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]

Markscheme

a. «pH = $pK_a + \log_{10}\left(\frac{[HCO_3^-]}{[CO_2]}\right) = 6.34 + \log_{10}(11.2) = 6.34 + 1.05$» = 7.39

[1 mark]

b. H^+ from aspirin reacts with HCO_3^- to form CO_2 and H_2O

OR

$H^+(aq) + HCO_3^-(aq) \rightleftharpoons CO_2(aq) + H_2O(l)$

OR

reverse reaction favoured «to use up some of the H^+ added»

pH decreases

No mark for "stating aspirin is a weak acid that dissociates partially to produce H^+" without reference to reaction with HCO_3^- or to the equation.

Reversible arrows not required for the mark.

*Do **not** accept "small pH change when small amount of H^+ is added".*

[2 marks]

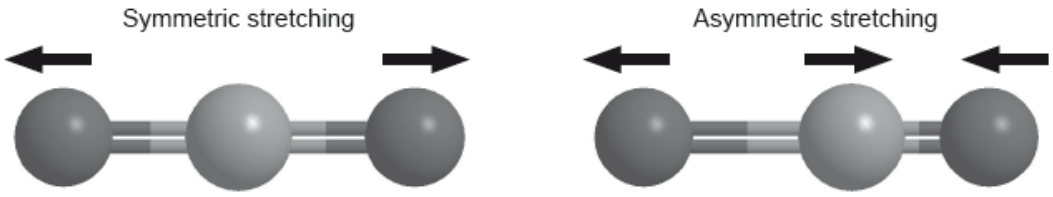
Examiners report

a. [N/A]
b. [N/A]

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]



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 temperature of the Earth's surface. [1]

Markscheme

a. computers can now carry out more complex calculations

OR

better understanding of the interactions between the various systems involved

OR

clear evidence of global warming

OR

«reliable» global temperature data now available

OR

techniques have been available to monitor carbon dioxide levels

Accept "better/faster computers".

Accept "better modelling".

Accept "better/more reliable/consistent data".

Accept "better measuring techniques".

Accept other scientifically based (not politically based) reasons.

Accept if specific relevant data is given.

*Do **not** accept "increased combustion of fossil fuels" or "increased concerns about global warming".*

[1 mark]

b. symmetric stretching will not absorb IR

OR

asymmetric stretching will absorb IR

change in polarity/dipole «moment» required «to absorb IR»

[2 marks]

c. $CO_2(aq) + H_2O(l) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$ «and pH decreases»

OR

$CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$ ***AND*** $H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$ «and pH decreases»

Accept reversible or non-reversible arrows for all.

[1 mark]

d. reduce it ***AND*** absorbing/reflecting sunlight

Accept "reduce it because of global dimming".

*Accept "reduce it **AND** blocking sunlight".*

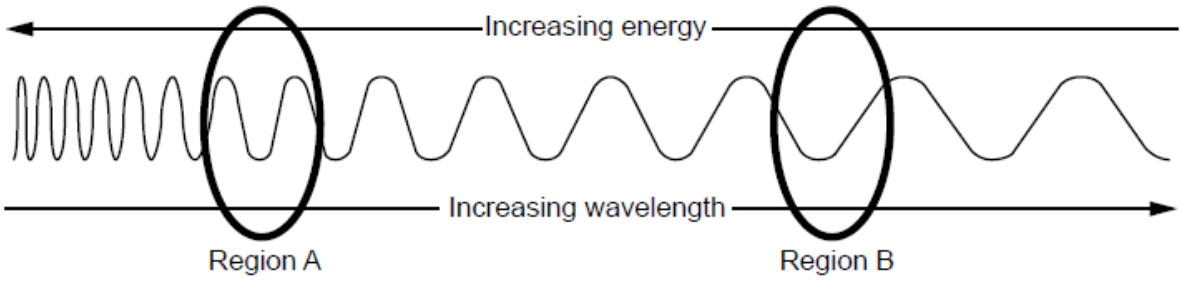
[1 mark]

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]

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.



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 steam. [1]

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]

Markscheme

a.

Type of radiation	Region
Incoming radiation from sun	A «and B»
Re-radiated from Earth's surface	B
Absorbed by CO_2 in the atmosphere	B ✓

Accept "B" alone for incoming radiation from sun.

All three correct answers necessary for mark.

[1 mark]

b.i. $CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$

*State symbols **AND** equilibrium arrow required for mark.*

Accept

$CO_2(aq) + H_2O(l) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$.

$CO_2(aq) + H_2O(l) \rightleftharpoons 2H^+(aq) + CO_3^{2-}(aq)$.

[1 mark]

b.ii. $CO_2(aq) + H_2O(l) \rightleftharpoons 2H^+(aq) + CO_3^{2-}(aq)$

OR

$CO_2(aq) + H_2O(l) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$

OR

$H_2CO_3(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + HCO_3^-(aq)$

OR

$H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$

OR

$H_2CO_3(aq) + 2H_2O(l) \rightleftharpoons 2H_3O^+(aq) + CO_3^{2-}(aq)$

OR

$H_2CO_3(aq) \rightleftharpoons 2H^+(aq) + CO_3^{2-}(aq)$

equilibrium shifts to the right causing increase in $[H_3O^+]/[H^+]$ «thereby decreasing pH»

Equilibrium sign needed in (b) (ii) but penalize missing equilibrium sign once only in b (i) and (ii).

*Do **not** accept "$CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$" unless equation was not given in b (i).*

[2 marks]

c.i. $C(s) + H_2O(g) \rightarrow CO(g) + H_2(g)$

OR

$3C(s) + H_2O(g) + O_2(g) \rightarrow 3CO(g) + H_2(g)$

OR

$4C(s) + 2H_2O(g) + O_2(g) \rightarrow 4CO(g) + 2H_2(g)$

OR

$5C(s) + H_2O(g) + 2O_2(g) \rightarrow 5CO(g) + H_2(g)$

*Accept other correctly balanced equations which produce both CO **AND** H_2.*

[1 mark]

c.ii. $8CO(g) + 17H_2(g) \rightarrow C_8H_{18}(l) + 8H_2O(g)$

[1 mark]

c.iii coal more plentiful than crude oil

OR

syngas can be produced from biomass/renewable source

OR

syngas can undergo liquefaction to form octanes/no need to transport crude

OR

syngas can be produced by gasification underground, using carbon

OR

capture/storage «to not release CO_2 to the atmosphere»

OR

coal gasification produces other usable products/slag

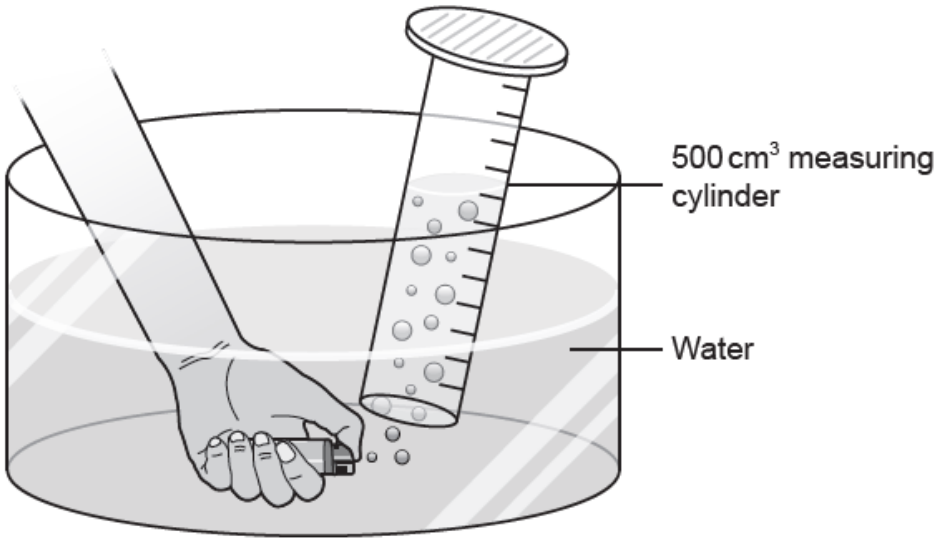
[1 mark]

Examiners report

a. [N/A]

b.i. [N/A]
b.ii. [N/A]
c.i. [N/A]
c.ii. [N/A]
c.iii. [N/A]

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:



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]

Markscheme

a. mass/*m* of lighter before ***AND*** after the experiment

volume of gas/V_{gas} «collected in the cylinder»

«ambient» pressure/*P* «of the room»

temperature/*T*

Accept "change in mass of lighter".

Accept "weight" for "mass".

*Do **not** accept just "mass of lighter/gas".*

Accept "volume of water displaced".

*Do **not** accept "amount" for "volume" or "mass".*

[4 marks]

b.i. *Any two of:*

pressure of gas not equalized with atmospheric/room pressure

too large a recorded volume «of gas produces a lower value for molar mass of butane»
OR
cylinder tilted

difficult to dry lighter «after experiment»
OR
higher mass of lighter due to moisture
OR
smaller change in mass but same volume «produces lower value for molar mass of butane»

using degrees Celcius/°C instead of Kelvin/K for temperature

Accept "vapour pressure of water not accounted for" ***OR*** *"incorrect vapour pressure of water used"* ***OR*** *"air bubbles trapped in cylinder". Do* ***not*** *accept "gas/bubbles escaping «the cylinder»" or other results leading to a larger molar mass.*

Accept "lighter might contain mixture of propane and butane".

Do ***not*** *accept only "human errors"* ***OR*** *"faulty equipment" (without a clear explanation given for each) or "mistakes in calculations".*

[2 marks]

b.ii. record vapour pressure of water «at that temperature»

OR

equalize pressure of gas in cylinder with atmospheric/room pressure

OR

tap cylinder before experiment «to dislodge trapped air»

OR

collect gas using a «gas» syringe/eudiometer/narrower/more precise graduated tube

OR

collect gas through tubing «so lighter does not get wet»

OR

dry lighter «before and after experiment»

OR

hold «measuring» cylinder vertical

OR

commence experiment with cylinder filled with water

Accept "adjust cylinder «up or down» to ensure water level inside cylinder matches level outside".

Accept "repeat experiment/readings «to eliminate random errors»".

Accept "use pure butane gas".

[1 mark]

Examiners report

a. [N/A]
b.i. [N/A]

b.ii. [N/A]

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.

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

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

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.

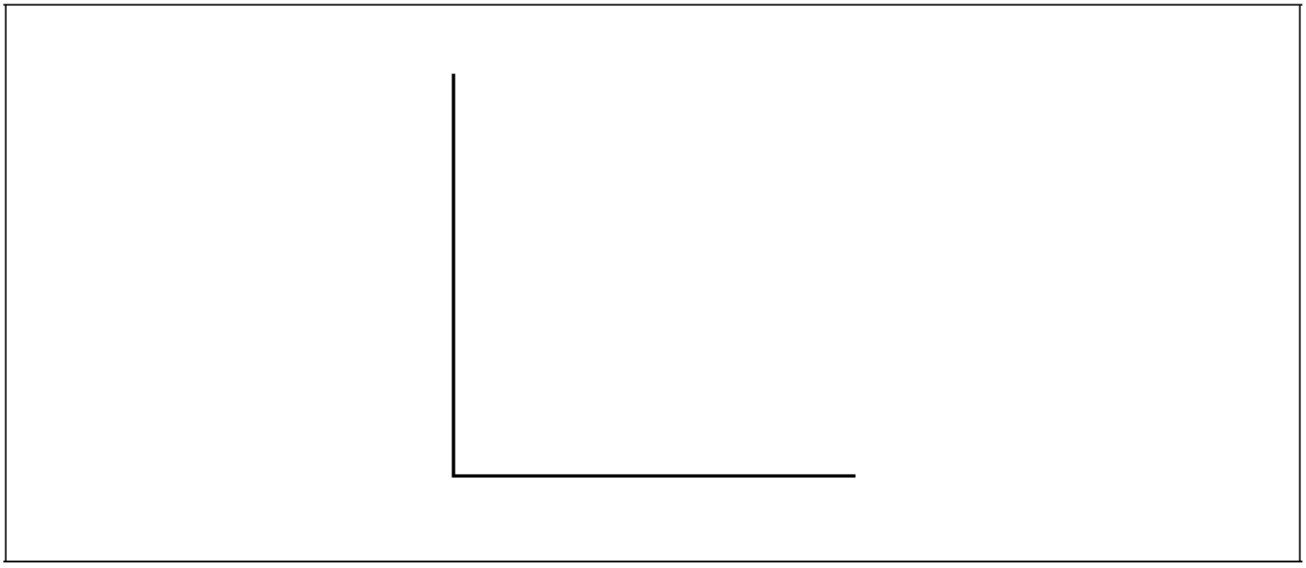
(iv) From your answer to (a) (iii) and the data in the table, comment on whether this treatment will be sufficient to inactivate 99% of bacterium **A**.

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 specific bacterium at stated values of pH and temperature. [4]

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:

$$Cl_2\ (g) + H_2O\ (l) \rightleftharpoons HOCl\ (aq) + HCl\ (aq)$$

$$HOCl\ (aq) \rightleftharpoons OCl^-\ (aq) + H^+\ (aq)$$

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.

Markscheme

a. i

HOCl: +1
AND
ClO_2: +4

Accept "I" and "IV" but ***not*** *"1+/1" and "4+/4" notations.*

ii

«most» CT values are higher for «bacterium» B
OR
«generally» higher dosage needed for «bacterium» B

Accept converse arguments. Accept "concentration" for "dosage"

iii

«$CT = 1.50 \times 10^{-5} \times 10^{3}$ mg $dm^{-3} \times 9.82$ min =» 1.47×10^{-1} «mg min dm^{-3}»

iv

lower than CT value/minimum dosage/1.8×10^{-1} «mg min dm^{-3}»
AND
no/insufficient

Accept "concentration" for "dosage".

b. i

higher CT value at lower temperature
OR
higher dosage «of chlorine» needed at low temperature

Accept "effectiveness decreases at lower temperature".
Accept "concentration" for "dosage".
Accept converse arguments.

ii

labeled axes (*y*: CT and *x*: pH)
AND
curve with increasing gradient

*Do **not** accept axes the wrong way round.*
Accept a linear sketch.

iii

values at pH 9.0 approximately 3 times values at pH 6.0
OR
increase in CT values in same ratio

The exact ratio is 2.9 times
*Do **not** accept just "increase in value".*

iv

[HOCl] decreases ***AND*** $[OCl^{-}]$ increases

c. plastic disposal/pollution

OR

plastic bottles use up petroleum/non-renewable raw material

OR

chemicals in plastic bottle can contaminate water

OR

«prolonged» storage in plastic can cause contamination of water

OR

plastic water bottles sometimes reused without proper hygiene considerations

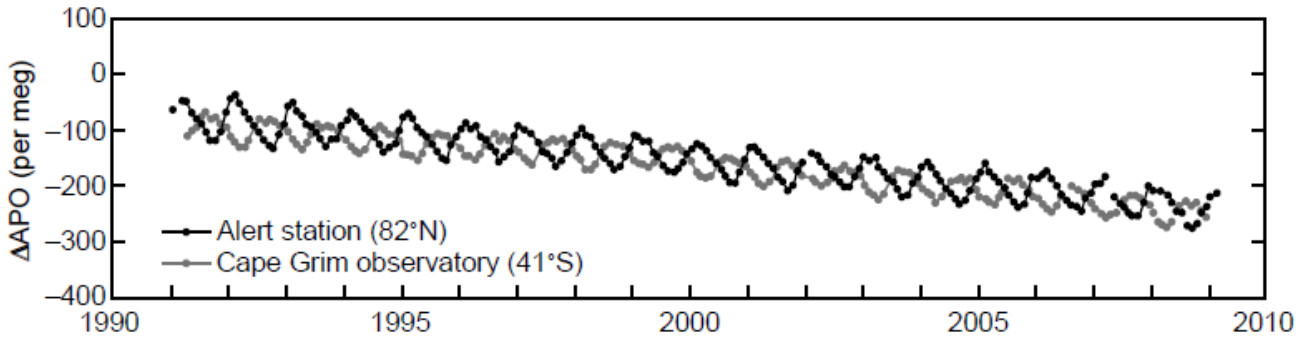
Accept other valid answers.
Accept economic considerations such as "greater production costs", "greater transport costs" or "bottled water more expensive than tap water"

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

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

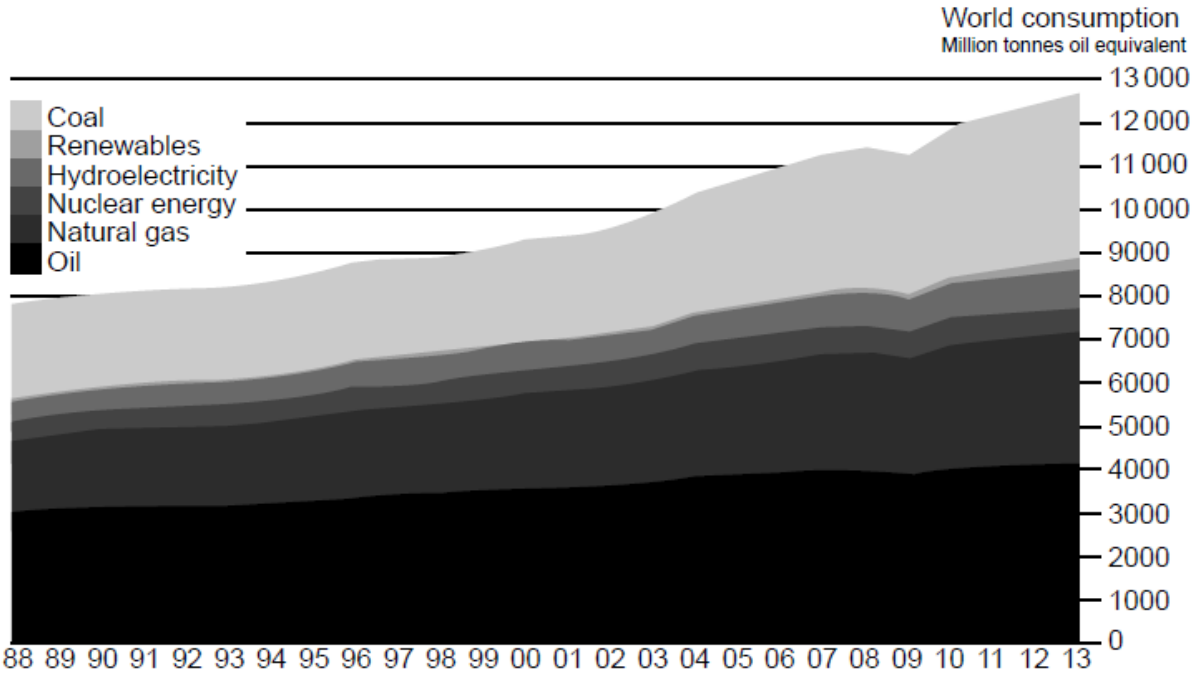
Climate induced changes in the ocean can be studied using measurements such as the Atmospheric Potential Oxygen (APO). Trends in APO concentration from two stations, one in each hemisphere, are shown below.



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

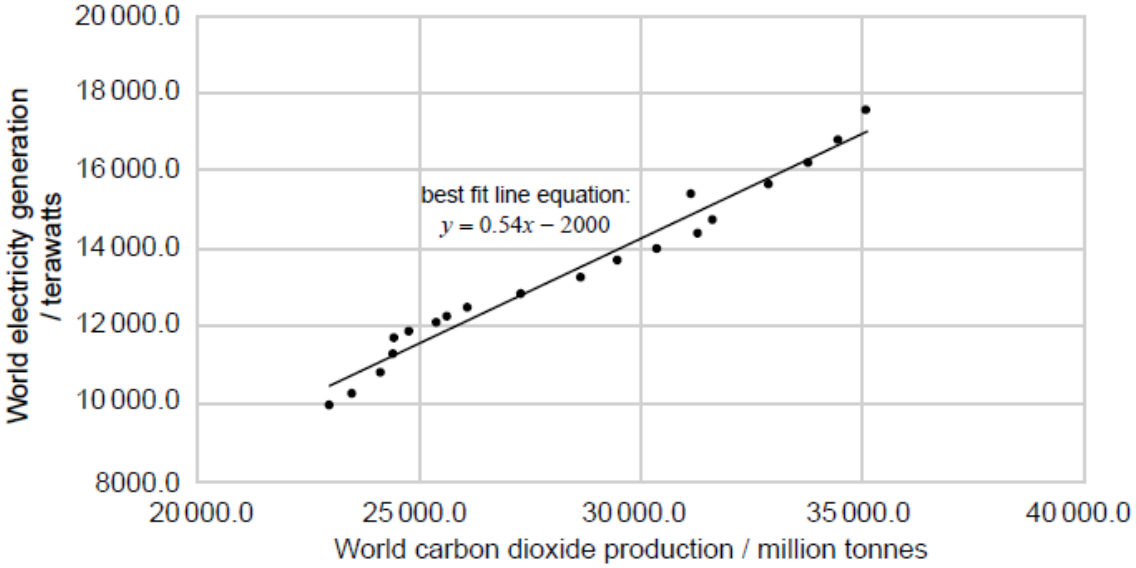
[Source: www.ioos.noaa.gov]

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 CO_2 production between 1994 and 2013. [2]



[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]

Markscheme

a. «$\frac{\sum(\text{renewables}+\text{hydroelectricity}+\text{nuclear})}{\text{total}}$»

«$\left(\frac{8800-7200}{12600}\right) \times 100$ =» 13 «%»

Accept range of "11–16%".

[1 mark]

b. «18000 = 0.54*x* – 2000»

x = 37037 «million tonnes of CO_2»

«$\frac{32.00}{44.01}$ x 37037 = 26930»

27000/2.7 x 10^4 «million tonnes of O_2»

Accept "37000 «million tonnes of CO_2»" for M1.

*Award **[2]** for correct final answer with two significant figures.*

*Award **[1]** for non rounded answers in range 26903–26936 «million tonnes of O_2».*

[2 marks]

c.i. increase in «atmospheric» pressure

OR

increase in $[O_2(g)]$/concentration of $O_2(g)$

OR

decrease in $[O_2(aq)]$/concentration of $O_2(aq)$

OR

decrease in temperature

*Accept "increase in volume of oceans «due to polar ice cap melting»" **OR** "consumption of O_2 in oceans/$O_2(aq)$ «by living organisms»".*

State symbols required for oxygen concentration.

[1 mark]

c.ii. summer in one station while winter in other

OR

stations are at different latitudes

oxygen dissolves better in colder water

Accept "opposite seasons «in each hemisphere»".

*Do **not** accept "different locations with different temperatures" **OR** "stations are in different hemispheres".*

[2 marks]

c.iii «$\left(\frac{209400}{209460} - 1\right) \times 10^6$ =» – 286.5 «per meg»

The nitrogen cancels so is not needed in the calculation.

Negative sign required for mark.

[1 mark]

c.iv decrease in $[O_2]$/concentration of O_2

OR

increasing combustion of fossil fuels «consumes more O_2 so $[O_2]$/concentration of O_2 decreases»

OR

warmer oceans/seas/water «as oxygen dissolves better in colder water»

OR

deforestation

Accept “decrease in level of O_2”.

Accept "increasing CO_2 production «consumes more O_2 so [O_2]/concentration of O_2 decreases»".

*Do **not** accept “decrease in amount of O_2” **OR** “increase in greenhouse gases”.*

[1 mark]

Examiners report

a. [N/A]
b. [N/A]
c.i. [N/A]
c.ii. [N/A]
c.iii. [N/A]
c.iv. [N/A]