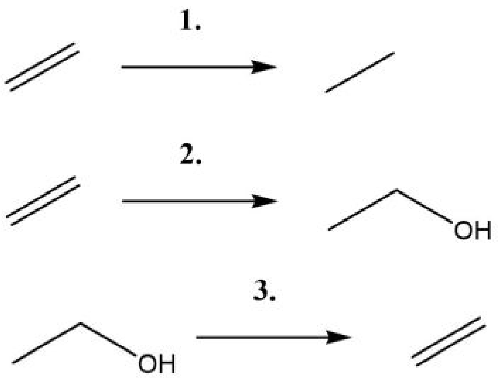
O.



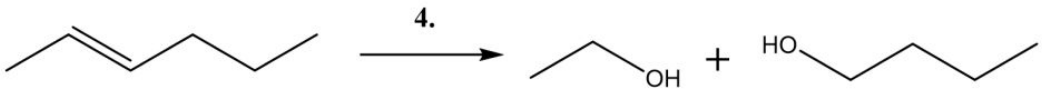
P.



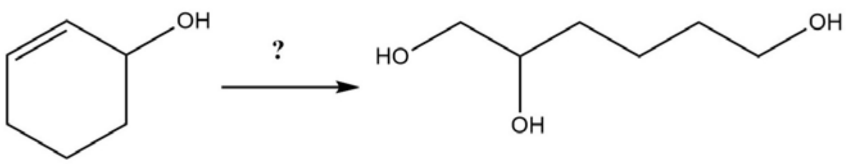
Recall reactions **1**, **2** and **3**:



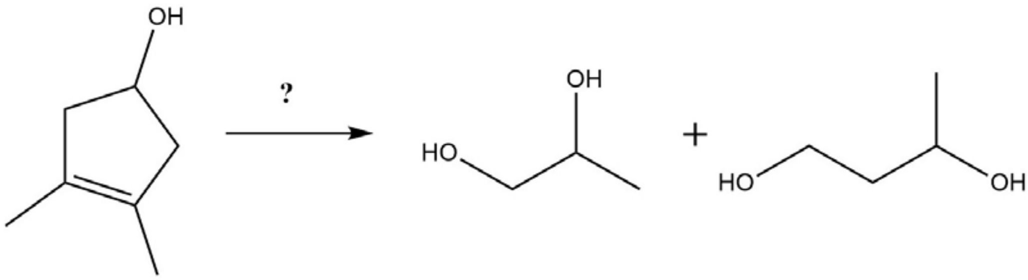
and reaction **4**:



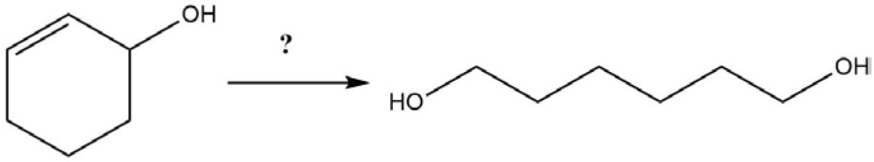
(h) Suggest a reaction or series of reactions to transform the reactant on the left to the product on the right. Note that more than one reaction may be required.



4

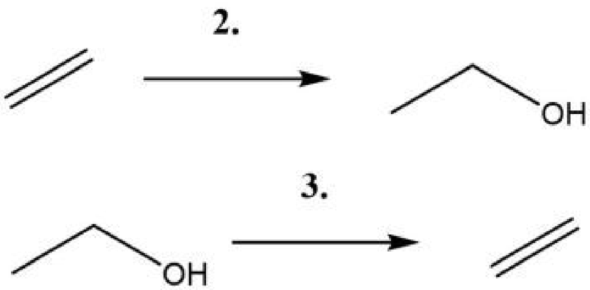


3,4



1,3,4

Recall reactions **2** and **3**:

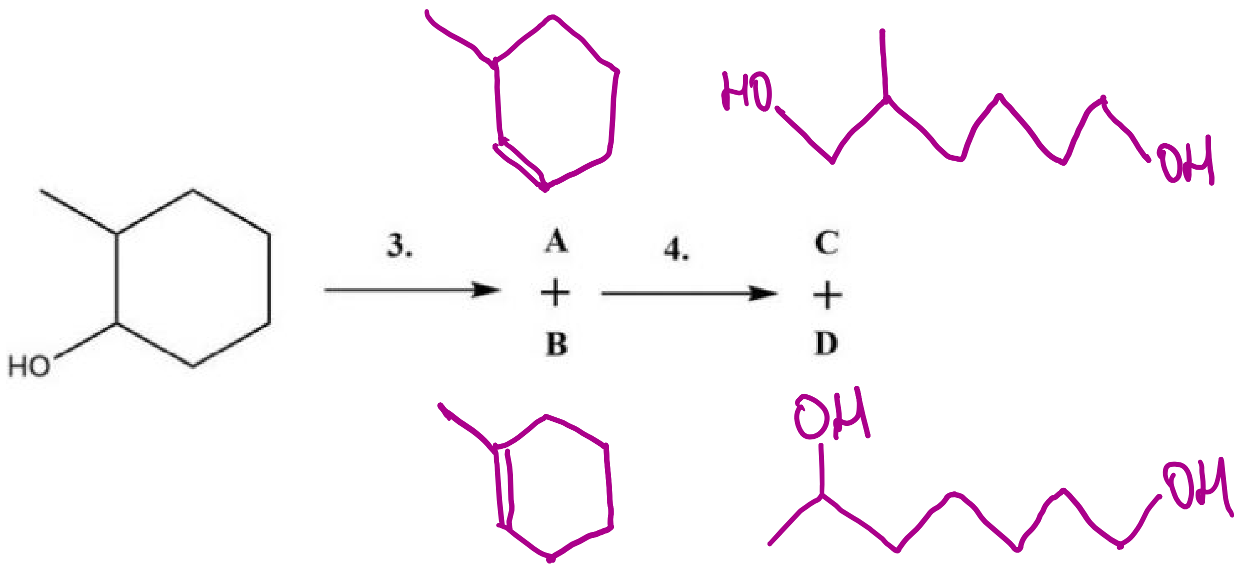


and reaction **4**:

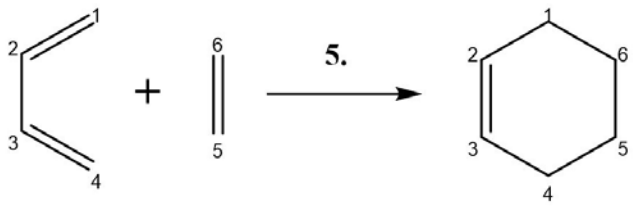
Consider the reaction scheme below.

- When reaction **3** is performed on the compound on the left it forms two compounds, **A** and **B**, which in turn react under reaction **4** to form compounds **C** and **D** respectively.
- When reaction **2** is performed on compound **C**, it produces **only one product**.

(i) Draw the structures of **A**, **B**, **C** and **D**.

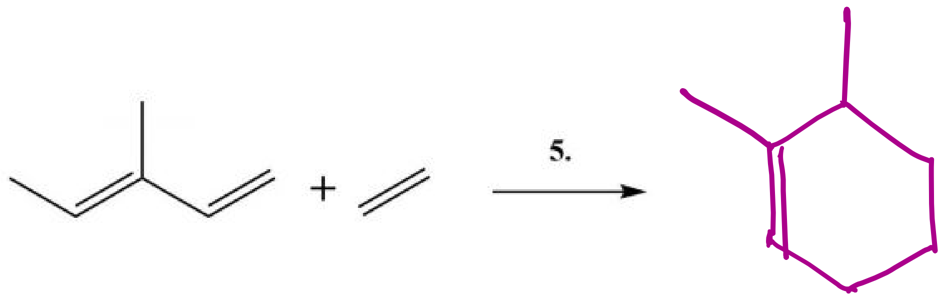


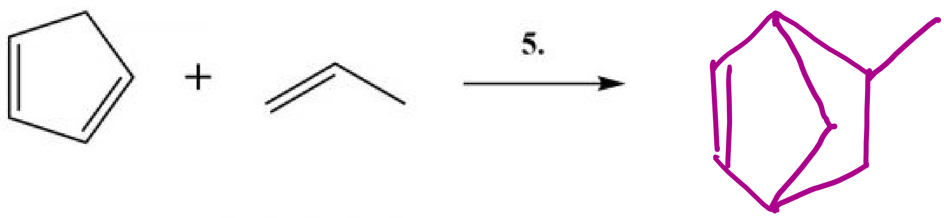
Now, consider a final reaction:



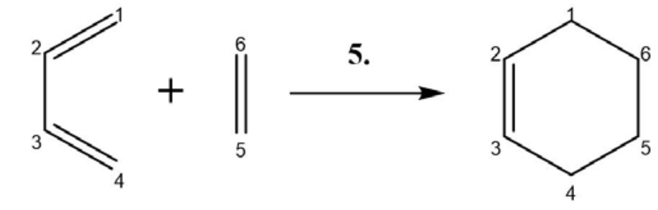
This reaction occurs between two molecules: one with two double bonds separated by a single bond, and the other with a double bond. A single bond is formed between the atoms 1 and 6, and between 4 and 5, as labelled above. The existing double bonds between atoms 1 and 2, between 3 and 4, and between 5 and 6, become single bonds; while a new double bond is formed between atoms 2 and 3.

(j) Draw the product of the following reaction to complete the equation. Where more than one product can form, draw only one possible product.

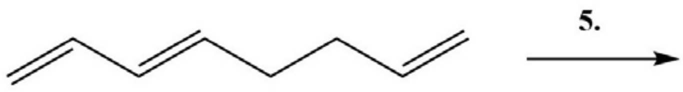


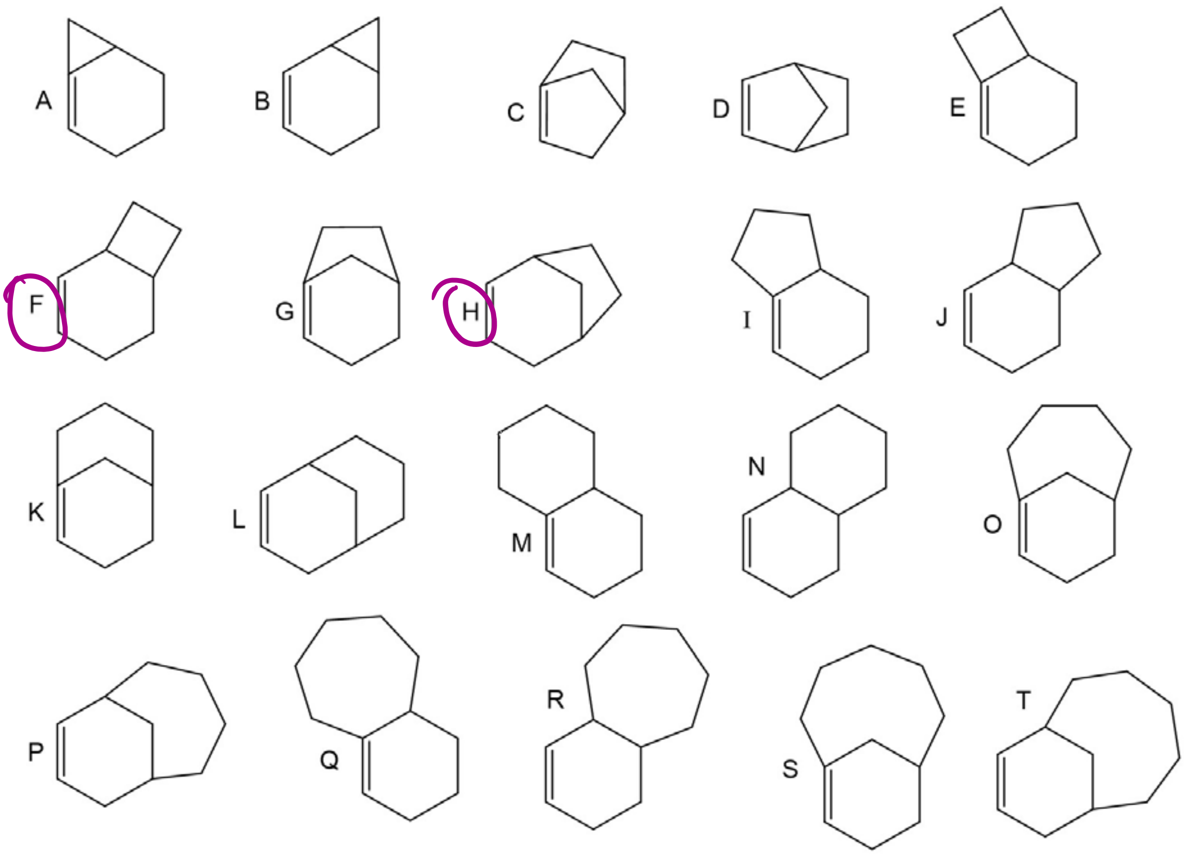


Recall reaction **5**:



Select **all** products of the following reaction:





Question 18

Bond energy is a measure of the energy required to break a chemical bond. For example, to turn one mole of hydrogen molecules into two moles of hydrogen atoms requires an energy input of 432 kJ. In equation form:

$H_2(g) \rightarrow 2H(g)$ Bond energy = 432 kJ mol^{-1}

(a) When 1 mol of hydrogen atoms react to form hydrogen molecules, is energy taken in by or released from the system?

Released

(b) What is this energy change (in kJ)?

−216 kJ

For molecules involving more than one of the same type of bond, this calculation is more involved. For example, each of the four C-H bonds in CH_4 can be broken, in a stepwise manner:

$CH_4(g) \rightarrow CH_3(g) + H(g)$	Bond energy = 425 kJ mol^{-1}
$CH_3(g) \rightarrow CH_2(g) + H(g)$	Bond energy = 438 kJ mol^{-1}
$CH_2(g) \rightarrow CH(g) + H(g)$	Bond energy = 451 kJ mol^{-1}
$CH(g) \rightarrow C(g) + H(g)$	Bond energy = 348 kJ mol^{-1}

(c) What is the total energy required to turn 1 mole of $CH_4(g)$ into C(g) and 4H(g)? Express your answer in kJ mol^{-1}.

Energy required = 425+438+451+348 = 1662 kJ mol^{-1}

(d) Using the data above, what is the average energy required to break a C-H bond in methane? Express your answer in kJ mol^{-1}, rounded to the nearest integer.

Average bond energy = $\frac{1662 \text{ kJ mol}^{-1}}{4}$ = 416 kJ mol^{-1}.

Glucose is broken down in a multi-step process called glycolysis. The ten steps of glycolysis are represented in abbreviated form in the table below. Glycolysis can be separated into 2 phases:

- The first phase is the energy investment phase (steps 1-5), where there is a net input of energy and production of two molecules of GA3P.
- The second phase is the energy recovery phase (steps 6-10), where there is a net release of energy.

These energy changes can be expressed as enthalpy changes, given the symbol ΔH and measured in kJ mol^{-1}. A negative sign for ΔH means a release of energy; a positive sign means an input of energy.

Step	**Reaction**	**ΔH (kJ mol^{-1})**
1	G → G6P	-16.7
2	G6P → F6P	3.7
3	F6P → F1,6BP	-10.2
4	F1,6BP → DHAP + GA3P	23.6
5	DHAP → GA3P	9.6
6	GA3P → 1,3BPG	6.3
7	1,3BPG → 3PG	-18.9
8	3PG → 2PG	4.4
9	2PG → PEP	1.8
10	PEP → Pyr	-30.9

(e) Calculate ΔH (in kJ mol^{-1}) for 1 mole of glucose (G) proceeding through the energy investment phase (steps 1-5).

$\Delta H = -16.7 + 3.7 - 10.2 + 23.6 + 9.6 = 10.0$ kJ mol^{-1}

(f) Calculate ΔH (in kJ mol^{-1}) for 1 mole of GA3P proceeding through the energy recovery phase (steps 6-10).

$\Delta H = 6.3 - 18.9 + 4.4 + 1.8 - 30.9 = -37.3$ kJ mol^{-1}

(g) Calculate ΔH (in kJ mol^{-1}) for 1 mole of glucose (G) proceeding through the entire process of glycolysis (steps 1-10).

$\Delta H = 10.0 + 2 \times (-37.3) = -64.6$ kJ mol^{-1}

Humans obtain energy from the metabolism of the food they eat. Practically all of the energy we extract from food comes from macronutrients, which are broken down in oxidative processes. Food chemists can measure this energy using another oxidation reaction: combustion.

The energy released from the combustion of a certain substance is called the heat of combustion ($\Delta_c H$), here expressed in kJ per gram of substance. The average heats of combustion for the three macronutrients are provided below.

macronutrient	**$\Delta_c H$ (kJ g^{-1})**
carbohydrates	17.6
lipids	39.3
proteins	22.8

A slice of white bread weighs 37.6 g and was found to contain 3.2 g of protein, 0.71 g of lipid and 17.3 g of carbohydrates, while the rest of the mass can be assumed to be water.

(h) Calculate the energy released from the combustion of **17.3 g of carbohydrates**. Express your answer in kJ, rounded to the nearest kJ.

Energy = 17·3g x 17·6 kJ g^{-1} = 304 kJ

(i) Calculate the **total** energy released from the combustion of 37.6 g of white bread. Express your answer in kJ, rounded to the nearest kJ.

Energy = 17·3x17·6 + 0·71x39·3 + 3·2x22·8 kJ
= 405 kJ

While combustion and our body's metabolism both involve oxidising macronutrients, the energy released from these two methods is not the same. On average, 15.7% of the mass of proteins cannot be oxidised by the body's metabolism.

(j) How much energy can actually be extracted from the metabolism of 1 g of protein? Express your answer in kJ, rounded to the nearest 0.1 kJ.

Energy = 22.8 kJ × (1 − 0.157) = 19.2 kJ.

Even worse, the protein components that cannot be oxidised are converted into urea before being excreted. This conversion requires energy input, and further reduces the energy that can be extracted from proteins.

(k) Recalculate how much energy can be extracted from the metabolism of 1 g of protein, given that the energy cost for converting protein components into urea is 3.81 kJ per gram of protein requiring conversion to urea. Express your answer in kJ , rounded to the nearest 0.1 kJ.

Energy = 19.2 − 3.81 × 0.157
= 18.6 kJ.

A slice of white bread weighs 37.6 g and was found to contain 3.2 g of protein, 0.71 g of lipid and 17.3 g of carbohydrates, while the rest of the mass can be assumed to be water.

(l) Recalculate the dietary energy that can be extracted from metabolism of a 37.6 g slice of white bread, given that the energy cost for converting protein components into urea is 3.81 kJ per gram of protein requiring conversion to urea. Express your answer in kJ, rounded to the nearest kJ.

Energy = 17.3 × 17.6 + 0.71 × 39.3 + 3.2 × 18.6
= 392 kJ

The world's most boring ham sandwich is composed of 2 slices of white bread and a slice of ham only. The sandwich was weighed and had a mass of 110.0 g. When food chemists tried to measure the dietary energy inside a ham sandwich and accounted for the lower dietary energy that could be extracted from proteins, they measured a value of 1390 kJ.

The following variables are used in this question:

- E(bread) is the energy released from one slice of bread.
- E(ham) is the energy released from one slice of ham.
- m(bread) is the mass of one slice of bread.
- m(ham) is the mass of one slice of ham

(m) Create expressions for the following:

i. How the **energy** content in the ingredients of the sandwich makes up the total dietary energy content.

2E(bread) + E(ham) = 1390 kJ

ii. How the **mass** of the ingredients make up the total mass of the sandwich. You may assume that the ham slice contains no carbohydrates and is composed of 30% water by mass.

2m(bread) + m(ham) = 110g.

(n) Calculate E(ham), the energy released from one slice of ham. (n.b. If you were unable to calculate the value previously, you may use 18 kJ as the energy released per gram of protein). Express your answer in kJ, rounded to the nearest 0.1 kJ.

E(ham) = 1390 − 2 × 392

= 606 kJ

(o) Find the mass of protein inside a slice of ham. Express your answer in g, rounded to the nearest 0.1 g. You may assume that the ham slice contains no carbohydrates and is composed of 30% water by mass.

(n.b. If you were unable to calculate the value previously, you may use 18 kJ as the energy released per gram of protein).

$m(\text{ham}) = 110\text{ g} - 2 \times 37.6 = 34.8\text{ g}$

$m(\text{lipid}) + m(\text{protein}) = 70\% \times 34.8\text{ g}$

$m(\text{lipid}) + m(\text{protein}) = 24.4\text{ g}$ (*)

$m(\text{lipid}) \times 39.3 + m(\text{protein}) \times 18.6 = 606\text{ kJ}$ (*)

Solving these two equations simultaneously gives $m(\text{protein}) = 17.0\text{ g}$.

END OF EXAM