Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 3

Thursday 17 May 2018 (morning)

1 hour 15 minutes

Candidate session number

Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[45 marks]**.

Section A	Questions
Answer all questions.	1 – 2

Section B	Questions
Answer all of the questions from one of the options.	
Option A — Materials	3 – 6
Option B — Biochemistry	7 – 12
Option C — Energy	13 – 18
Option D — Medicinal chemistry	19 – 27

2218–6115

Section A

Answer **all** questions. Answers must be written within the answer boxes provided.

1. The table summarizes some properties of graphite and graphene.

Property	Graphite	Graphene
Delocalization (Hybridization)	Yes (sp^2)	Yes (sp^2)
Electron mobility / $cm^2\ V^{-1}\ s^{-1}$	1800	15 000–200 000
Average bond length / nm	0.142	0.142
Distance between layers / nm	0.335	Not applicable (N/A)
Tensile strength / Pascals	$4.8–76 \times 10^6$	1.3×10^{11}
Density / g cm^{-3}	1.80–2.23	(N/A)
Melting point at 1×10^6 kPa / K	4300	4510
Specific surface area / $m^2\ g^{-1}$	90	2630

[Source: © Graphenea. Used with permission]

(a) (i) Graphene is two-dimensional, rather than three-dimensional, material.

Justify this by using the structure of graphene and information from the table. [2]

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(ii) Show that graphene is over 1600 times stronger than graphite. [1]

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(This question continues on the following page)

(Question 1 continued)

(iii) Identify a value from the table which can be used to support the information about graphene given below. [1]

Removed for copyright reasons

Electrons in a solid are restricted to certain ranges, or bands, of energy (vertical axis). In an insulator or semiconductor, an electron bound to an atom can break free only if it gets enough energy from heat or a passing photon to jump the “band gap”, but in graphene the gap is infinitely small.

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(b) Diamond, graphene, and graphite are all network solids.

Suggest, giving a reason, the electron mobility of diamond compared to graphene. [2]

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(This question continues on the following page)

(Question 1 continued)

(c) The melting point of diamond at 1×10^6 kPa is 4200 K (in the absence of oxygen).

Suggest, based on molecular structure, why graphene has a higher melting point under these conditions. [2]

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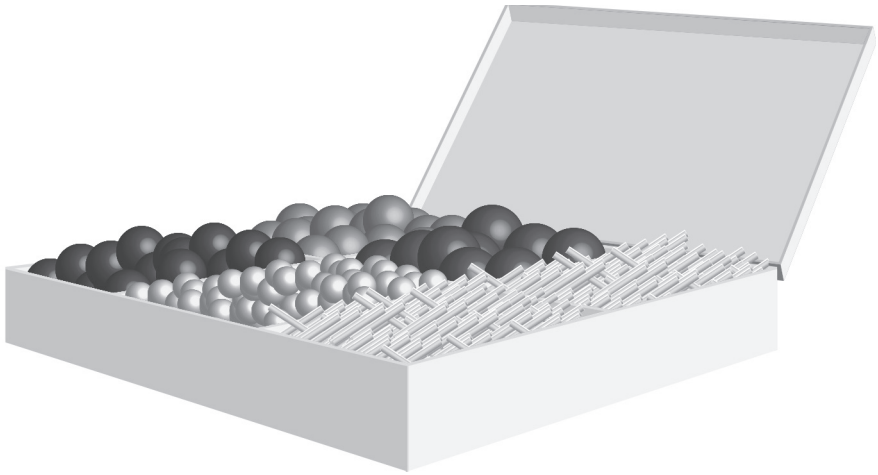
2. Organic molecules can be visualized using three-dimensional models built from kits such as that pictured below.



[Source: © International Baccalaureate Organization 2018]

(a) Describe **two** differences, other than the number of atoms, between the models of ethane and ethene constructed from the kit shown. [2]

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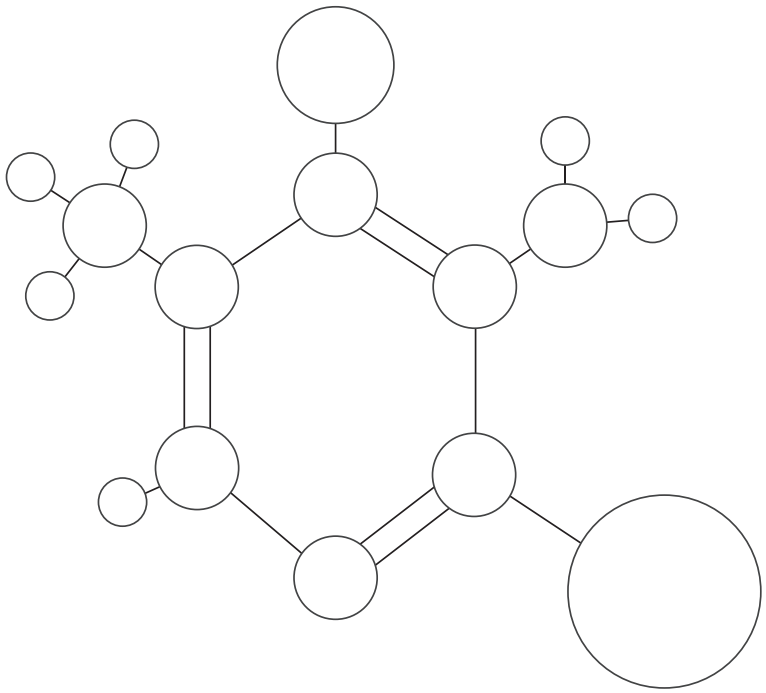
(This question continues on the following page)

(Question 2 continued)



[Source: © International Baccalaureate Organization 2018]

(b) (i) The above ball and stick model is a substituted pyridine molecule (made of carbon, hydrogen, nitrogen, bromine and chlorine atoms). All atoms are shown and represented according to their relative atomic size.

Label each ball in the diagram, excluding hydrogens, as a carbon, C, nitrogen, N, bromine, Br, or chlorine, Cl. [3]

(ii) Suggest **one** advantage of using a computer generated molecular model compared to a ball and stick 3-D model. [1]

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(iii) Pyridine, like benzene, is an aromatic compound.

Outline what is meant by an aromatic compound. [1]

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Section B

Answer **all** of the questions from **one** of the options. Answers must be written within the answer boxes provided.

Option A — Materials

3. Inductively Coupled Plasma (ICP) used with Mass Spectrometry (MS) or Optical Emission Spectrometry (OES) can be used to identify and quantify elements in a sample.

(a) ICP-OES/MS can be used to analyse alloys and composites. Distinguish between alloys and composites. [2]

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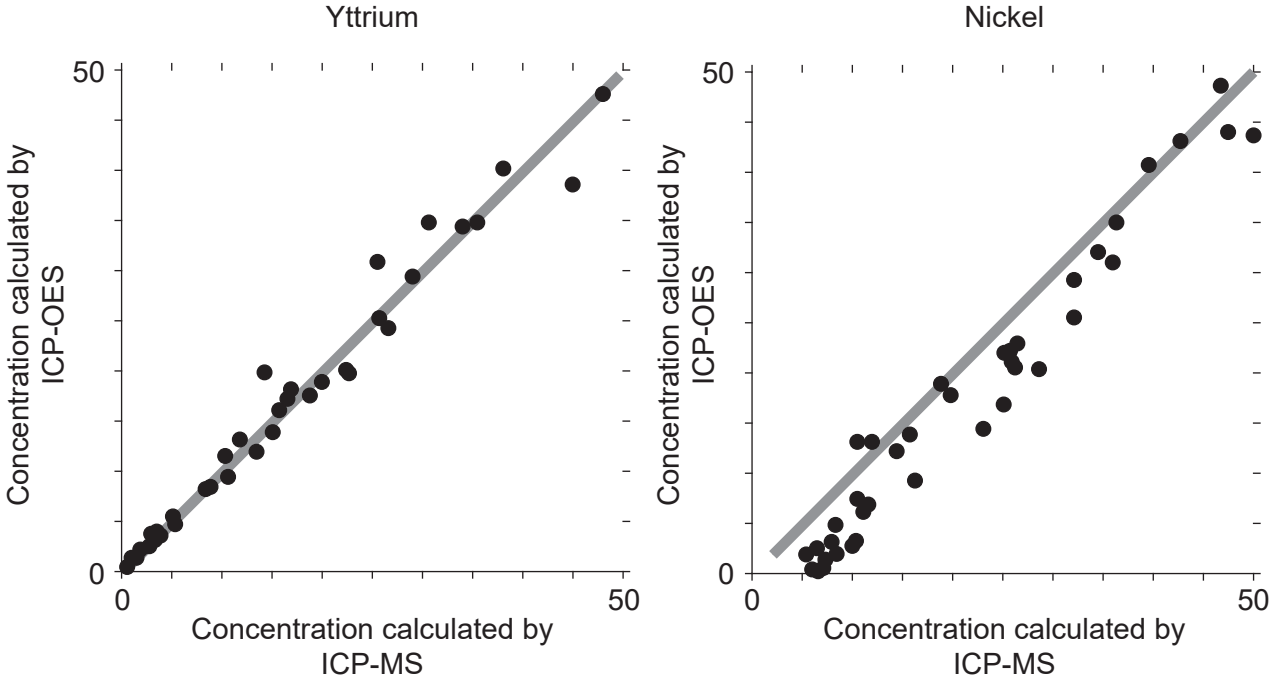
(Option A continues on the following page)

(Option A, question 3 continued)

(b) ICP-MS is a reference mode for analysis. The following correlation graphs between ICP-OES and ICP-MS were produced for yttrium and nickel.



[Source: http://www.emse.fr/~moutte/kola/report/cmp_icpms.htm © Jacques Moutte]

Each y-axis shows concentrations calculated by ICP-OES; each x-axis shows concentrations for the same sample as found by ICP-MS.

The line in each graph is $y = x$.

Discuss the effectiveness of ICP-OES for yttrium and nickel. [2]

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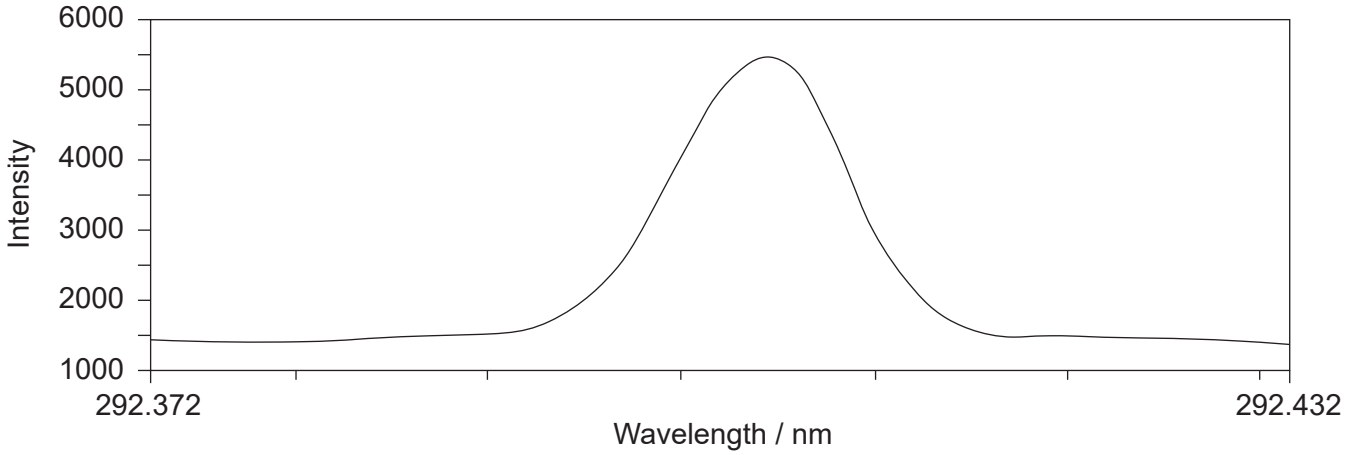
(Option A continues on the following page)

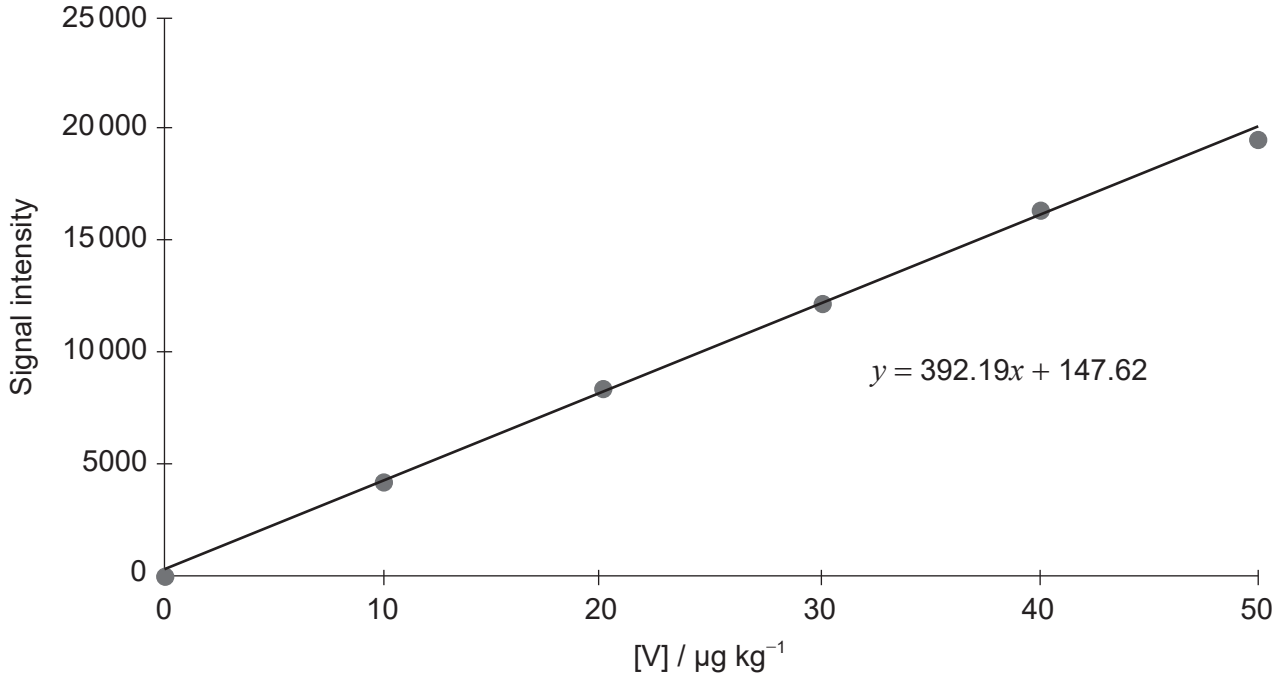
(Option A, question 3 continued)

(c) The following graphs represent data collected by ICP-OES on trace amounts of vanadium in oil.

Graph 1: Calibration graph and signal for 10 µg kg^{-1} of vanadium in oil



Graph 2: Calibration of vanadium in µg kg^{-1}



[Source: © Agilent Technologies, Inc.1998. Reproduced with Permission, Courtesy of Agilent Technologies, Inc.]

(Option A continues on the following page)

(Option A, question 3 continued)

(i) Identify the purpose of each graph. [2]

Graph 1:

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Graph 2:

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(ii) Calculate, to four significant figures, the concentration, in μg kg^{-1}, of vanadium in oil giving a signal intensity of 14 950. [1]

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(iii) Vanadium(V) oxide is used as the catalyst in the conversion of sulfur dioxide to sulfur trioxide.

$$SO_2(g) + V_2O_5(s) \rightarrow SO_3(g) + 2VO_2(s)$$

$$\frac{1}{2}O_2(g) + 2VO_2(s) \rightarrow V_2O_5(s)$$

Outline how vanadium(V) oxide acts as a catalyst. [2]

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(Option A continues on the following page)

(Option A continued)

4. Vanadium forms a body centred cubic (BCC) crystal structure with an edge length of 303 pm, (303×10^{-12} m).

(a) (i) Deduce the number of atoms per unit cell in vanadium. [1]

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(ii) Calculate the expected first order diffraction pattern angle, in degrees, if x-rays of wavelength 150 pm are directed at a crystal of vanadium. Assume the edge length of the crystal to be the same as separation of layers of vanadium atoms found by x-ray diffraction. Use section 1 of the data booklet. [2]

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(iii) Calculate the average mass, in g, of a vanadium atom by using sections 2 and 6 of the data booklet. [1]

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(iv) Determine the volume, in cm^3, of a vanadium unit cell. [1]

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(Option A continues on the following page)

(Option A, question 4 continued)

(v) Determine the density, in g cm^{-3}, of vanadium by using your answers to (a)(i), (a)(iii) and (a)(iv). [2]

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(b) (i) Vanadium and other transition metals can interfere with cell metabolism.

State and explain **one** process, other than by creating free radicals, by which transition metals interfere with cell metabolism. [2]

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(ii) Vanadium(IV) ions can create free radicals by a Fenton reaction.

Deduce the equation for the reaction of V^{4+} with hydrogen peroxide. [1]

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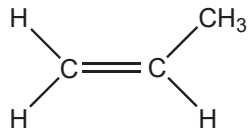
(Option A continues on the following page)

(Option A continued)

5. Propene can polymerize to form polypropene.

Propene monomer: 

(a) Sketch four repeating units of the polymer to show atactic and isotactic polypropene. [2]

Atactic:

Isotactic:

(b) Compare **two** ways in which recycling differs from reusing plastics. [2]

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(Option A continues on the following page)

(Option A, question 5 continued)

(c) (i) Distinguish between the manufacture of polyester and polyethene. [2]

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(ii) Civilizations are often characterized by the materials they use.

Suggest an advantage polymers have over materials from the iron age. [1]

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(Option A continues on the following page)

(Option A continued)

6. Chemical vapour deposition (CVD) produces multi-walled carbon nanotubes (MWCNT) of a more appropriate size for use in liquid crystals than production by arc discharge.

(a) State the source of carbon for MWCNT produced by arc discharge and by CVD. [2]

Arc discharge:

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CVD:

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(b) MWCNT are very small in size and can greatly increase switching speeds in a liquid crystal allowing the liquid crystal to change orientation quickly.

Discuss **two other** properties a substance should have to be suitable for use in liquid crystal displays. [2]

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End of Option A

Option B — Biochemistry

7. Lipids provide energy and are an important part of a balanced diet.

(a) Identify the type of chemical reaction that occurs between fatty acids and glycerol to form lipids and the by-product of the reaction. [2]

Type of reaction:

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By-product:

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(b) Arachidonic acid is a polyunsaturated omega-6 fatty acid found in peanut oil.

Determine the number of carbon–carbon double bonds present if the iodine number for the compound is 334. (Arachidonic acid $M_r = 304.5$) [2]

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(c) Deduce the structure of the lipid formed by the reaction between lauric acid and glycerol (propane-1,2,3-triol) using section 34 of the data booklet. [2]

(Option B continues on the following page)

(Option B, question 7 continued)

(d) Outline **one** impact food labelling has had on the consumption of foods containing different types of lipids. [1]

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(e) Determine, to the correct number of significant figures, the energy produced by the respiration of 29.9 g of $C_5H_{10}O_5$.

ΔH_c ($C_5H_{10}O_5$) = 205.9 kJ mol^{-1} [2]

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(Option B continues on the following page)

(Option B continued)

8. Amino acids are the building blocks of proteins.

(a) Draw the dipeptide represented by the formula Ala-Gly using section 33 of the data booklet. [2]

(b) Deduce the number of ^{1}H NMR signals produced by the zwitterion form of alanine. [1]

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(c) Draw the structures of the main form of glycine in buffer solutions of pH 1.0 and 6.0. The pK_a of glycine is 2.34. [2]

pH = 1.0	pH = 6.0

(d) Calculate the pH of a buffer system with a concentration of 1.25×10^{-3} mol dm^{-3} carbonic acid and 2.50×10^{-2} mol dm^{-3} sodium hydrogen carbonate. Use section 1 of the data booklet.
pK_a (carbonic acid) = 6.36 [1]

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(Option B continues on the following page)

(Option B, question 8 continued)

(e) Sketch the wedge and dash (3-D) representations of alanine enantiomers. [1]

(f) UV-Vis spectroscopy can be used to determine the unknown concentration of a substance in a solution.

Calculate the concentration of an unknown sample of pepsin with an absorbance of 0.725 using section 1 of the data booklet.
Cell length = 1.00 cm
Molar absorptivity (extinction coefficient) of the sample = 49650 $dm^3 cm^{-1} mol^{-1}$ [1]

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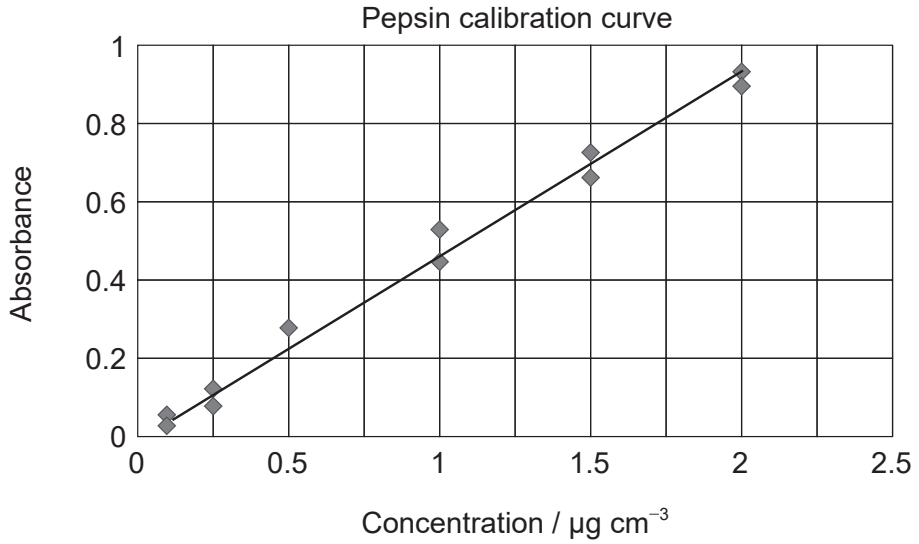
(Option B continues on the following page)

(Option B, question 8 continued)

(g) A different series of pepsin samples is used to develop a calibration curve.



[Source: https://openwetware.org/wiki/File:Calibration_Curve_for_Pepsin_DML_2013_09_10.png. Image by Daniel-Mario Larco]

Estimate the concentration of an unknown sample of pepsin with an absorbance of 0.30 from the graph. [1]

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(Option B continues on the following page)

(Option B continued)

9. Green Chemistry reduces the production of hazardous materials and chemical waste.

Outline **two** specific examples or technological processes of how Green Chemistry has accomplished this environmental impact. [2]

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10. (a) Explain the solubility of vitamins A and C using section 35 of the data booklet. [2]

Vitamin A:

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Vitamin C:

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(b) Explain how the structure of vitamin A is important to vision using section 35 of the data booklet. [3]

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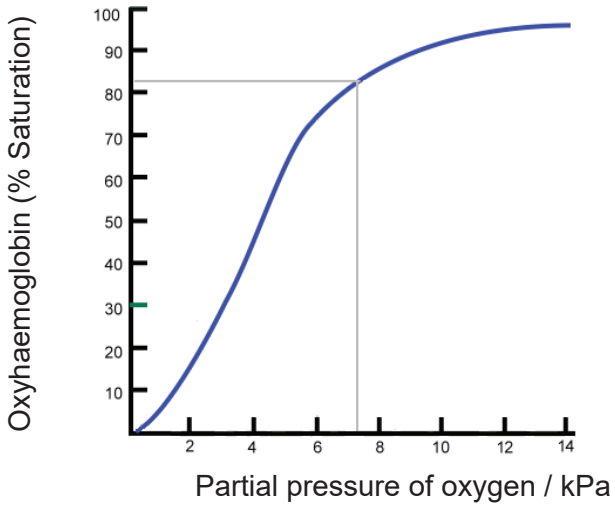
(Option B continues on the following page)

(Option B continued)

11. Hemoglobin contains an iron ion that can bind to oxygen as part of the process of respiration.

(a) Hemoglobin's oxygen dissociation curve is shown at a given temperature. Sketch the curve on the graph at a higher temperature. [1]



[Source: Adapted from Ratznium/Wikipedia]

(b) Outline **two** differences between normal hemoglobin and foetal hemoglobin. [2]

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12. DNA is a biopolymer made up of nucleotides. List **two** components of a nucleotide. [2]

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End of Option B

Option C — Energy

13. Crude oil is a useful energy resource.

(a) Outline **two** reasons why oil is one of the world's significant energy sources. [2]

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(b) (i) Outline how higher octane fuels help eliminate "knocking" in engines. [1]

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(ii) The performance of hydrocarbons as fuels can be improved by catalytic reforming.

Outline how catalytic reforming increases a fuel's octane rating. [1]

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(Option C continues on the following page)

(Option C, question 13 continued)

(c) Fuel cells have a higher thermodynamic efficiency than octane. The following table gives some information on a direct methanol fuel cell.

Anode reaction	$CH_3OH(aq) + H_2O(l) \rightarrow 6H^+(aq) + 6e^- + CO_2(g)$	
Cathode reaction	$\frac{3}{2}O_2(g) + 6H^+(aq) + 6e^- \rightarrow 3H_2O(l)$	
Net equation	$CH_3OH(aq) + \frac{3}{2}O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$	$\Delta H = -726\,kJ\,mol^{-1}$

Determine the thermodynamic efficiency of a methanol fuel cell operating at 0.576 V. Use sections 1 and 2 of the data booklet. [3]

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14. Carbon dioxide is a product of the combustion of petrol.

(a) Explain the molecular mechanism by which carbon dioxide acts as a greenhouse gas. [3]

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(Option C continues on the following page)

(Option C, question 14 continued)

(b) Discuss the significance of **two** greenhouse gases, other than carbon dioxide, in causing global warming or climate change. [2]

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15. The process of converting heat to electricity is limited by its thermal (Carnot) efficiency.

$$\text{Thermal efficiency} = \frac{\text{temp. of steam at source}(\text{K}) - \text{temp. heat sink}(\text{K})}{\text{temp. of steam at source}(\text{K})} \times 100$$

(a) Calculate the thermal efficiency of a steam turbine supplied with steam at 540°C and using a river as the choice of sink at 23 °C. [1]

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(b) Power plants generating electricity by burning coal to boil water operate at approximately 35 % efficiency.

State what this means and suggest why it is lower than the thermal efficiency. [2]

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(Option C continues on the following page)

(Option C continued)

16. Nuclear power is another source of energy.

(a) Compare and contrast the process of nuclear fusion with nuclear fission. [3]

One similarity:

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Two differences:

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(b) Dubnium-261 has a half-life of 27 seconds and rutherfordium-261 has a half-life of 81 seconds.

Estimate what fraction of the dubnium-261 isotope remains in the same amount of time that $\frac{3}{4}$ of rutherfordium-261 decays. [1]

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(c) ^{235}U atoms can be used in nuclear reactors whereas ^{238}U cannot. A centrifuge is used to separate isotopes.

(i) Calculate the relative rate of effusion of $^{235}UF_6(g)$ to $^{238}UF_6(g)$ using sections 1 and 6 of the data booklet. [2]

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(Option C continues on the following page)

(Option C, question 16 continued)

(ii) Explain, based on molecular structure and bonding, why diffusion or centrifuging can be used for enrichment of UF_6 but not UO_2. [3]

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17. One method of producing biodiesel is by a transesterification process.

(a) Deduce the equation for the transesterification reaction of pentyl octanoate, $C_7H_{15}COOC_5H_{11}$, with methanol. [1]

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(b) Outline why the ester product of this reaction is a better diesel fuel than pentyl octanoate. [1]

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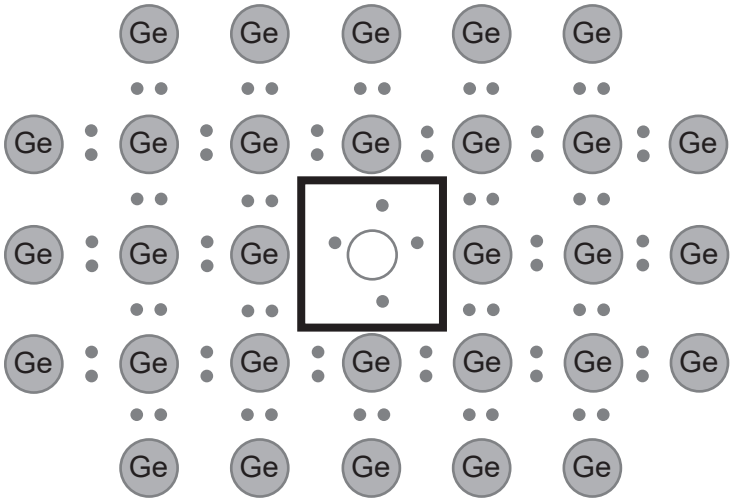
(Option C continues on the following page)

(Option C continued)

18. The conductivity of a germanium semiconductor can be increased by doping.

(a) Draw the Lewis (electron dot) structure for an appropriate doping element in the box in the centre identifying the type of semiconductor formed. [2]



Type of semiconductor:

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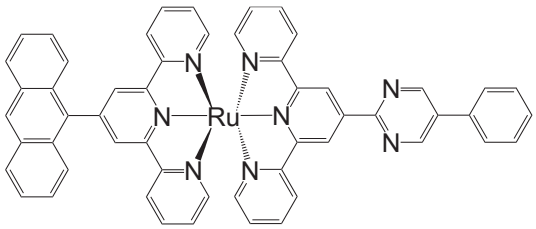
[Source: http://www.radartutorial.eu/21.semiconductors/hl07.tr.html by Christian Wolff]

(Option C continues on the following page)

(Option C, question 18 continued)

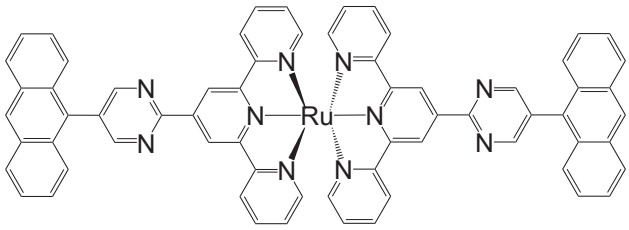
(b) A dye-sensitized solar cell uses a ruthenium(II)–polypyridine complex as the dye. Two ruthenium(II) complexes, A and B, absorb light of wavelengths 665 nm and 675 nm respectively.

Complex A



$\lambda_{max} = 665\,nm$

Complex B



$\lambda_{max} = 675\,nm$

[Source: © International Baccalaureate Organization 2018]

(i) State the feature of the molecules responsible for the absorption of light. [1]

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(ii) Outline why complex B absorbs light of longer wavelength than complex A. [1]

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End of Option C

Option D — Medicinal chemistry

19. Drug testing is necessary to determine safe and effective doses.

Distinguish between the lethal dose (LD_{50}) and the toxic dose (TD_{50}). [2]

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20. (a) Penicillins and aspirin are important medicines.

(i) Describe how penicillin combats bacterial infections. [2]

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(ii) State how penicillins may be modified to increase their effectiveness. [1]

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(b) State the type of reaction used to synthesize aspirin from salicylic acid. [1]

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(c) Explain why aspirin is **not** stored in a hot, humid location. [2]

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(Option D continues on the following page)

(Option D continued)

21. Morphine and diamorphine (heroin) are both opioids.

Explain why diamorphine is more potent than morphine using section 37 of the data booklet. [2]

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22. Excess acid in the stomach is often treated with calcium carbonate.

(a) Formulate a chemical equation for the neutralization of stomach acid with calcium carbonate. [1]

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(b) Calculate the amount, in mol, of stomach acid neutralized by an antacid tablet containing 0.750 g calcium carbonate. [1]

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(c) Explain how omeprazole (Prilosec) regulates pH in the stomach. [2]

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(Option D continues on the following page)

(Option D continued)

23. Antiviral medications such as zanamivir (Relenza) are commonly available for consumer use.

Identify the names of **two** functional groups present in zanamivir using section 37 of the data booklet. [2]

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24. Drug synthesis often involves solvents.

Identify a common hazardous solvent and a Green solvent that could replace it. [2]

Hazardous solvent:

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Green solvent:

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25. Taxol was originally obtained from the bark of the Pacific yew tree.

Outline how Green Chemistry has improved the process of obtaining Taxol. [2]

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(Option D continues on the following page)

(Option D continued)

26. Radioisotopes can be used to treat a wide variety of diseases.

(a) Phosphorous-32 undergoes beta decay. Formulate a balanced nuclear equation for this process. [1]

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(b) The half-life of phosphorus-32 is 14.3 days. Calculate the mass, in g, of ^{32}P remaining after 57.2 days if the initial sample contains 2.63×10^{-8} mol. Use table 1 of the data booklet and $M_r = 31.97\,g\,mol^{-1}$. [2]

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(c) Explain the targeted alpha therapy (TAT) technique and why it is useful. [3]

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(Option D continues on the following page)

(Option D continued)

27. Ethanol can be detected by a variety of instruments.

(a) Fuel cells use an electrochemical process to determine the concentration of ethanol. Formulate the overall equation for this process. [1]

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(b) Predict the chemical shifts and integration for each signal in the ^{1}H NMR spectrum for ethanol using section 27 of the data booklet. [3]

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End of Option D

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