SL Paper 3

The buffer formed by carbon dioxide, $CO_2(aq)$ and hydrogen carbonate ion, $HCO_3^-(aq)$, plays an important role in maintaining the pH of blood.

a. Calculate the pH of the buffer from the following data and section 1 of the data booklet. [1]

  $pK_a(CO_2) = 6.34$

  $[HCO_3^-(aq)] = 1.40 \times 10^{-2}$ mol dm^{-3}

  $[CO_2(aq)] = 1.25 \times 10^{-3}$ mol dm^{-3}

b. Explain the effect of a large amount of aspirin on the pH of blood. [2]

A link between the combustion of fossil fuels and an increase in the temperature of the Earth's atmosphere was proposed over a century ago.

a. Suggest why it is only in recent years that specific predictions of the future effects of fossil fuel combustion have been made. [1]

b. Carbon dioxide has two different bond stretching modes illustrated below. [2]

Symmetric stretching   Asymmetric stretching
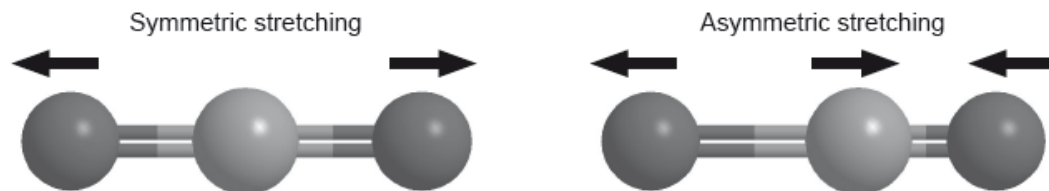
  Predict, with an explanation, whether these stretching modes will absorb infrared radiation.

c. Outline, giving the appropriate equation(s), how increasing levels of carbon dioxide will affect the pH of the oceans. [1]

d. Many combustion processes also release particulate matter into the atmosphere. Suggest, giving your reason, how this might affect the [1]

  temperature of the Earth's surface.

The combustion of fossil fuels produces large amounts of CO_2, a greenhouse gas.

The diagram below illustrates a range of wavelengths in the electromagnetic spectrum.

Increasing energy

Increasing wavelength
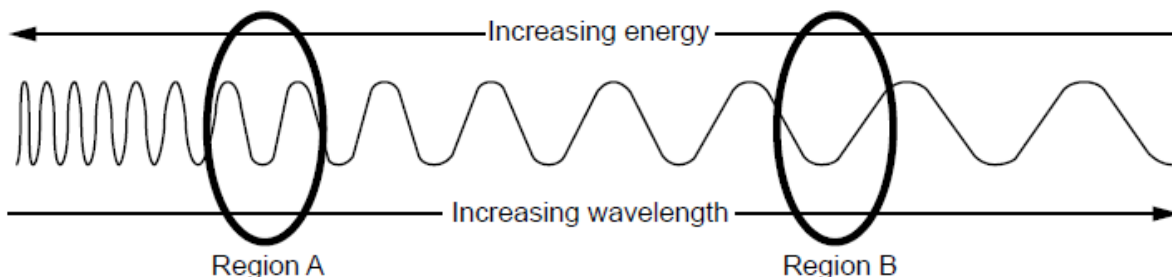
Region A   Region B

Synthesis gas, or syngas, mainly composed of CO(g) and H_2(g), is an alternative form of fuel. It can be produced by coal or biomass gasification, passing steam over the source material in a low oxygen environment.
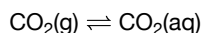
a. Identify which region, **A** or **B**, corresponds to each type of radiation by completing the table.   [1]

Type of radiation	Region
Incoming radiation from sun	. . . .
Re-radiated from Earth's surface	. . . .
Absorbed by CO_2 in the atmosphere	. . . .

b.i. Oceans can act as a carbon sink, removing some CO_2(g) from the atmosphere.   [1]

$$CO_2(g) \rightleftharpoons CO_2(aq)$$

Aqueous carbon dioxide, CO_2(aq), quickly reacts with ocean water in a new equilibrium reaction. Construct the equilibrium equation for this reaction including state symbols.

b.ii. Describe how large amounts of CO_2 could reduce the pH of the ocean using an equation to support your answer.   [2]

c.i. Suggest an equation for the production of syngas from coal.   [1]

c.ii. The Fischer-Tropsch process, an indirect coal liquefaction method, converts CO(g) and H_2(g) to larger molecular weight hydrocarbons and   [1]
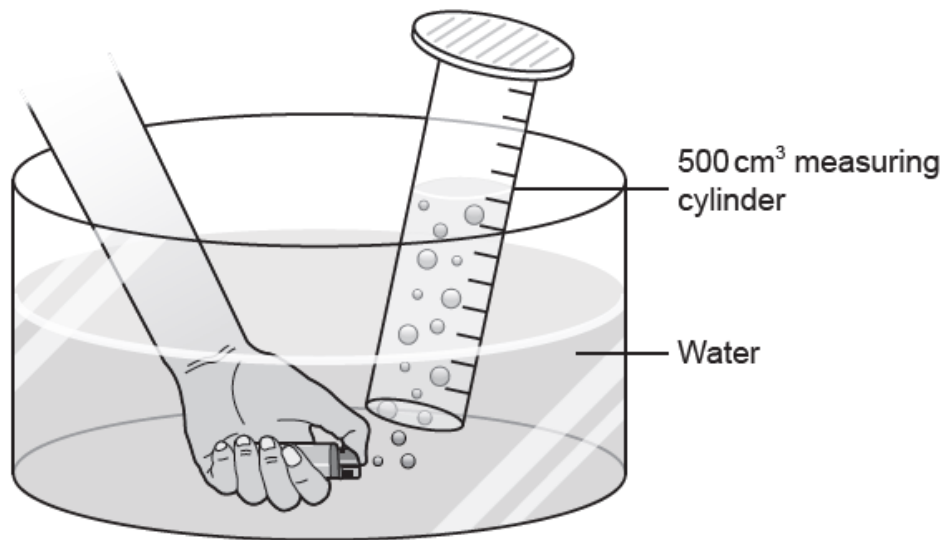
steam.

Deduce the equation for the production of octane by this process.

c.iii. Suggest a reason why syngas may be considered a viable alternative to crude oil.   [1]

Disposable plastic lighters contain butane gas. In order to determine the molar mass of butane, the gas can be collected over water as illustrated below:

500 cm³ measuring cylinder

Water

a. List the data the student would need to collect in this experiment. [4]

b.i.Explain why this experiment might give a low result for the molar mass of butane. [2]

b.ii.Suggest **one** improvement to the investigation. [1]

In order to provide safe drinking water, a water supply is often treated with disinfectants, which aim to inactivate disease-causing bacteria in the water.

To compare the effectiveness of different disinfectants, a **CT value** is used as a measure of the dosage of disinfectant needed to achieve a certain level of inactivation of specific bacteria.

$$\text{CT value (mg min dm}^{-3}) = C \text{ (mg dm}^{-3}) \text{ concentration of disinfectant} \times T \text{ (min) contact time with water}$$

a. The table below compares the CT values of different disinfectants necessary to achieve 99% inactivation of two types of bacteria, listed as **A** [4] and **B**.

Disinfectant	CT value / mg min dm⁻³ for 99 % inactivation of bacteria	
	Bacterium A	**Bacterium B**
Hypochlorous acid, $HOCl$	4×10^{-2}	8×10^{-2}
Hypochlorite ion, OCl^-	9.2×10^{-1}	3.3
Chlorine dioxide, ClO_2	1.8×10^{-1}	1.3×10^{-1}
Monochloramine, NH_2Cl	64	94

(i) Deduce the oxidation state of chlorine in the following disinfectants.

$HOCl$:

· ·

ClO_2:

· ·

(ii) From the data on CT values, justify the statement that bacterium **B** is generally more resistant to disinfection than bacterium **A**.

(iii) CT values can be used to determine whether a particular treatment process is adequate. Calculate the CT value, in mg min dm^{-3}, when 1.50 × 10^{-5} g dm^{-3} of chlorine dioxide is added to a water supply with a contact time of 9.82 minutes.

(iv) From your answer to (a) (iii) and the data in the table, comment on whether this treatment will be sufficient to inactivate 99% of bacterium **A**.

b. CT values are influenced by temperature and by pH. The table below shows the CT values for chlorine needed to achieve 99% inactivation of a   [4]
specific bacterium at stated values of pH and temperature.

| pH	Temperature / °C				
	0.5	5.0	10.0	15.0	20.0
6.0	97	69	52	35	26
7.0	137	97	73	49	37
8.0	197	140	105	70	53
9.0	281	201	151	101	75

(i) With reference to the temperature data in the table, suggest why it may be more difficult to treat water effectively with chlorine in cold climates.

(ii) Sketch a graph on the axes below to show how the CT value (at any temperature) varies with pH.
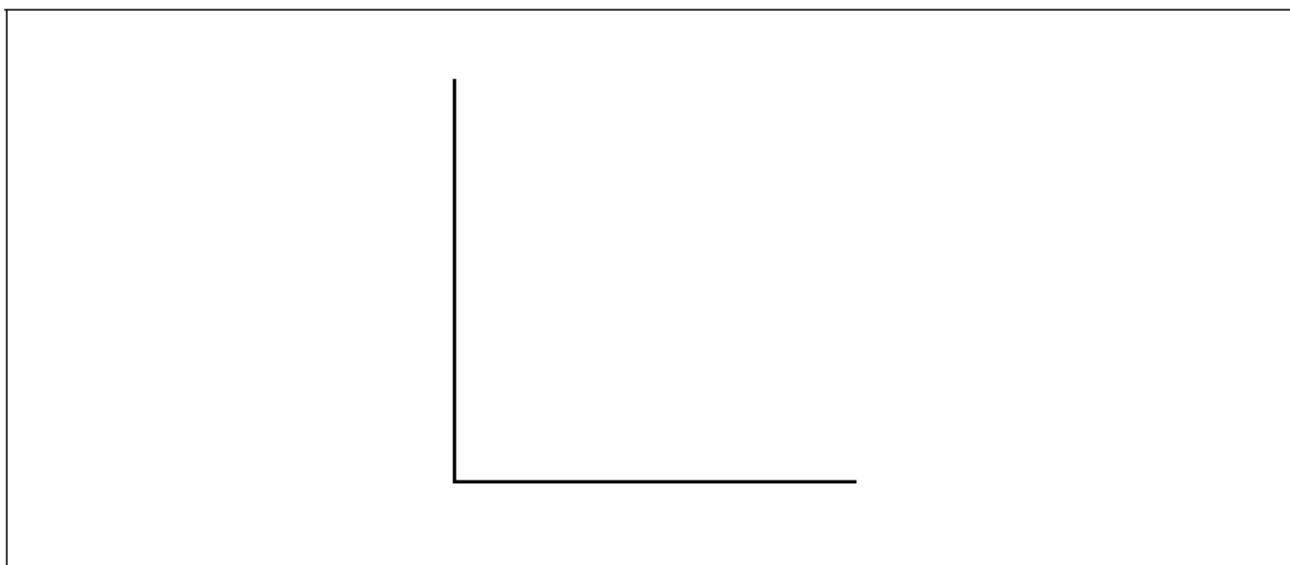
(iii) Comment on the relative CT values at pH 6.0 and pH 9.0 at each temperature.

(iv) Chlorine reacts with water as follows:

$$Cl_2 \text{ (g)} + H_2O \text{ (l)} \rightleftharpoons HOCl \text{ (aq)} + HCl \text{ (aq)}$$
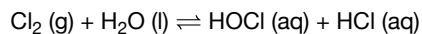
$$HOCl \text{ (aq)} \rightleftharpoons OCl^- \text{ (aq)} + H^+ \text{ (aq)}$$

Predict how the concentrations of each of the species HOCl (aq) and OCl$^-$ (aq) will change if the pH of the disinfected water increases.

HOCl (aq):

. . . .

OCl$^-$ (aq):

. . . .

c. Despite widespread improvements in the provision of safe drinking water, the sale of bottled water has increased dramatically in recent years.   [1]

State one problem caused by this trend.

There is a link between world energy consumption and carbon dioxide production.

Climate induced changes in the ocean can be studied using measurements such as the Atmospheric Potential Oxygen (APO). Trends in APO concentration from two stations, one in each hemisphere, are shown below.
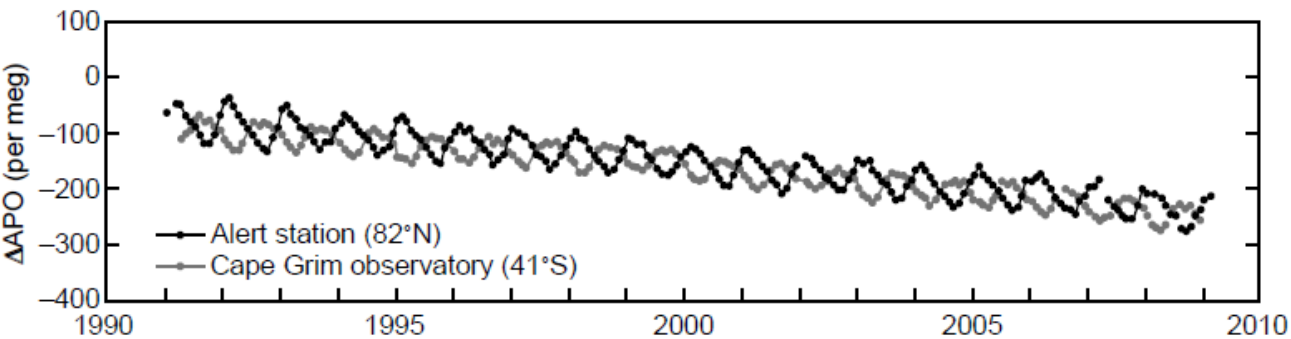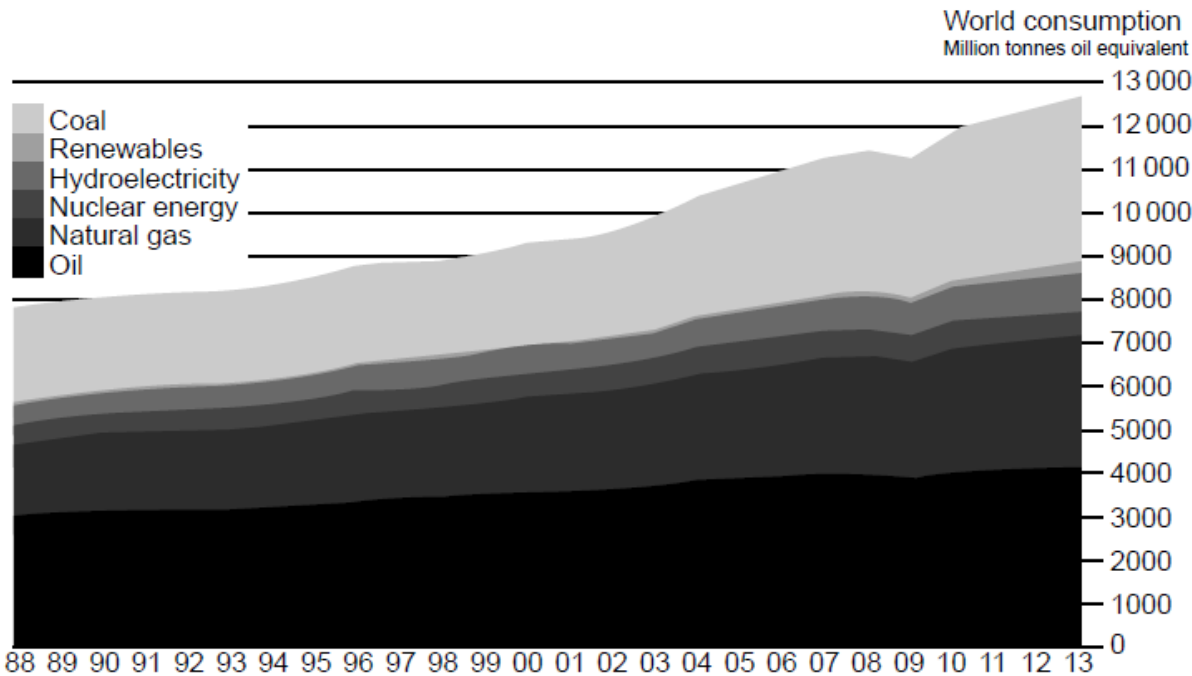

Trends in atmospheric potential oxygen (APO) based on monthly averages between 1990 and 2010.

[Source: www.ioos.noaa.gov]

a. The following graph represents world energy consumption by type for the years 1988–2013. [1]
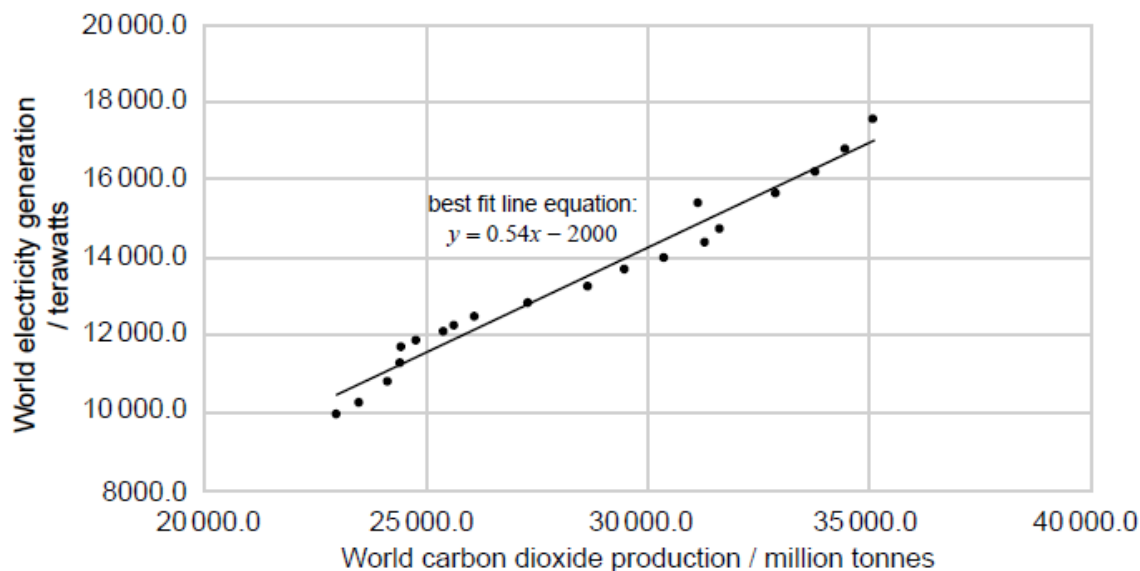

Estimate the percentage of energy consumption which did **not** directly produce CO_2 in 2013.

b. O_2 is consumed in producing CO_2 for electricity generation. The graph shows the relationship between the world's electricity generation and [2] CO_2 production between 1994 and 2013.

[Source: BP statistical review of world energy, www.bp.com]

Calculate the mass, in million tonnes, of oxygen gas ultimately found in CO_2 which is consumed in generating 18 000 terawatts of electricity using the equation given for the best fit line. Give your answer to 2 significant figures.

Assume coal is the only energy source.

c.i. The equilibrium expression for O_2 exchange between the atmosphere and ocean is $O_2(g) \rightleftharpoons O_2(aq)$. Identify **one** factor which shifts the equilibrium to the right. [1]

c.ii. Factors such as photosynthesis and respiration are excluded so that APO is influenced by oceanic changes only. Suggest why the seasonal cycles from Alert station and Cape Grim observatory are different. [2]

c.iii. The change in APO O_2/N_2 ratio, per meg, is measured relative to an O_2/N_2 reference. [1]

$$\Delta(O_2/N_2) = \left(\frac{(O_2/N_2)_{\text{sample}}}{(O_2/N_2)_{\text{reference}}} - 1 \right) \times 10^6$$

Calculate the APO $\Delta(O_2/N_2)$ value for an oxygen concentration of 209 400 ppm assuming that any change in N_2 concentration is negligible. Reference values for O_2 and N_2 are 209 460 and 790 190 ppm respectively.

c.iv. Suggest a reason for the general negative gradient of the APO curve given in (c). [1]