Answers to Option C exam-style questions

1 a Renewable energy sources are replenished naturally– they will not run out.
Non-renewable energy sources are finite – they will eventually run out. **[2]**

b *Advantage* – one of:
energy from the sun is free/
non-polluting in use/
does not produce greenhouse gases/
can be useful in remote locations.
Disadvantage – one of:
not a very concentrated form of energy/
huge banks of solar cells/panels are required/
solar cells are expensive to manufacture and buy/
a lot of energy and resources needed in manufacture, which can produce pollution/
dependent on weather and do not produce electricity at night. **[2]**

c i Total amount of energy from combustion of 10.0 mol of hydrogen is:
$10.0 \times 286 = 2860\,\text{kJ}$
$$\text{Efficiency (\%)} = \left(\frac{\text{useful energy out}}{\text{total energy in}}\right) \times 100$$
$$= \left(\frac{1500}{2860}\right) \times 100 = 52.4\%$$ **[2]**

ii Relative molecular mass of methanol = 32.05
volume occupied by 1 mol of methanol =
$$\frac{32.05}{0.79} = 41\,\text{cm}^3 \text{ or } 0.041\,\text{dm}^3$$
$$\text{Energy density} = \frac{726}{0.041} = 18\,000\,\text{kJ dm}^{-3}$$ **[3]**

iii Although methanol has a lower specific energy, it is a liquid at room temperature, whereas hydrogen is a gas. Methanol therefore has a much higher energy density and a smaller space is needed to store the fuel. **[2]**

2 a The process is called fractional distillation – separation depends on the different fractions having different boiling points.
The crude oil is heated in a furnace.
The liquid–vapour mixture is passed into a fractionating tower which is hot at the bottom and cooler at the top.
Gaseous compounds travel up the column until they condense and are drawn off as liquids.
Compounds with lower boiling points are drawn off higher up the tower. **[4]**

b i Octane number is a measure of the tendency of a fuel not to undergo auto-ignition/cause knocking in an engine.
The higher the octane number, the lower the tendency for auto-ignition. **[1]**

ii Catalytic cracking involves breaking long-chain hydrocarbons into shorter ones.
Short-chain alkanes have a higher octane number than longer chain ones and so cracking increases the octane number of a petroleum fraction.
Alkenes are also produced in cracking reactions and these have a higher octane number than the equivalent alkanes.
Catalytic cracking also increases the octane number because it produces more branched-chain alkanes and aromatic compounds, which have higher octane numbers than straight-chain alkanes. **[3]**

c i Total amount of fuel consumed = $5570 \times 14.0 = 77\,980\,\text{dm}^3$
Total amount of CO_2 produced = $77\,980 \times 2.00 = 155\,960\,\text{kg}$
Amount of CO_2 produced per passenger =
$$\frac{155\,960}{500} = 312\,\text{kg}$$
Carbon footprint = 312 kg CO_2e **[3]**

ii The total volume of fuel consumed for the journey is $\left(\frac{5570}{100}\right) \times 13 = 724.1\,\text{dm}^3$
The mass of fuel burned can be calculated from the density:
mass = density × volume
$0.700 \times 724\,100 = 506\,870\,\text{g}$
Number of moles of octane is $\frac{506\,870}{114.26}$
= 4436 mol
The equation for the combustion of octane is:
$$C_8H_{18}(l) + \tfrac{25}{2}O_2(g) \rightarrow 8CO_2(g) + 9H_2O(l)$$
So $8 \times 4436 = 35\,489$ mol CO_2 are produced.
The mass of CO_2 produced is
$35\,489 \times 44.01 = 1.562 \times 10^6\,\text{g}$ or 1562 kg.
The carbon footprint per person is therefore
$$\frac{1562}{2} = 781\,\text{kg } CO_2\text{e}$$ **[5]**

3 a Nuclear fission is the breakdown of a large nucleus into two smaller fragments of comparable masses. **[1]**

b If uranium-235 undergoes a fission reaction it breaks apart into two nuclei with higher binding energies per nucleon (more stable nuclei). A fusion reaction would involve the formation of a nucleus with a lower binding energy per nucleon. **[2]**

c The mass numbers and atomic numbers must balance on both side of the equation. The total mass number on the left is 236 and that on the right (without the neutrons) is $135 + 99 = 234$. Therefore there must be two neutrons. **[1]**

d i The time it takes for the number of radioactive nuclei present in a sample at any given time to fall to half its value.

ii The amount present halves every 1.7 s

$$100\% \xrightarrow{1.7\,s} 50\% \xrightarrow{1.7\,s} 25\% \xrightarrow{1.7\,s} 12.5\% \xrightarrow{1.7\,s} 6.25\%$$

6.8 s is equivalent to four half-lives; so the amount of antimony-135 remaining is 6.25% of the amount originally present. **[2]**

e Three of: *Health* – exposure to radiation can cause serious problems such as radiation sickness and cancer, which can result in death.

Accidents – can result in meltdown and escape of radioactive material into the environment.

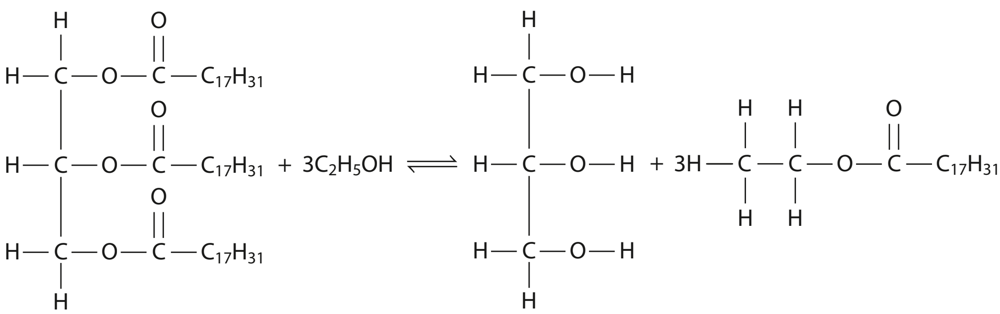
Disposal of waste – there is currently no completely safe way of disposing of high-level nuclear waste.

Security – nuclear fuels from reprocessing plants could be stolen and used in making nuclear weapons. **[3]**

4 a The long conjugated system of alternating double and single bonds. **[1]**

b $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$ **[1]**

c i



[2]

ii Sunflower oil has a much higher relative molecular mass and therefore there are stronger London forces between its molecules than in biodiesel.

Stronger intermolecular forces means a decreased tendency to flow. **[2]**

d There are many possible answers here – for example:
Advantage – one of:
Biofuels are renewable and so will not run out, but fuels derived from petroleum are finite.
Biodiesel is biodegradable so there is less environmental impact from a major spillage.
Biodiesel contains no sulfur so there are no sulfur dioxide emissions when it is burned.
Disadvantage – one of:
Biodiesel is more expensive than petrodiesel.
Biodiesel releases less energy per gram than petrodiesel when burned.
Growing crops that will be converted to biofuels requires vast areas of land that could be used for growing food crops. **[2]**

5 a i In CO_2 and CH_4, certain stretching and bending modes cause a change in dipole moment and they are able to absorb IR radiation.
N_2 and O_2 are non-polar diatomic molecules and can only undergo symmetrical stretching which does not cause a change in dipole moment. **[3]**

ii Some of the short wavelength solar radiation from the Sun passes through the atmosphere to reach the Earth's surface.
The surface absorbs some of this radiation and heats up.
The warmed surface radiates longer wavelength, infrared radiation.
Some of this radiation is absorbed by greenhouse gases such as CO_2 in the atmosphere.
Of the radiation absorbed by the greenhouse gases, some is re-radiated back to Earth.
The overall effect is that heat is 'trapped' by some gases in the atmosphere. **[4]**

iii Large-scale burning of fossil fuels/deforestation/increased agriculture have increased the amount of carbon dioxide and other greenhouse gases in the atmosphere.
A consequence of this is global warming/climate change. **[3]**

b Carbon dioxide is the most abundant greenhouse gas; but methane is much better than carbon dioxide at absorbing infrared radiation. **[2]**

c Particulates in the atmosphere cause sunlight to be reflected back into space, which causes cooling of the Earth. **[2]**

6 a Because the batteries are of the same type they will produce the same voltage; however, a bigger battery is likely to contain more materials and so should last longer. **[1]**

b i Primary cells cannot usually be recharged using mains electricity – the reaction in the cell is non-reversible.
The chemical reactions in a rechargeable battery are reversible and can be reversed by connecting the battery to an electricity supply. **[2]**

ii *Anode*: $Cd(s) + 2OH^-(aq) \rightarrow Cd(OH)_2(s) + 2e^-$; oxidation
Cathode: $2NiO(OH)(s) + 2H_2O(l) + 2e^- \rightarrow 2Ni(OH)_2(s) + 2OH^-(aq)$; reduction **[3]**

c They are very heavy and do not produce much energy per kilogram, so enough batteries to power a vehicle would add greatly to the overall mass of the vehicle. **[2]**

d $Q = \frac{1}{[Cu^{2+}(aq)]} = \frac{1}{0.800} = 1.25$
The number of electrons transferred is 2 and so we have:

$$E = E^{\ominus} - \left(\frac{RT}{nF}\right)\ln Q$$

$$= 0.34 - \left(\frac{8.31 \times 292}{2 \times 96\,500}\right)\ln 1.25$$

$$= 0.34\,V$$

To two significant figures the answer comes out the same as the literature value, therefore the small variations in temperature and concentration cannot explain the difference between the student's value and the literature value. **[3]**

7 a Mass defect is the difference between the mass of a nucleus and the sum of the masses of the individual nucleons.
Nuclear binding energy is the energy required to break apart a nucleus into protons and neutrons. **[2]**

b The nucleus is composed of just one particle – a proton. **[1]**

c i A tritium atom contains one electron. The mass of the nucleus is calculated by subtracting the mass of the electron from the mass of the atom:
mass of tritium nucleus $= 3.016\,05 - 0.000\,548\,6 = 3.015\,501\,4$ u **[1]**

ii Mass defect = mass of (protons + neutrons) − mass of nucleus
$\Delta m = (1.007\,276 + 2 \times 1.008\,665) - 3.015\,501\,4 = 0.009\,104\,6$ u
To convert to kg we multiply by the mass of 1 u, given in the IB Chemistry data booklet as 1.66×10^{-27} kg:
mass defect $= 0.009\,104\,6 \times 1.66 \times 10^{-27} = 1.51 \times 10^{-29}$ kg **[2]**
Note: This answer has been rounded to three significant figures but the answer with more significant figures will be carried through to the next part of the question.

iii Using $E = mc^2$ we can convert the mass defect to the equivalent amount of energy:

$E = 1.51 \times 10^{-29} \times (3.00 \times 10^8)^2 = 1.36 \times 10^{-12}$ J

This is the nuclear binding energy – to work out the binding energy per nucleon this must be divided by the total number of nucleons:

$\frac{1.36 \times 10^{-12}}{3} = 4.53 \times 10^{-13}$ J **[2]**

d Total mass of the reactants = 3.016 05 + 3.016 05 = 6.032 1 u

Total mass of products = 4.002 60 + 2 × 1.008 665 = 6.019 93 u

Decrease in mass = 6.032 1 − 6.019 93 = 0.012 17 u

This must be converted to kg:

$0.01217 \times 1.66 \times 10^{-27} = 2.02 \times 10^{-29}$ kg

$E = mc^2 = 2.02 \times 10^{-29} \times (3.00 \times 10^8)^2$

$= 1.82 \times 10^{-12}$ J

The energy released per mole is:

$1.82 \times 10^{-12} \times 6.02 \times 10^{23} = 1.09 \times 10^{12}$ J mol^{-1}, or 1.09×10^9 kJ mol^{-1}

e $\lambda = \frac{\ln 2}{t_{\frac{1}{2}}} = \frac{0.6931}{12.26} = 0.05654$ y^{-1} **[4]**

Note: This answer has been rounded to four significant figures but more figures have been carried through for further calculations.

$\frac{N}{N_0} = e^{-\lambda t} = e^{-0.05654 \times 20.00} = 0.3228$

This is multiplied by 100.0 μg to get the mass remaining: 32.28 μg **[3]**

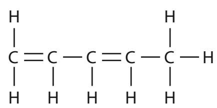
f i The rate of effusion depends on the molar mass; the molecule that will effuse most slowly is ^{3}H–^{3}H because this has the highest molar mass; the one that will effuse most quickly is ^{1}H–^{1}H. **[2]**

ii $\frac{\text{rate of effusion of gas } ^1H_2}{\text{rate of effusion of gas } ^3H_2} = \frac{\sqrt{\text{molar mass of gas } ^3H_2}}{\sqrt{\text{molar mass of gas } ^1H_2}}$

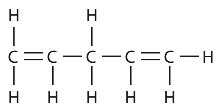
$= \frac{\sqrt{6.0321}}{\sqrt{2.01565}} = 1.73$

$^1H_2$ will effuse 1.73 times quicker than $^3H_2$ **[2]**

8 a i



penta-1,3-diene



penta-1,4-diene

[2]

ii Penta-1,3-diene will absorb the longer wavelength of UV radiation because the double bonds are conjugated. The double bonds in penta-1,4-diene are separated by two single bonds, so they are not conjugated and delocalisation is not possible. Penta-1,3-diene has a longer conjugated system, and so a smaller energy gap between lower and upper molecular orbitals. This means that lower energy radiation (longer wavelength) must be absorbed to promote an electron to a higher molecular orbital in penta-1,3-diene. **[3]**

iii **X** is coloured because it has the longer conjugated/delocalised system. The conjugated system in **X** extends over the whole molecule, but in **Y** there are three single bonds in a row in the middle of the molecule and the conjugated system is broken. The conjugated system in **X** is long enough for it to absorb visible light and so it appears coloured. **Y** absorbs only UV radiation and is therefore colourless. **[4]**

b The energy from photons of light causes electrons to be promoted from the valence band to the conduction band, where they are free to move. Holes in the valence band are also generated, and these can also move. **[2]**

c Light causes electrons in the dye sensitiser to be promoted to a higher energy level.

The electrons are transferred to the conduction band of TiO_2 nanoparticles.

The sensitiser has now been oxidised and is reduced back to its original state by electrons from the I^- ions in the electrolyte.

The electrons at high energy in the conduction band of the TiO_2 flow through the external circuit to the cathode, where they reduce the I_3^- ions back to I^-. **[4]**