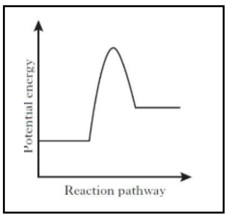
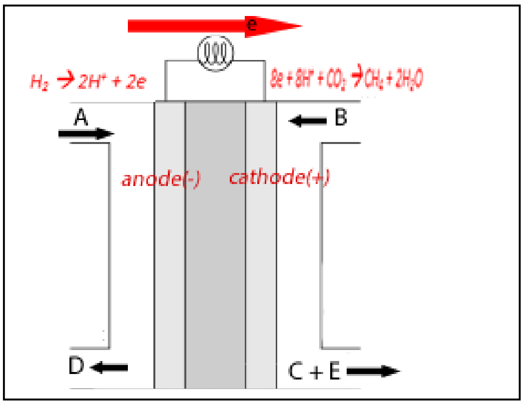
| | Fuel Cells | Secondary Cells | Primary Cells | Electrolytic cells |
|---|---|---|---|---|
| Rechargeable | | True | | |
| Relatively inexpensive | | True | True | |
| Electrodes | | | | |
| - Porous | True | | | |
| - Act as catalysts | True | | | |
| - Separate reactant from electrolyte | True | | | |
| - Are inert | True | | | |
| - May act as reductants | | True | True | True |
| Produce heat energy | True | True | True | True |
| Efficient energy production when compared to coal fired power stations | True | True | True | |
| Maintains constant voltage and current throughout extended operation | True | | | True |
| Store a finite amount of chemical energy . | | True | True | True |
| Can operate at very high temperatures. | True | | | |
| Usually used for small scale energy production | | True | True | |
| Negative ions migrate to the anode via an electrolyte. | True | True | True | True |
| Anode always has a positive polarity | | | | True |
| The anode is the electrode where oxidation always takes place. | True | True | True | True |
| Concentration of the electrolyte does not change during the course of operation | True | | | True |
| Primary function is to convert chemical energy into electrical energy. | True | True | True | |
| Is capable of converting electrical energy into chemical energy. | | True | | True |
| Spontaneous redox reactions are the only type of reaction taking place during the life of the cell. | True | | True | |
| Electrons always travel from the anode to the cathode | True | True | True | True |
| Has an external, electrical power source central to its operation throughout the life of the cell. | | True | | True |
| Involves predominantly combustion reactions for the production of electrical energy. | True | | | |
| The following energy profile diagram may apply at some stage during the life of the cell.   | | True | | True |

2) An innovative $CO_2/H_2$ fuel cell can convert $CO_2$ into methane ($CH_4$) while generating electricity instead of consuming it. In this new cell, $H_2$ is oxidized, while $CO_2$ forms $CH_4$. This cell uses a proton exchange membrane as the electrolyte.




a. Give the balanced half reactions, sates not required, that occur at the:

anode ________________ *$H_2 \rightarrow 2H^+ + 2e$*

cathode ___________ *$8e + 8H^+ + CO_2 \rightarrow CH_4 + 2H_2O$*

b. Give the balanced equation for the overall cell reaction. *$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$*

c. Identify the oxidizing agent _________________ *$CO_2$ ($CO_2$ must be specified not C. C is reduced from +4 to -4, but carbon was not a reactant. This is a common error. The oxidizing agent is the reactant which is reduced, in this case it is $CO_2$)*

d. Identify the reducing agent _________________ *$H_2$*

e. Consider the image above of a fuel cell. Label the:

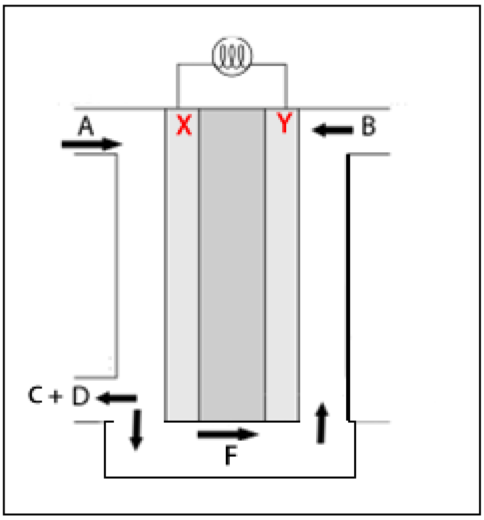
- direction of electron flow.
- anode
- cathode

f. Identify the ions flowing through the membrane and indicate their direction.
*$H^+$ ions flow from anode to cathode*

g. Identify substances:

- A - *$H^+$ ions*
- B - *$CO_2$*
- C – *$H_2O$*
- D – *excess $H_2$*
- E – *$CH_4$*

h. The methane produced is then used in a methane/oxygen molten carbonate fuel cell, shown on the right.




i. Identify A, B, D, C and F
*A = $CH_4$, B = $O_2$, F = $CO_2$, D and C = $CO_2$ and $H_2O$*

ii. Give the balanced equation to the reaction taking place at the :

- anode. *$4CO_3^{-2} + CH_4 \rightarrow 5CO_2 + 2H_2O + 8e$*
- cathode *$4e + + O_2 + 2CO_2 \rightarrow 2CO_3^{-2}$*

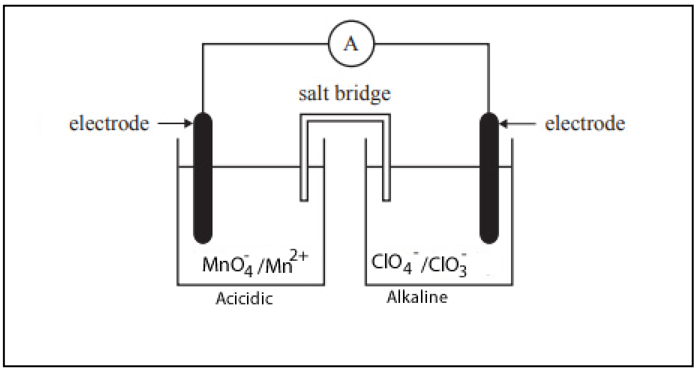
iii. What is the role substance "F" plays in the operation of this cell?

*It acts as carrier molecule for $O^{-2}$ ions through the electrolyte. The $CO_2$ used up at the cathode is liberated at the anode.*

iv. Identify the reducing agent *$CH_4$*

v. What ions move through the electrolyte and in what direction? *$CO_3^{-2}$ from Y to X*

3) Consider the galvanic cell shown on the right. It is constructed using 1M solutions at 25°C




The following unbalanced half-cell reactions occur in this cell

$ClO_4^-(aq) \rightarrow ClO_3^-(aq)$ +0.36 V

$MnO_4^-(aq) \rightarrow Mn^{2+}(aq)$ +1.28 V

a. Will a spontaneous reaction occur when both electrodes are connected? Explain your reasoning.

*Students should firstly:*

- *identify all oxidants (oxidising agents) present.*
- *identify all reductants (reducing agents) present.*
- *Using the data sheet determine which is the strongest oxidant and reductant present, making sure they are not in the same half-cell, otherwise, only heat is produced.*
- *The oxidant will undergo reduction at the cathode while the reductant will undergo oxidation at the anode.*

*Yes*

*$MnO_4^-(aq) \rightarrow Mn^{2+}(aq)$ +1.28 V*

*$ClO_4^-(aq) \rightarrow ClO_3^-(aq)$ +0.36 V*

*$ClO_3^-$ is the reducing agent (reductant)*

*$MnO_4^-$ is the oxidising agent (oxidant)*

b. Give the balanced half-cell equations, no states required, for the reactions taking place at the:

- cathode *$5e + 8H^+(aq) + MnO_4^-(aq) \rightarrow Mn^{2+}(aq)\ 4H_2O(l)$*

- anode *$2OH^-(aq) + ClO_3^-(aq) \rightarrow ClO_4^-(aq) + H_2O(aq) + 2e$*

c. How does the pH of each half-cell change as the cell discharges? Explain.

*In the half cell with the cathode $H^+$ ions are used up hence the pH will increase.*

*In the half cell with the anode $OH^-$ ions are used up so pH will decrease.*

d. Write the balanced overall equation, with states.

$6H^+(aq) + 2MnO_4^-(aq) + 5ClO_3^-(aq) \rightarrow 5ClO_4^-(aq) + 3H_2O(aq) + 2Mn^{2+}(aq)$

e. In the diagram above label the:

- anode and its polarity - *the anode is the electrode that is in the half-cell $ClO_4^-$ / $ClO_3^-$*
- direction of negative ion flow - *from left to right via the salt bridge.*
- direction of electron flow - *right to left via the external circuit*

f. Calculate the cell EMF. *1.28 – 0.36 = 0.98V*

g. Can this cell be recharged and if so what is the voltage that should be supplied? Explain

*Yes it can be recharged. The products are still in contact with the electrodes even though they can initially diffuse away from the electrodes. Students should recognise that for electrolysis (recharging) to occur, the voltage supplied has to be greater than the cell EMF. Use of exactly the cell EMF will not generate any reaction due to the overpotential needed to overcome internal resistance. So a voltage greater than 0.92 V was accepted.*

h. Which of the following is the reducing agent? Circle your answer and give an explanation.
$MnO_4^-$, $Mn^{2+}$, $ClO_4^-$, $ClO_3^-$, $H_2O$ , $H^+$, $Mn^{+7}$, $Cl^{+5}$, $O^{-2}$.
*$ClO_3^-$ is the reactant and so is the reductant which is itself oxidised. Although it is the Cl that changes oxidation state from +5 in $ClO_3^-$ to +7 in $ClO_4^-$ it is the $ClO_3^-$ that is actually the reactant and hence the reductant.*

i. Offer a possible material that each electrode should be made from and the properties that each electrode should possess. Explain
*Graphite or Platinum. They need to be inert and conduct electrons.*

4) Ethane undergoes complete combustion in a fuel cell with oxygen gas to produce electrical energy and two products, one of which is a liquid. The fuel cell is 65% efficient.

a. Write a balanced thermochemical equation for the overall reaction occurring in the fuel cell

$2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(l)\ \Delta H = -3120\ kJ\ mol^-$

b) Calculate, to the right number of significant figures, the amount of ethane, in kilograms, used to produce $3.132 \times 10^4$ kJ of electrical energy.

*Step 1 Find the amount of chemical energy needed to be supplied in order to produce 31320 Kj of electrical energy at 65% efficiency.*
*=> Y X 0.65 = 31320 kJ (where Y is the total chemical energy supplied.*
*=> Y = 31320 / 0.65 = 48184 kJ*

*Step 2 Find the amount, in grams, of ethane necessary to produce 48184 kJ of energy.*
*=> From the data sheet we find that ethane produces 51.9 Kj/g.*
*=> amount of ethane in grams needed = 48184 / 51.9 = 928.4 grams or 0.93 kg (2 sig figs*

c) A student argued that a hydrogen-oxygen fuel cell is better for the environment as it produces zero greenhouse emissions. Is the student correct? Explain.

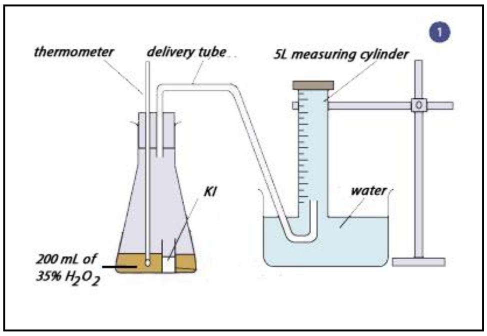
*No*

*A hydrogen fuel cell produces $H_2O$ as a product. It must be noted that $H_2O$ is also a greenhouse gas as is $CO_2$ and methane($CH_4$). Its impact on climate change, however, is less detrimental than $CH_4$ and $CO_2$ as it tends to form clouds which serve to reflect solar radiation back out into space and hence has a cooling effect on climate.*

5) Consider the data below collected by a student.

| | *Volume of gas evolved seconds after decomposition reaction of* $H_2O_2$ starts *(mL)* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $2H_2O_2 \xrightarrow[Catalyst]{KI(s)} 2H_2O + O_2$ $\Delta H$ = negative | | | | | | | | |
| *Time after reaction starts(s)* | *5* | *10* | *15* | *20* | *30* | *35* | *40* | *50* | *60* |
| *Potassium iodide. (1.00 g) in large crystals.* | *12.0* | *24.1* | *48.8* | *98.1* | *394* | *1,200* | *1,450* | *1,550* | *1,600* |
| *Potassium iodide. (1.00 g) in finely crushed powder* | *50.0* | *203* | *820.0* | *1,701* | *1,710* | *1,735* | *1,738* | *1,740* | *1,735* |

A student set up the experiment shown in the diagram on the right. Data collected was then presented as a table, shown above.




As part of the student's practical report the following set of steps were included in dot point form.

1. Set up the apparatus as shown on the diagram
2. Measure 200mL of a 35% v/v $H_2O_2$ solution and place it in the flask as shown in the diagram.
3. Using an electronic balance measure 1.00 g of KI in large crystal form.
4. Place the KI crystal into a small crucible inside the flask and seal the flask with the stopper, thermometer and delivery tube as shown in the diagram.
5. Shake the flask until the KI crystals are totally immersed in the $H_2O_2$ solution.
6. Start measuring the volume of gas produced over time until no more gas is formed
7. Using an electronic balance measure 1.00 g of KI in large crystal form.
8. Use a mortar and pestle to finely crush the 1.00 gram of crystals into a fine powder.
9. Repeat steps 4-6.

a. Use the graph paper provided on the next page to construct a detailed and properly labelled graph of the results from the table above.

*A clear labelled graph with:*

- *labelled axis with units*
- *heading*
- *correctly plotted results*
- *line of best fit rather than a line joining all dots.*
- *uniform increments on each axis.*
- *The independent variable is on the x-axis while the dependent variable is on the y-axis.*

b. What is the independent variable?
*The surface area of the catalyst*

c. What is the dependent variable and how is it measured?
*The rate at which gas is formed. This is measured by collecting the gas and measuring the volume at certain time intervals.*

d. Name a controlled variable and explain how it should be controlled and its impact on the results if it's not controlled.
*Any valid controlled variable with an accurate description of how it should be controlled and its impact on the results. For example.*
*- Temperature of the water in the measuring cylinder is a controlled variable. This should be consistent at every trial and the tap water used should be given time to reach room temperature during both trials. If the temperature is not consistent then the gas level due to the heat of the water increasing the kinetic energy of the gas particles which may increase the volume of water displaced and hence give a higher reading of gas evolution and hence give a greater rate of reaction.*
e. What is the student testing for and are the results valid?
*It appears that the student is testing the impact of catalyst surface area on the rate of a given reaction. Considering that a great deal of heat will be given off, due to the fact that it is an exothermic reaction, the experiment now has two independent variables, surface area of catalyst and possible temperature. So the experimental results are not valid as we cannot conclude that the data obtained is due solely to the surface area of the catalyst since the reaction vessel will also increase in temperature.*
f. What is a possible systematic error? What can be done to account for this error?
*Any plausible suggestion with an equally plausible solution. For example, considering the degree of bubbling that may occur it would be difficult to measure the volume of gas at the height of the reaction. Bubbling of the water would distort the student's ability to read the level of liquid at the time intervals recorded. The student would be forced to guess at a value of water level. This error would be consistent throughout each trial hence it would be a systematic error.*
*A possible solution may be to use a floatation device inside the measuring cylinder with a marker that is easily spotted and matched to the calibrations of the measuring cylinder.*

*Students should be aware that only a change in procedure or experimental method can minimise systematic errors.*

g. Describe a possible random error that may have occurred and indicate a solution that would minimise the impact of random errors on the results.

*Once again any plausible random error will suffice. Students should remember that a random error is unlikely to occur twice. As the name implies it is a random error and as such cannot be totally removed as the experimenter is unable to predict it. For example, may be the bottle of hydrogen peroxide that was to be used for trial 1 had being left in the warm prep room for several days while waiting for the experiment to be conducted and a significant amount of the peroxide had reacted while the hydrogen peroxide for the second trial was from a new bottle* *and fresh out of the fridge. Only by conducting multiple trials and removing outliers from the set of data can the impact of random errors be minimised.*

h. Without reference to the data collected during the investigation, predict the relationship between the independent variable and the dependent variable prior to the investigation being conducted. Explain your prediction

*As surface area of the catalyst increases, the rate of reaction increases and more gas is produced per unit time.*

*This is because increased surface area of the catalyst increases the frequency of collisions between the catalyst and the reactant particles. Since interaction with the catalyst lowers the activation energy required between reactants a greater rate of reaction occurs.*

*A greater number of particles will have the lower activation energy and hence overcome the activation energy barrier resulting in a greater proportion of collisions that are successful which also increases the rate of reaction.*

i. Analyse the graph of the student's results. Does it support your prediction in h. above? Give your reasoning.

*The data does support an increase in rate is related to an increase in catalyst surface area. Since we did not control for temperature of the reaction mixture, however, the results are not valid. We cannot conclude that an increase in surface area of the catalyst leads to an increase rate of reaction. It is plausible, however, to suggest that an increase in surface area of the catalyst causes an increase in the rate of reaction which releases more heat in a smaller period of time which causes the reaction mixture to increase in temperature further increasing the rate of the reaction. It does appear that the reaction does proceed at a faster rate with a greater surface area of catalyst but further investigation is needed where the temperature of the reaction vessel can be controlled.*

*Any solution offered must take into account the impact of the temperature increase*

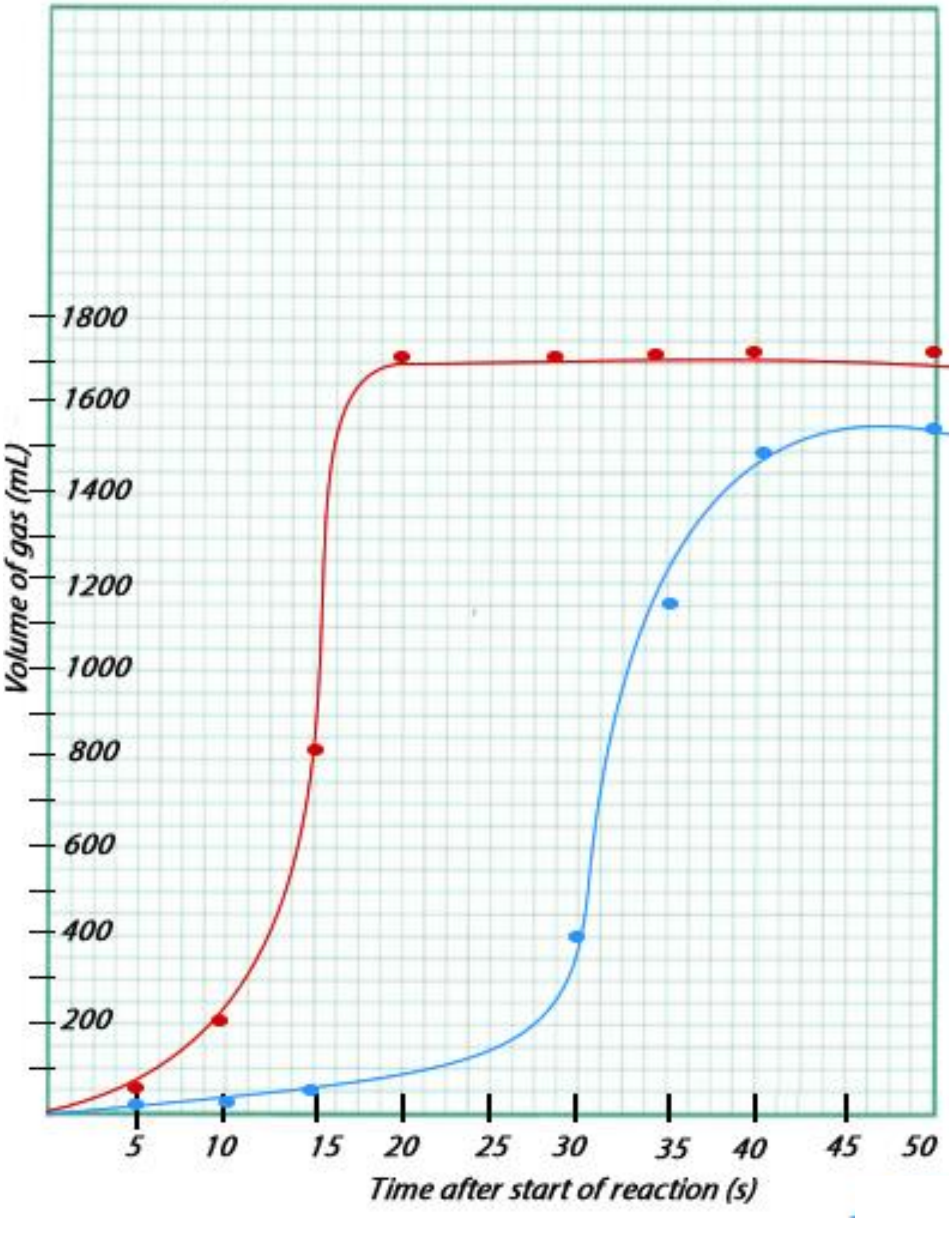
j. Offer one suggestion for improvement to this investigation and mention how the improvement will impact the data.

*Any plausible suggestion with a clear and accurate statement of how the change will impact the data collected. For example:*

*- use a syringe to capture the gas expelled and hence avoid students trying to read a turbulent water surface to try to estimate the level of fluid in the measuring cylinder. This will lead to more precise readings of volume change and cause less fluctuations in the data collected.*

*- Use a water bath to control the temperature of the reaction mixture and a lower volume and concentration of hydrogen peroxide to reduce the amount of heat evolved. Keeping the temperature constant will make the data valid as there will be only one independent variable.*

Surface area of catalyst versus rate of reaction



6) Consider the following 6 options.

i. Heating the reaction vessel.

ii. Increasing the concentration of the reactants.

iii. Increasing the pressure of gaseous reactants.

iv. Introducing a catalyst.

v. Mixing the reactants thoroughly.

vi. Crushing solid reactants into a powder.

vii. Increasing the volume of the reaction vessel.

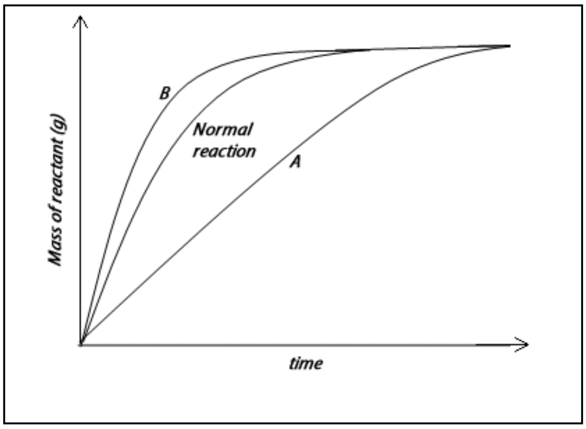
a. Which option/s listed will result in an increase in the rate of a chemical reaction? Explain
*All but for option vii. Options I, ii, iii, v, and vi cause an increase in the number of collisions that occur over time. At any given temperature there will always be a number of particles with enough activation energy to undergo a fruitful collision. SO increasing the number of collisions should ultimately increase the rate of the reaction by some magnitude. Option iv, however, does not increase the number of collisions but increases the proportion of collisions that are fruitful. It does this by decreasing the activation energy needed for a fruitful collision. This will result in more particles having the necessary minimum amount of energy (activation energy) to undergo a fruitful collision at any given temperature which ultimately will increase the rate of the reaction. Option vii, will decrease the distance between reactant particles and hence decrease the chance of collisions. Mixing the reactants thoroughly brings them in close proximity and hence increases the chance of a collision.*

b. Which option/s will increase the rate of a reaction without increasing the number of collisions per second of the reactant particles? Explain
*Option iv as mentioned above*

c. Which option/s will reduce the activation energy of the reaction? Explain
*Option iv*

d. Which option/s will increase the average speed of the reactant particles? Explain
*Option i*

e. Consider the graph shown on the right. Each reaction involves the exact same amount of reactants. Which option/s could have changed the graph of the normal reaction to the one represented by "A"? Explain
*Option vii. The rate has decreased and so the only option that can have this impact is an increase in the reaction vessel. Since dilution causes a greater separation of reactant particles and hence reduces the chance of collisions.*




f. Which options will increase the rate of a reaction at a particular temperature? Explain
*All options ii, iii, iv, v, vi increase the possibility of collisions occurring by making the reactant particles available and in close proximity so that they collide with each other.*