

# Markscheme

**November 2015**

**Chemistry**

**Higher level**

**Paper 3**

22 pages

This markscheme is the property of the International Baccalaureate and must **not** be reproduced or distributed to any other person without the authorization of the IB Assessment Centre.

## Subject Details: Chemistry HL Paper 3 Markscheme

### Mark Allocation

Candidates are required to answer questions from **TWO** of the options [**2 x 25 marks**]. Maximum total = [**50 marks**].

1. A markscheme often has more marking points than the total allows. This is intentional.
2. Each marking point has a separate line and the end is shown by means of a semicolon (;).
3. An alternative answer or wording is indicated in the markscheme by a slash (/). Either wording can be accepted.
4. Words in brackets ( ) in the markscheme are not necessary to gain the mark.
5. Words that are underlined are essential for the mark.
6. The order of marking points does not have to be as in the markscheme, unless stated otherwise.

**Option A — Modern analytical chemistry**

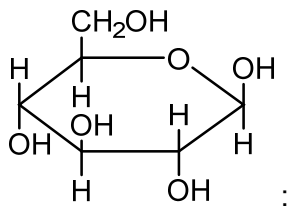
1. (a) each (type of) bond absorbs a specific frequency/wavelength/wavenumber (of IR radiation);  
bonds absorb radiation that has same frequency as their natural frequency of vibration;  
(frequencies/wavenumbers associated with) troughs/peaks/region (in IR spectrum) allow identification of bonds (present in molecule); **[2 max]**
- (b) compound **A**;  
contains C=O corresponding to the absorption at (about) 1760 cm<sup>-1</sup>/  
1700–1750 cm<sup>-1</sup> (from data booklet);  
*Accept any specific value in the range 1700–1780 cm<sup>-1</sup> or any range given between 1680 cm<sup>-1</sup> and 1820 cm<sup>-1</sup>.*
- contains OH of a carboxylic acid corresponding to the absorption at (about) 3000 cm<sup>-1</sup>/2500–3300 cm<sup>-1</sup> (from data booklet) / does not contain OH of an alcohol corresponding to absorption in the range 3200–3600 cm<sup>-1</sup> (from data booklet); **[3]**  
*Accept any specific value in the range 2800–3200 cm<sup>-1</sup>.*
- Award [1 max] for answers choosing compound **B** because it contains C=O and OH.*
- (c) compound **C**: (is the only one that) has 6 signals;  
compound **A**: has 5 signals with ratio of areas 3:2:2:2:1;  
compound **B**: has 5 signals with ratio of areas 3:3:2:1:1; **[3]**
- The numbers in the ratios can be in any order.  
Accept “peaks” for “signals”.*
- Award [1 max] for M2 and M3 for stating “**A** and **B** have 5 signals each”.  
Award [2 max] for stating “**A** and **B** have 5 signals each **and C** has six signals”.*
2. (a) identification of metal (ions) in  
water/solutions/blood/urine/soil/plants/foods/pharmaceuticals/oils;  
determination of the concentration of metal (ions) in water/solutions/  
blood/urine/soil/plants/foods/pharmaceuticals/oils; **[1 max]**  
*Accept specific metal ions or specific examples.  
Accept “detection” for “identification” or “determination”.*
- (b) *Fuel*:  
forms a combustion mixture;  
*Accept “creates a high temperature / produces heat”.  
Accept “(produces a flame that) atomises sample”.  
Do not accept just “vaporizes sample”.*
- Monochromatic detector*:  
determines absorbance/intensity of light absorbed (at each wavelength) /  
compares the intensity of the beam passing through the sample with the  
reference beam (for each wavelength) / converts the intensity of light (absorbed)  
into an electrical signal; **[2]**  
*Accept “amount of absorption” or “amount of light absorbed” instead of “intensity  
of light absorbed”.  
Do not accept just “detects absorbance/absorption”.*

3. (a) *Absorption spectra:*  
 electrons absorb a photon/light/wavelength/frequency/energy/radiation **and** move to higher energy level(s);  
 Accept “excited state(s)” for “higher energy level(s)”.
- Emission spectra:*  
 (excited) electrons move down to lower energy level(s) **and** release a photon/light/wavelength/frequency/energy/radiation; [2]  
 Accept “state” for “level” throughout.
- Award [1 max] if the movement between energy levels is described correctly but the involvement of a photon/light/wavelength/frequency/energy/radiation is omitted.*  
 Accept suitable diagrams.
- (b) electric discharge is passed through the sample / high voltage/potential applied (under reduced pressure) / sample is heated strongly;  
 sample emits a photon/light/wavelength/frequency/energy/radiation that is passed through a prism/diffraction grating (to separate the wavelengths); [2]
4. (a) double bonds / pi/π electrons; [1]  
 Accept “pi/π bonds”.  
 Accept “unsaturation/unsaturated groups” or “conjugation”.  
 Accept specific chromophores such as “carbonyl/C=O” and accept “C=C”.  
 Accept “benzene ring/aromatic ring”, “phenol”, “phenyl” (though not strictly correct) but not “benzene / arene”.
- (b) octyl salicylate (offers better protection);  
 less conjugation in octyl salicylate / more (extensive) conjugation in dioxybenzone;  
 (better protection because) absorbs higher frequency/shorter wavelength (more harmful radiation); [3]  
 M3 can be scored independently of M1 and M2.
5. (a) *Stationary phase:*  
 long-chain/high molecular mass/large hydrocarbon/alkane (adsorbed/coated on solid support) / high boiling point/non-volatile liquid / carbowax / silicon dioxide/silica/SiO<sub>2</sub> (as solid support) / aluminium oxide/Al<sub>2</sub>O<sub>3</sub> (as solid support);  
 Accept “polymer”.  
 Do not accept just “solid support” or “oxide”.
- Mobile phase:*  
 inert/noble/unreactive gas / He / Ar / N<sub>2</sub>; [2]  
 Do not accept just “gas”.  
 Accept “H<sub>2</sub>” or “CO<sub>2</sub>”.  
 Accept either formula or name.
- (b) substances have different affinities/solubilities/adsorption for the hydrocarbon/alkane/stationary phase/oxide (and carrier gas/mobile phase) / components partitioned between stationary and mobile phases/two phases based on their relative affinities/boiling points/volatilities/solubilities (in the two phases) / OWTTE;  
 different retention times / emerge at different times / travel at different rates; [2]

- (c) area under (alcohol) peak (is proportional to its concentration/standard/amount); **[1]**  
*Accept "size of peak".*  
*Do not accept "height of peak".*
- (d) (sugar) would decompose at the high temperature used; **[1]**

**Option B — Human biochemistry**

6. (a) (i)



[1]

(ii) ( $\alpha$ -glucose) OH/hydroxyl on C<sub>1</sub> is below the ring;  
 Accept "alcohol/hydroxy" for "OH/hydroxyl" but not "hydroxide". Penalize this once only on paper.

[1]

(b) ( $\beta$ -)1,4 glycosidic;  
 Accept "( $\beta$ -)1,4 glycoside".  
 Accept "1-4" for "1,4".

[1]

7. (a) vitamin C more soluble as it has four/several/more OH/hydroxyl (groups);  
 forms hydrogen bonds with water;  
 Accept converse argument for vitamin D.  
 Accept "alcohol/hydroxy (groups)" for "OH/hydroxyl (groups)" but not "hydroxide".  
 Penalize this only once on paper.

[2]

Award [1 max] for stating "Vitamin C is water-soluble **and** Vitamin D is fat-soluble".

(b) (eating) fresh foods/fruits / foods rich in vitamins/minerals;  
 adding nutrients missing in commonly consumed foods / (vitamin/mineral) fortification;  
 providing (nutritional) supplements;  
 Accept any specific examples.

genetic modification of food;  
 educating the population in healthy eating/taking a balanced diet / better labelling of food with more information on products / OWTTE;

[3 max]

8. (a) (i) substrate/glucose binds to active site / lock and key mechanism / formation of substrate/glucose-enzyme complex / induced fit mechanism;  
 Accept "active site (of enzyme) and substrate have complementary shape/structure".  
 Accept "model" for "mechanism".

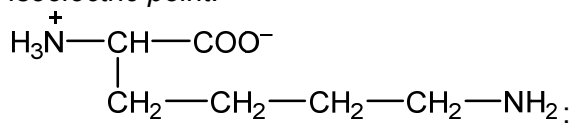
active site depends on tertiary/quaternary enzyme structure;  
 (as substrate/glucose binds) bonds break **and** products/enzyme released;

[2 max]

(ii) at higher temperatures enzyme becomes less effective/inactive/denatured;  
 tertiary structure becomes disrupted / active site deformed / OWTTE;

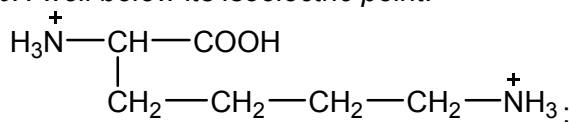
[2]

(b) *At its isoelectric point:*



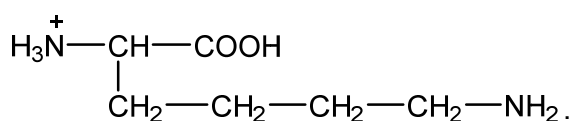
*Accept alternate structure where  $\beta$ -C has  $\text{NH}_2$  and  $\text{NH}_3^+$  is at end of carbon chain.*

*At a pH well below its isoelectric point:*



[2]

*Accept*



*Accept alternate structure where  $\beta$ -C has  $\text{NH}_2$  and  $\text{NH}_3^+$  is at end of carbon chain.*

9. (a) (i) aerobic **and** (ii) anaerobic;

[1]

(b) *Cytochromes:*

carry/transport electrons;

*Accept "catalyse (redox) reactions/act as enzymes".*

*Hemoglobin:*

carries/transport oxygen (in the blood) / iron (in hemoglobin) can bond to oxygen (to form oxyhemoglobin);

[2]

10. (a) *Progesterone:*

(two) carbonyl (groups) **and** alkene;

*Accept "ketone" **and** "alkenyl/carbon-carbon double bond".*

*Estradiol:*

(two) hydroxyl (groups) **and** benzene ring/aromatic ring;

*Accept "alcohol", "hydroxy" for "hydroxyl", "phenol" for "benzene ring/aromatic ring" but not "hydroxide", "benzene" or "phenyl". Penalize this once only on paper.*

*Award [1 max] for one different functional group identified for both hormones.*

[2]

(b) *Medical use:*

increase/recover muscle mass / induce (delayed) male puberty / treat hormone disorders/sex change;

*Do not accept just "gains weight".*

*Example of abuse:*

taken as performance enhancing drugs/PED (in sports to gain unfair advantage) / OWTTE;

*Do not accept "increase/recover muscle mass" or just "overuse" for abuse.*

[2]



11. (a) two (poly)nucleotide strands (coiled around same axis);  
sugar-phosphate backbone (on outside);  
*Accept “deoxyribose/pentose” for “sugar” but not “ribose”.*

nitrogenous bases (on inside);  
strands held together by hydrogen bonding (between bases) / hydrogen bonding  
between bases;  
only certain base pairings possible / T–A **and** C–G;  
*Marks may be scored from suitably labelled diagrams.*

**[3 max]**

- (b) criminal/forensic cases / paternity/maternity determination / mapping of  
evolutionary trees of extinct species (in palaeontology) / determination of  
population/family relationships (in study of migration/ecology/evolution) /  
identification of victims following a disaster (*eg*, from a tsunami etc.);

**[1]**

**Option C — Chemistry in industry and technology**

12. (a) *Negative electrode (anode):*  
cadmium (metal);

*Electrolyte:*

(aqueous) potassium hydroxide;

Accept “(aqueous) sodium hydroxide” or “(aqueous) lithium hydroxide”.

**[2]**

*Names required not chemical symbols.*

- (b) *Negative electrode (cathode):*  $\text{Cd}(\text{OH})_2(\text{s}) + 2\text{e}^- \rightarrow \text{Cd}(\text{s}) + 2\text{OH}^-(\text{aq})$

**and**

*Positive electrode (anode):*  $\text{Ni}(\text{OH})_2(\text{s}) + \text{OH}^-(\text{aq}) \rightarrow \text{NiO}(\text{OH})(\text{s}) + \text{H}_2\text{O}(\text{l}) + \text{e}^-$ ;

**[1]**

*Ignore state symbols.*

*Accept anode half-equation balanced with  $2\text{e}^-$ .*

*Accept e for  $\text{e}^-$ .*

- (c) *Any one for [1 max] from:*  
both convert chemical energy to electrical energy;  
Accept “both are voltaic/galvanic cells”.

both involve spontaneous reactions;

both have anode acting as negative electrode / both have cathode acting as positive electrode / both have reduction taking place at positive

electrode/cathode / both have oxidation taking place at negative electrode/anode;

*Any two for [2 max] from:*

fuel cells work non-stop while rechargeable batteries cannot work while recharging;

fuel cells have longer operating life;

fuel cells need a constant supply of reactants/fuel (producing electrical energy as long as fuel is provided to cell) while rechargeable batteries have stored chemical energy providing power until chemicals are used up;

fuel cells convert energy **and** rechargeable batteries store energy;

fuel cell products must be constantly removed (but not for rechargeable batteries);

fuel cells have inert/inactive electrodes/components while rechargeable have active/non-inert electrodes;

fuel cells run at higher temperatures (compared to rechargeable batteries);

fuel cells require pumps/cooling systems (while rechargeable batteries do not);

chemicals in rechargeable batteries are pollutants / chemicals in fuel cells are not pollutants;

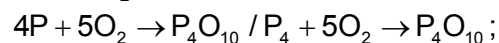
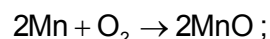
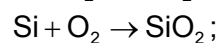
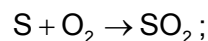
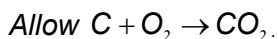
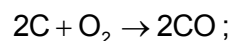
Accept “fuel cells are more expensive (than rechargeable batteries)”.

**[3 max]**

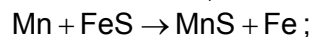
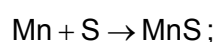
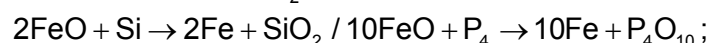
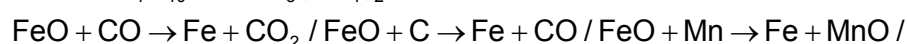
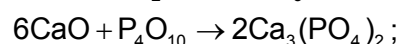
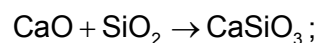
13. (a) in a nanotube all atoms are held together by (strong) covalent bonds;  
 in graphite there are (weak) intermolecular/London/dispersion/instantaneous  
 induced dipole-induced dipole forces between layers; [2]  
*Accept "vdW/van der Waals' forces" for "London forces".*

(b) hazards/long term effects (associated with small airborne particles) are not  
 known;  
 nanoparticles have potential to penetrate skin/cell membranes (resulting in  
 unintended effects) / nanoparticles can affect lung tissue/cause breathing  
 problems / workers can be exposed to inhalation of large amounts of  
 nanoparticles / nanoparticles can cause tumours/cancer (by changing genetic  
 material) / nanoparticles can cause heart problems;  
 human/animal immune system may be defenceless against new nanoscale  
 products;  
 may not be covered by current toxicology/toxicity regulations (as properties  
 depend on size of nanoparticle); [2 max]  
*Accept "nanoparticles can be toxic".*

14. (a) *Any two from:*



*Accept "P<sub>2</sub>O<sub>5</sub>" instead of "P<sub>4</sub>O<sub>10</sub>".*



*Ignore state symbols.*

[2 max]

(b) high-carbon steel is less malleable/less ductile/harder/more brittle (than  
 low-carbon steel);  
 high-carbon steel is stronger (than low-carbon steel);  
 high-carbon steel has a lower melting point (than low-carbon steel);  
 high-carbon steel is less resistant to corrosion (than low-carbon steel); [2 max]  
*Accept converse points for low-carbon steel.*

15. (a) rod-like/rigid molecules have random positions/are distributed without positional order;  
(on average) align in same direction/parallel / have directional order (due to their polarity);

[2]

(b) *Biphenyl group*:  
makes molecule rod-shaped/rigid;

*Nitrile group*:  
makes molecule polar (to allow alignment) / increases intermolecular interactions so orientation controlled by electric field;

*Long alkyl group*:  
ensures molecules cannot pack too closely (to maintain liquid crystal phase);  
Accept "provides a rod-like shape to molecule".

[3]

16. (a)

	<i>Addition polymer</i>	<i>Condensation polymer</i>
<i>Name of polymer</i>	Polyethyne / Polypropene <b>and</b>	Nylon 6,6 / PET;
<i>Structural formula of monomer(s)</i>	<p><b>EITHER</b></p> <p><i>Polyethyne:</i> HCCH</p> <p><b>OR</b></p> <p><i>Polypropene:</i> CH<sub>2</sub>CHCH<sub>3</sub>;</p> <p><i>Accept full or condensed structural formulas but not molecular formulas.</i></p>	<p><b>EITHER</b></p> <p><i>Nylon:</i> HOOCCH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>COOH <b>and</b> H<sub>2</sub>NCH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>NH<sub>2</sub></p> <p><b>OR</b></p> <p><i>PET:</i> HOOC<sub>6</sub>H<sub>4</sub>COOH <b>and</b> HOCH<sub>2</sub>CH<sub>2</sub>OH;</p> <p><i>Accept full or condensed structural formulas but not molecular formulas.</i></p>

[3]

(b) increased (electrical) conductivity;

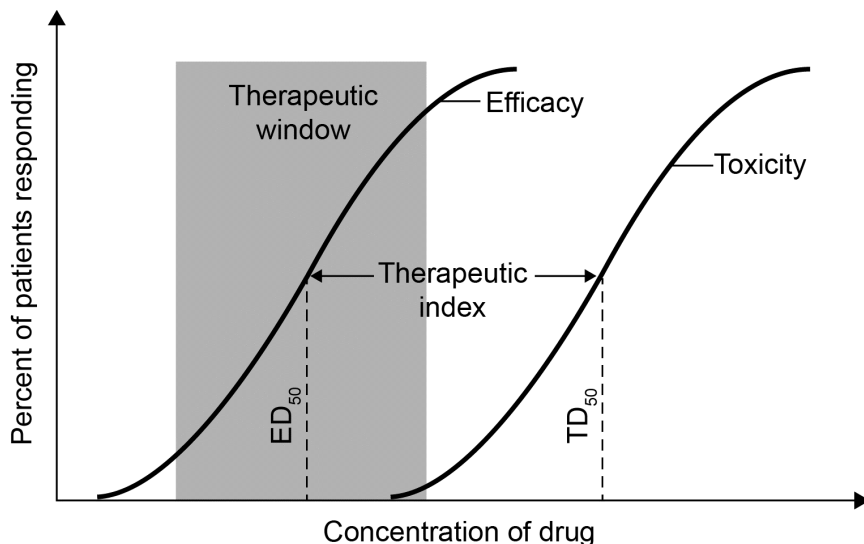
[1]

(c) non-biodegradable / needs to be treated to become biodegradable;  
can be recycled;  
accumulation in landfills/oceans/deserts / impact on animals/marine life / OWTTE;  
made from non-renewable resources/petroleum products;  
subsequent combustion/burning of PET can result in degradation products which impact the environment / OWTTE;  
Accept correctly identified degradation products such as CO, benzene etc.

[2 max]

**Option D — Medicines and drugs**

17. *Therapeutic window:*  
 range of concentration/dosage over which a drug provides the therapeutic effect without causing adverse effects (to patients) / range of concentration/dosage of drug (able to treat disease successfully) staying within safety limit;  
*M1 may be scored from a correctly labelled diagram.*



*Accept "levels" or "doses".*  
*Accept "is the relative margin of safety of the drug".*

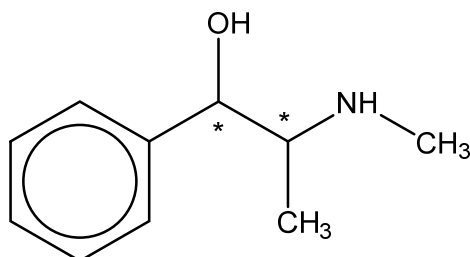
*Tolerance:*  
 patient needs to take larger amounts of a drug to have the original effect / OWTTE; [2]  
*Do not accept just "body adapts to action of the drug" / OWTTE.*  
*Accept the more precise medical definition of tolerance from the American Academy of Pain Medicine ie, "tolerance is a state of adaptation in which exposure to a drug induces changes that result in a diminution of one or more of the drug's effects over time".*

18. (a) condensation / esterification/acetylation; [1]  
*Accept "diesterification/diacetylation".*

(b) *Diamorphine:*  
 temporarily binds to/blocks/interferes with receptor sites in the brain / prevents transmission of pain impulses within the CNS/central nervous system;

*Mild analgesics:*  
 intercept the pain stimulus at source / blocks/interferes with production of prostaglandins/compounds that cause pain/swelling/fever / inhibits/blocks /interferes with enzyme at site of pain; [2]  
*Do not award M2 if prostaglandin is said to be an enzyme.*

19. (a) (i)



both chiral centres correctly identified;

[1]

(ii) different enantiomers have different (physiological) effects on the body / OWTTE;

one enantiomer of thalidomide used to treat morning sickness/induced sleep in pregnant women but other caused fetal abnormalities/other was teratogenic / one enantiomer of ibuprofen more effective/(pharmacologically) active compared to other / one DOPA enantiomer helps management of Parkinson's disease/DRD/Segawa's disease but other has no effect;

[2]

*Do not accept just "causes calmness" for "treating morning sickness".  
Accept "one enantiomer of ibuprofen has analgesic/anti-inflammatory properties (but other does not)".*

*Accept "isomer" for "enantiomer".*

*M1 may be scored if M2 is correct.*

(b) chiral auxiliaries are chiral/optically active (reagents) / OWTTE;  
(chiral auxiliary) attaches to/reacts with non-chiral molecule/substrate (allowing desired enantiomer to form) / chiral auxiliary creates stereospecific condition to follow specific pathway forming one/desired enantiomer / OWTTE;  
once desired enantiomer forms chiral auxiliary is removed/recycled;

[2 max]

(c) (i) increase (mental) alertness/brain activity;  
*Do not accept just "increase concentration".*

relax air passages;

reduce appetite;

(in large amounts) can cause

restlessness/sleeplessness/insomnia/delusions/hallucinations/fits;

cause palpitations/tremors;

increase blood pressure / constricts blood vessels;

increase heart rate;

[2 max]

*For (mental) alertness/brain activity, blood pressure and heart rate there must be reference to an increase in these.*

*Do not accept "increase in sweating".*

*Do not accept "addiction".*

(ii) mimics effect of adrenaline / stimulates sympathetic nervous system;  
*Do not accept "mimics sympathetic nervous system".*

[1]

(iii) drug molecule becomes ionic/more polar / amino (group) converted into ion/salt;  
*Accept "amine" for "amino".*

increases solubility in water / more concentrated in blood stream / more easily absorbed by body;

[2]

20. (a) alter cell's genetic material;  
 (changes cell membrane so that it) inhibits virus entry/binding to cell;  
 prevents virus from leaving cell (after reproduction);  
 becomes part of DNA of virus / alters virus / blocks enzyme (polymerase) which  
 builds DNA;  
 prevents virus from using cell to multiply/reproduce/replicate; **[2 max]**

(b) leads to resistance / makes antibiotics less effective;  
 destroys useful/beneficial bacteria;  
 destroyed bacteria replaced by more harmful bacteria;  
 resistant bacteria grow/pass on their immunity/mutation to next generation /  
 OWTTE; **[2 max]**  
*Do not accept "increased cost of developing antibiotics".*

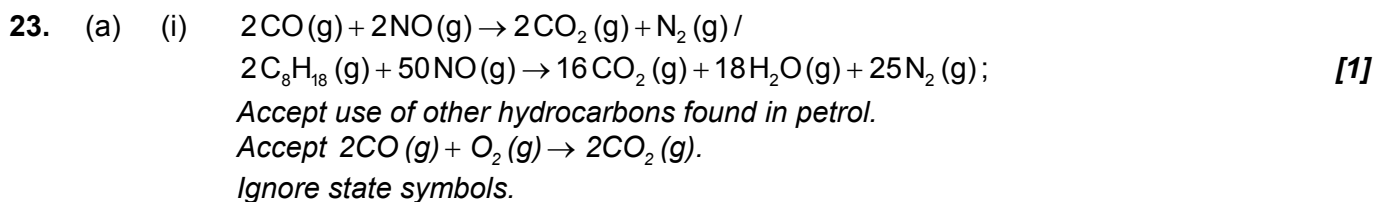
21. (a) *Colour change:*  
 orange to green;  
 Accept "yellow to green".  
  
*Type of reaction:*  
 redox / oxidation **and** reduction; **[2]**

(b) *Infrared:*  
 absorption of C–H / 2850–3100 cm<sup>-1</sup> measured;  
 Accept any specific wavenumber in this range.  
 Accept "absorption of C–O / 1050–1410 cm<sup>-1</sup> measured".  
  
 compare absorption/height/size of peak/intensity to standard/reference;

**OR**

*Fuel cell:*  
 ethanol is oxidised (to CO<sub>2</sub> and H<sub>2</sub>O);  
 current/voltage/potential is proportional to ethanol concentration/level; **[2]**

22. (secondary) amino (group);  
 Accept "(secondary) amine".  
  
 alkene;  
 Accept "alkenyl".  
  
 benzene ring / aromatic ring;  
 Do not accept "benzene", "arene" or "phenyl (group)". Penalize this once on paper  
 only. **[2 max]**  
  
 Accept "indole (group)".

**Option E — Environmental chemistry**

(ii) increase efficiency/rate / provide a large surface area (of catalyst); [1]

(b) (i) (as the concentration/amount of air/oxygen increases) CO/carbon monoxide emissions decrease;  
 as CO/carbon monoxide is oxidized/reacts with O<sub>2</sub>/oxygen (to form carbon dioxide/CO<sub>2</sub>) / as more complete combustion occurs (in engine); [2]

(ii) N<sub>2</sub>/nitrogen and O<sub>2</sub>/oxygen react to produce NO<sub>x</sub>/nitrogen oxides;  
 (as air to fuel ratio increases) amount of air (in engine) increases;  
 more NO<sub>x</sub>/nitrogen oxides produced (as a result);  
 at very large air to fuel ratios/in a lean burn engine the temperature in engine drops (less fuel burning);  
 (and reaction between N<sub>2</sub>/nitrogen and O<sub>2</sub>/oxygen) requires high temperatures; [4 max]

(iii)  $2\text{NO}\cdot(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}_2\cdot(\text{g})$  /  $\text{NO}\cdot(\text{g}) + \text{O}_3(\text{g}) \rightarrow \text{NO}_2\cdot(\text{g}) + \text{O}_2(\text{g})$  /  $\text{NO}\cdot(\text{g})$  forms  $\text{NO}_2\cdot(\text{g})$  /  $\text{NO}_2\cdot(\text{g}) + \text{UV} \rightarrow \text{NO}\cdot(\text{g}) + \text{O}\cdot(\text{g})$ ;  
*Accept  $hf/h\nu$  for UV.*

*Award [1 max] for any of the following for M2:*

$\text{O}\cdot(\text{g}) + \text{O}_2(\text{g}) \rightarrow \text{O}_3(\text{g})$  /  $\text{O}\cdot(\text{g}) + \text{H}_2\text{O}(\text{g}) \rightarrow 2\text{HO}\cdot(\text{g})$  / formation of ozone/hydroxyl radicals from oxygen radicals;

$\text{RH}(\text{g}) + \text{O}\cdot(\text{g}) \rightarrow \text{R}\cdot(\text{g}) + \text{HO}\cdot(\text{g})$  / formation of (alkyl and) hydroxyl radical from VOCs/hydrocarbons;

$\text{RH}(\text{g}) + \text{HO}\cdot(\text{g}) \rightarrow \text{R}\cdot(\text{g}) + \text{H}_2\text{O}(\text{g})$  / formation of alkyl radical (and water) from VOCs/hydrocarbons;

$\text{R}\cdot(\text{g}) + \text{O}_2(\text{g}) \rightarrow \text{RO}_2\cdot(\text{g})$ ;

$\text{RO}_2\cdot(\text{g}) + \text{NO}\cdot(\text{g}) \rightarrow \text{RO}\cdot(\text{g}) + \text{NO}_2\cdot(\text{g})$  / reaction of peroxy radical with nitrogen monoxide to form nitrogen dioxide;

$\text{RO}\cdot(\text{g}) + \text{O}_2(\text{g}) \rightarrow \text{R}'\text{CHO}(\text{g}) + \text{HO}_2\cdot(\text{g})$  / formation of aldehyde (and hydroperoxyl radical);

$\text{R}'\text{CO}\cdot(\text{g}) + \text{O}_2(\text{g}) \rightarrow \text{R}'\text{COO}_2\cdot(\text{g})$  / formation of peroxy radical;

$\text{R}'\text{CHO}(\text{g}) + \text{HO}_2\cdot(\text{g}) \rightarrow \text{R}'\text{CO}\cdot(\text{g}) + \text{H}_2\text{O}(\text{g})$ ;

VOCs/hydrocarbons/aldehydes/peroxy radical **and** nitrogen dioxide/

nitrogen dioxide radical combine to form PANs/R'COO<sub>2</sub>NO<sub>2</sub>

/  $\text{R}'\text{COO}_2\cdot(\text{g}) + \text{NO}_2\cdot(\text{g}) \rightarrow \text{R}'\text{COO}_2\text{NO}_2(\text{g})$ ; [3]

*For M1, M2 and M3 allow NO(g)/NO·(g) and NO<sub>2</sub>(g)/NO<sub>2</sub>·(g).*

*For M3 allow R for R'.*

*Accept representation of radicals without · if consistent throughout the answer but penalize inconsistent usage once only in Q23(b)(iii) and Q25(a).*

*Ignore state symbols.*



24. (a) due to irrigation;  
salts (in irrigation water) accumulate in soil as water evaporates;  
poor drainage; **[2 max]**
- (b) source of nutrients;  
contributes to resilience of soil;  
improves structural stability of soil;  
improves water-retention;  
alters soil's thermal properties;  
enhances ability of soil to buffer pH changes;  
forms stable complexes with cations;  
contributes to cation-exchange capacity/CEC / ability to hold nutrient ions;  
binds to contaminants/heavy metals/pesticides (reducing their effect) /  
binds to organic/inorganic substances; **[3 max]**  
*For last marking point there must be some reference to "binding" / OWTTE.*
25. (a)  $\text{CCl}_2\text{F}_2(\text{g}) \xrightarrow{\text{UV}} \text{Cl}\cdot(\text{g}) + \cdot\text{CClF}_2(\text{g})$ ;  
*UV is required for M1.*  
*Accept "hf/hv" for "UV".*
- $\text{Cl}\cdot(\text{g}) + \text{O}_3(\text{g}) \rightarrow \text{ClO}\cdot(\text{g}) + \text{O}_2(\text{g})$ ;  
 $\text{ClO}\cdot(\text{g}) + \text{O}\cdot(\text{g}) \rightarrow \text{Cl}\cdot(\text{g}) + \text{O}_2(\text{g})$ ; **[3]**  
*Accept representation of radical without • (eg, Cl, ClO) if consistent throughout mechanism but penalize inconsistent usage once only in Q23(b)(iii) and Q25(a). Ignore state symbols.*
- (b) *Advantage:*  
does not deplete ozone as they do not contain Cl/C–Cl bonds;  
*Accept answer based on comparative bond enthalpy values.*
- Disadvantage:*  
absorb IR radiation/are greenhouse gases / contribute to global warming; **[2]**
26. (a) *Award [1] for any two from:*  
food  
animal waste  
dead animals/plants; **[1]**  
*Accept "organic material/sewage".*
- (b) as oxygen-demanding wastes are high at the farm BOD is high / decay of excess plant growth at farm causes high BOD;  
oxygen-demanding wastes broken down downstream from farm decreasing BOD;  
oxygen levels decrease as oxygen is used up in the decomposition (of plants);  
oxygen levels increase further down as more oxygen dissolves from air/less BOD;  
respiration of plants (at night) causes decrease in dissolved oxygen; **[3 max]**

**Option F — Food chemistry**

27. (a) elaidic acid; [1]
- (b) closer packing (of fatty acids) for *trans* isomer / has a greater surface area / greater distortion of electron cloud; greater London/dispersion/instantaneous induced dipole-induced dipole forces (in *trans* isomer); [2]  
 Accept “vdW/van der Waals’ forces” for “London forces”.  
 Accept “greater intermolecular forces (in *trans* isomer)”.  
 Accept converse arguments for *cis* isomer.

28.

<i>Characteristic</i>	<i>Nutrient</i>
<i>Contains an ester group</i>	fats/oils/lipids/triglycerides; Accept “vitamin C/ascorbic acid”.
<i>Made up of monosaccharides</i>	carbohydrates; Accept specific correct examples of disaccharides, polysaccharides.
<i>Essential for healthy bones</i>	calcium (ion) / vitamin D/calciferol; Accept other nutrients such as “phosphorus”, “magnesium” or “protein” but not just “vitamins”.

[3]

Accept names, structures or chemical formulas.

29. (a) (i) bad/disagreeable smell/appearance/texture/taste; [1]
- (ii)  $R\cdot + O_2 \rightarrow ROO\cdot$  ;
- $ROO\cdot + RH \rightarrow R\cdot + ROOH$  ; [2]  
 Accept representation of radicals without  $\cdot$  (eg, R) if consistent in both steps. Penalize this once only on paper.
- (b) (lower salt content leads to) higher water content; more microbial spoilage/activity / more reactions involving micro-organisms will take place; [2]
30. (a) carotenoids; [1]  
 Do not accept “carotenes”.  
 Accept “Lycopene: carotene **and** Zeaxanthin: carotenoid”.
- (b) (i) absorb light in the visible region of the spectrum / absorbs visible light; transmit the complementary light; [2]  
 Accept “reflect” for “transmit” but not “emits”.
- Accept explanations based on pigments having extensive conjugation and needing less energy to excite the electrons so absorption occurs in the visible region of the spectrum / OWTTE.

- (ii) bromine/Br<sub>2</sub> reacts with C=C/double bonds / number of C=C/double bonds decreases (in conjugated molecule);

absorbed energy shifts to violet (from green) / higher energy/higher frequency/lower wavelength in visible region absorbed (resulting in complementary yellow colour);

[2]

31. (a) (kinetically) stable mixture of one phase in another (largely) immiscible phase;

[1]

- (b) hydrophobic/non-polar end attracts oils/fats **and** hydrophilic/polar/ionic end attracts water;  
lecithin acts as an interface/surface between phases (in the dispersed system);

[2]

- (c) *Chelating agents:*

reduce (free) metal ion concentration / form stable complexes with metal ions / act as ligands / form coordination/coordinate bonds with metal ions;  
*Accept "dative (covalent) bonds" for "coordination/coordinate" bonds.*  
*Do not accept "metal" for "metal ions".*

*Free-radical quenchers:*

inhibit/interrupt radical chain mechanism/radical formation / interrupt/inhibit initiation/propagation step (in auto-oxidation) / form stable/less reactive radical;  
*Accept suitable equation if explanation is evident.*

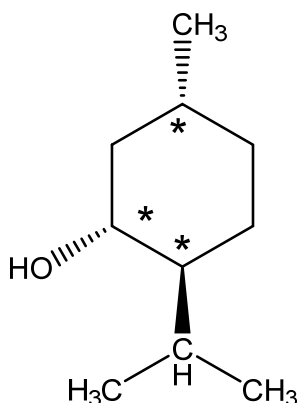
*Reducing agents (electron donors):*

remove/reduce concentration of oxygen / become oxidised (instead of food);  
*Accepts "reacts with oxygen".*

[3]

32. (a) 3 chiral centres identified correctly;

[1]



- (b) *R,S:*  
represents absolute configuration (of groups around the chiral centre) / based on R/rectus/right/clockwise **and** S/sinister/left/counter-clockwise system worked out from the structure of the molecule / priority group (according to atomic number/molar mass) ordered clockwise or anti-clockwise (according to the Cahn-Ingold-Prelog/CIP convention) / *OWTTE*;

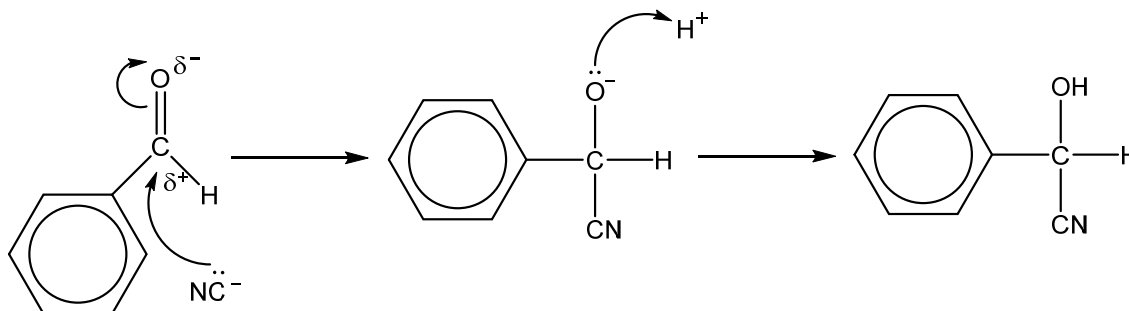
*(+)/(d) and (-)/(l):*

represents direction of rotation of plane-polarized light;

[2]

**Option G — Further organic chemistry**

33. (a)



curly arrow going from lone pair/negative charge on C in  $\text{CN}^-$  to carbonyl C **and**  
 curly arrow going from bond in  $\text{C}=\text{O}$  to O;  
 Do not allow curly arrow originating on N of  $\text{CN}^-$ .  
 Partial charges not required.

representation of intermediate anion with negative charge on O;  
 Lone pair on O not required.

curly arrow going from lone pair/negative charge on O of intermediate anion to  $\text{H}^+$ ;

[3]

(b) (i)  $\text{CH}_3\text{MgBr}/\text{CH}_3\text{MgI}$ ;  
 Accept " $\text{CH}_3\text{MgCl}$ ".

[1]

(ii) magnesium/Mg **and** bromomethane/ $\text{CH}_3\text{Br}$ /iodomethane/ $\text{CH}_3\text{I}$ ;  
 Accept "*chloromethane/ $\text{CH}_3\text{Cl}$* " for haloalkane.

ether/diethyl ether/ethoxyethane / dry/absence of water;  
 Accept "*non-polar solvent*".

[2]

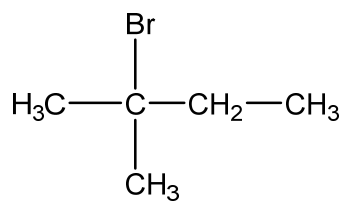
(c) *Type of reaction:*  
 elimination/dehydration;

*Reagent:*  
 (conc) phosphoric acid/ $\text{H}_3\text{PO}_4$ ;  
 Accept "*(conc) sulfuric acid/ $\text{H}_2\text{SO}_4$* ".

*Condition:*  
 heat/reflux/ $180\text{ }^\circ\text{C}$ ;  
 Accept any specific value in the range  $150\text{--}250\text{ }^\circ\text{C}$ .

[3]

34. (a)



Accept either a condensed or full structural formula.

[1]

- (b)  $(\text{CH}_3)_2\text{C}^+\text{CH}_2\text{CH}_3$ ;  
 more electron-releasing/electron-donating groups in tertiary / inductive effect of alkyl groups pushes electron-density onto positive carbocation in tertiary / OWTTE;  
 tertiary carbocation more stable than secondary carbocation / OWTTE;

[3]

Do not award marks for reference to Markovnikov's rule without explanation.  
 Accept structure of secondary carbocation for M1 if consequent converse argument is then conveyed (eg M3: secondary less stable than tertiary).

35. For the Cl atom directly attached to the ring:

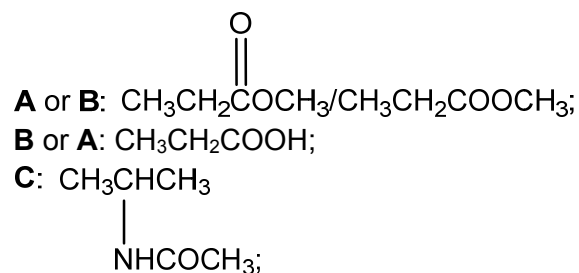
C-Cl bonds stronger/less polar owing to delocalization of lone pair on Cl (with the pi electrons in benzene ring) / pi electrons in benzene ring repel  $\text{OH}^-$ /nucleophile / benzene ring/electron cloud prevents  $\text{OH}^-$  attacking from opposite direction to C-Cl bond / OWTTE;

For the Cl atoms attached to the  $-\text{C}_2\text{H}_4-$  group:

$\text{OH}^-$ /nucleophile attacks the electron-deficient/ $\delta^+$ C atom attached to Cl;

[2]

36.



[3]

Accept full or condensed structural formulas.

37. (a)  $\text{HNO}_3 + 2\text{H}_2\text{SO}_4 \rightleftharpoons \text{NO}_2^+ + 2\text{HSO}_4^- + \text{H}_3\text{O}^+$ 

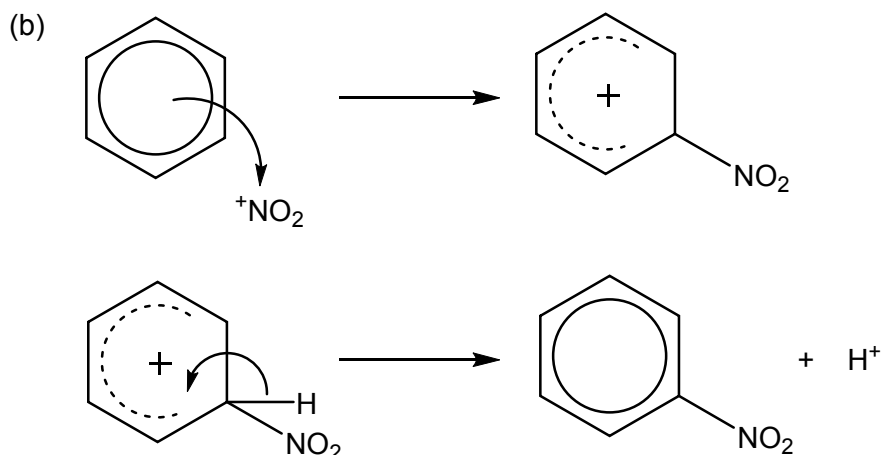
OR



[1]

Do not penalize use of single arrow.

Accept  $\text{HNO}_3 + \text{H}_2\text{SO}_4 \rightleftharpoons \text{NO}_2^+ + \text{HSO}_4^- + \text{H}_2\text{O}$ .



curly arrow going from delocalized electrons in benzene to  $^+\text{NO}_2$ ;  
 Do not penalize if  $\text{NO}_2^+$  is written.

representation of cation with correct formula **and** positive charge on ring;  
 curly arrow going from CH bond to benzene ring cation;  
 formation of organic product nitrobenzene **and**  $\text{H}^+$ ;  
 Allow mechanism with corresponding Kekulé structures.

[3 max]

- (c) nitro/ $\text{NO}_2$  (group) deactivates ring/is electron-withdrawing/reduces electron density in ring (hence ring becomes less reactive towards electrophile);  
 Accept "negative inductive effect" for "electron withdrawing".

[1]

- (d) in 2- and 4- positions intermediate carbocation has positive charge on carbon atom bonded to methyl group;  
 Accept a diagram showing this intermediate.

carbocation is stabilized by positive inductive effect of methyl group / OWTTE;  
 Do not award M2 for stating "methyl is electron-donating/activating" alone.

[2]