Research Design (6 marks)

Research Question

- ☐ Describe your Research question: include the independent & dependent (quantitative indications i.e. "how measured") variables and method that you are studying. e.g. *e.g What is the activation energy of the catalysed decomposition of 20 ml of 2.94 mol dm^{-3} (10%) hydrogen peroxide by 0.040 g manganese dioxide, determined using the Arrhenius Plot and a series of temperatures (approximately 20°C, 30°C, 40°C, 50°C, 60°C), with the rate of reaction found at each temperature by measuring the volume of oxygen produced in a gas syringe in 20 seconds?*

Background information

- ☐ Explain the specific chemical processes involved in the investigation.
- ☐ Explain scientific knowledge that is relevant to fully understand the process and outcomes of the investigation.
- ☐ Briefly consider possible methodologies to address the research question.
- ☐ Explain and justify the chosen methodology.
- ☐ Considers strengths and weaknesses of your chosen methodology.
- ☐ Include **chemical equations** for the key reactions associated with your investigation
- ☐ Consider expected results and make a prediction (hypothesis) *[If there is relevant existing knowledge]*
- ☐ Explain the reasons for your prediction based on scientific understanding (refer to background information).
- ☐ Refrain from simple brand analyses of food or pharmaceutical products. Any trends identified would be explainable in terms of business principles.
- ☐ Include citations and in-text references when explaining the scientific context.

Variables

- ☐ **Dependent variable** (the one you measure):
  - Identify and justify the choice of this variable - this could be reasoned with knowledge from academic research and/or preliminary experimentation
  - Explain number of repeats/trials you are aiming for to collect sufficient relevant data
  - Explain the methods used to measure/derive variable
  - Clearly distinguish between measured (directly dependent) and derived variable.
- ☐ **Independent variable** (the one you change/investigate/manipulate) variable
  - Explain and justify the range (a minimum of 5 manipulations are needed to draw a trendline). Refer to preliminary experimentation to reason your choices.
  - Explain methods used to change the variable
  - Indicate size/length of intervals or measurements (e.g. How long will each trial be recorded for?). Reference to preliminary experimentation should be given here.
- ☐ **Control variables:**
  - Explain how and why these variables will need to be controlled
- ☐ **Uncontrolled/monitored variables:**
  - Explain why they are difficult to control or can be considered negligible
  - Explain the data used to monitor them (e.g. air temperature/humidity/atmospheric pressure)
  - If using a database, simulations or other, explain how you have selected them and how data is sampled.

Materials

- ☐ An apparatus list must be established, listing all the materials as well as their measurement uncertainty.
- ☐ Uncertainties and degrees of precision should be mentioned (e.g 10 cm piece of Magnesium ribbon, Stopwatch (± 0.01s)), 10cm^3 measuring cylinder (+/- 0.1cm^3)
- ☐ Use precise glassware such as volumetric or graduated pipettes, burettes instead of beakers and measuring cylinders (to reduce uncertainty and increase precision of measurements!)

Procedure

- ☐ Design a preliminary experiment/trial and explain how this helped to fine-tune your method. *[If relevant]* Indicate where the original idea for the procedure/protocol came from (with a reference).
- ☐ Discusses challenges/problems faced when designing the procedure.
- ☐ Discuss the outcomes/modifications/changes implemented after/during preliminary experiments
- ☐ Write a very detailed, accurate step by step procedure for your experiment.

- ☐ Include relevant steps to control variables previously mentioned in the variable section.
- ☐ *[If relevant]* Procedure contains separate sections for each part of the experiment e.g. making/diluting solutions, making a calibration curve, carrying out the reaction.
- ☐ Include when and how to calibrate instruments such as pH meters, temperature, spectrophotomer

Safety and risk assessment

- ☐ Indicate any safety measures to be taken with the solutions or substances in use: e.g. "Hydrogen peroxide is usually a water solution. It is an oxidizing and bleaching agent used in deodorants, water and sewage treatment, disinfectant etc. Hydrogen peroxide can irritate the lungs. It can also cause temporary whitening of the skin and stinging sensations..." Ideally you should research on the chemicals which you will use. Refer to hazard symbols and potential health effects.
- ☐ Indicate environmental issues: small volumes and quantities should be used to avoid waste of materials and reactants, address correct disposal of substances.
- ☐ Explain how chemical substances will be disposed of correctly (use this link to find out more: CLEAPPS or Thomas Seilnacht – Entsorgung/Disposal or https://chemicalsafety.com/sds-search/
- ☐ Ensure a comment on the use of appropriate safety equipment (lab coat, safety goggles, gloves…etc)
- ☐ Briefly mention any ethical issues, if applicable.

Analysis (6 marks):

Recording data:

- ☐ Record all your **quantitative (numerical)** raw data in a clear and well-organized table.
  - If data samples are very large (e.g. from dataloggers) include a sample only
  - If data is derived from datalogging graphs (e.g. rate of respiration) include screenshot of original sample and clearly explain how and why data is used that way.
- ☐ Record **qualitative (observations)** data in a paragraph/bullet points below the table
  - Include here the measurement of controlled variables, such as temp., pressure, voltage and any other observations referring to changes in sizes, colour, things that were difficult to control…etc.
  - Images may be included, if relevant and referred to in the text.

Format & Communication of numerical results:

- ☐ Keep the **number of decimal places** consistent with the uncertainties of measurement. (If measuring time, use seconds rather than min:sec as calculations would be not possible).
- ☐ Include an **informative & descriptive title** mentioning both variables!! E.g. Table 1 *"Results to show the effect of an increasing concentration of aqueous HCl (0.5M, 1M, 1.5M, 2.0M, 2.5M) on a strip of magnesium metal by measuring the H_2 gas production in a gas syringe (in ml, ± 0.01)."*
- ☐ Include **clear labels for both, dependent and independent variable, and units of measurement**.
- ☐ **Don't split** your table from one page to the next.
- ☐ **Gridlines** of the table must be shown.
- ☐ **Center data** in the middle of the columns and align the decimal points of all values.
- ☐ The order of the columns must follow a logical sequence, ie the independent data column on the left and the values arranged in ascending order. Dependent variable on the right (including number of trials).

Consideration of uncertainties:

- ☐ **Absolute uncertainties** of all measurement devices, shown in the header of the data table and graph labels
  - ***Analogue instruments***: ± ½ of the smallest unit measurable by the instrument (thermometer e.g. °C (± 0.5°C), measuring cylinder (±0.5 ml or cm^3), burette, pipette, measuring tape, or as indicated on device.
  - ***Digital instruments:*** ± 1 unit of measurement when using a digital device (balance, stop clock, light meters, pH-meters,.etc) **or** a ruler (since the uncertainty is taken on both ends of the measurements à 2x ± ½ = ± 1) or as indicated on device (manufacturer's manual).
- ☐ **Propagating uncertainties:**
  - Error propagation of random errors (uncertainties) of measurement equipment includes **% uncertainty**, **total % uncertainty** as well as an **absolute (quantifiable) error**. (Watch the video for help)
  - When calculating the mean, the magnitude of uncertainty stays the same.

- When adding or subtracting, the uncertainties are added too. For example, if the initial and final readings from a balance each have an uncertainty of ±0.01 g then the propagated uncertainty for the total mass change is: (±0.01 g) + (±0.01 g) = (±0.02 g).
- When multiplying or dividing, it becomes more complicated - you will have to add up the percentage (fractional) uncertainties of all the steps (and each trial) in the method which had an uncertainty associated with it (% uncertainty = equipment uncertainty/value * 100). From this the mean % uncertainty can then be related to the mean result. For example,
  - Mass change of potato chip: 0.48g Calculating % uncertainty = [±0.02g/0.48g] × 100 = 4.16 %
  - Time: 23.2 seconds Calculating % uncertainty = [±0.1/23.2] ×100 sec = 0.43%
  - The total % uncertainty = 4.16% + 0.43% = 4.59%
  - Therefore, calculated rate = 0.48g/23.2sec = 0.021 g sec^{-1} ±4.59%
  - You may convert the calculated total percent uncertainty back into an absolute error or leave it as a percentage: 0.021 ± 0.001

☐ **Demonstrating measurement uncertainties** can be shown in a variety of different ways
- Well-constructed best fit graph lines
- Error-bars on graphs showing uncertainties of measurement or half-range
- Appropriate consideration of outlier data
- Showing equation of a graph line and the **R^2 value** (goodness of fit)

Processing Data

☐ Explain, in words and descriptively, each stage of processing.

☐ Show an **example of a calculation** made e.g. percentage change or concentration calculations. Summarize all other results in a **table of processed data**.

☐ Processed data may include any of the below:
- Mean, Mode, Median, Range (maximum & minimum values) – not only an "average"!!
- Calculating a rate (how fast something is happening in unit time. Eg gas collected given off from a reaction. The rate is given by volume of gas given off/time for volume to be given off)
- Calculating mass percentage change (initial mass – final mass/initial mass x 100)
- Calculations (e.g. rate, volume, distance, % change etc) are done before calculating the mean of the trials!
- Consistently apply decimal place or significant figure conventions throughout processing. Means should be quoted to the same number of decimal places as the data it is calculated from.

☐ Show **error margins (degree of precision/uncertainty) in the headers of the table (incl. units)**

☐ Consistently propagate uncertainty through each stage of the processing.

☐ Plot a **graph** of the final **processed results** – ensure to use the correct graph and don't plot 3D graphs.

☐ **Clear and descriptive title for your graphs (mention the variables within the title)**

☐ Clear **labels** and **units of measurements** along the axes – use the same as within the data table

☐ Numbers displayed on the axes should be to the same number of decimal places as data they are based on.

☐ Use a sensible size and good scale, with increments being at equal distances

☐ Graphs should always have grid lines and the bigger the better for ease of reading and interpretation

Conclusion (6 marks):

Interpreting the data and trends (this may already occur below your processed data):

☐ Interpret **all the processed data** from the previous section (refer to **calculated** values)

☐ Compare results from different trials and look for trends or patterns.

☐ **Compare and interpret** the calculated rates, ratios, correlations, etc. if applicable.

☐ Consider the impact of random and or systematic errors in the results (you will evaluate them later as well, but you should acknowledge their impact already here).

☐ **Describe the graph** and trendline (and the relationship between variables) you have drawn in a few words and justify the choice of trendline. E.g. positive correlation, strong negative correlation, exponential growth etc.
- Don`t confuse linear negative slopes with inversely proportional ones
- Don`t confuse any deviation from linearity in a positive slope with an exponential line

☐ **Error bars** in Chemistry are not expected, but if used they should be discussed/described.

☐ Comment on the R^2 value of the trend line.

☐ *[If relevant*] Calculate the y-intercept if it is expected pass through the origin.

Response to RQ

- ☐ Restate Research Question (or at least refer to it)
- ☐ Use processed data to justify your response to the research question.
- ☐ Refers to specific tables and/or graphs from processed data.
- ☐ Consider total % uncertainties or absolute errors when drawing a conclusion.

Justify a conclusion with relevance to the scientific context

- ☐ Uses relevant scientific knowledge to explain findings (here you may refer to the background information.
- ☐ Make a comparison to experimentally determined quantities, literature values or publications to readily available literature, course material, textbook or other ensuring comparable conditions to your investigation.
  - *[If individual values can be compared with literature data]* Calculates a % error for processed data.
  - *[If % error cannot be calculated]* Qualitatively compare trends and/or likely outcomes with established scientific knowledge.
- ☐ Fully reference any literature that is quoted.

Evaluation (6 marks):

Evaluate **methodological and procedural weaknesses** of the investigation

- ☐ **Methodological weaknesses** relating to the design of the experiment.
  - Evaluate the effectiveness of control variables
  - Discuss incorrectly calibrated devices or background interference caused by the samples
  - Discuss small sample size/number of repeats increasing random errors and reducing reliability
  - Discuss the precision of measurement instruments of chosen/available measurement devices
- ☐ **Procedural weaknesses** relating to the conduction of the experiment are identified. This refers to:
  - Spills, delays or other human/random errors during the experimentation
  - Happenstances such as fluctuations in temperature, pH or other during the experiment
  - Difficulty with the manipulation of measurement equipment/devices
  - Unexplainable outcomes such as unrealistic volumes/measurements etc during an experiment which reduce the sample size and overall validity of the experiment
  - Refer to observations from your own data such as outliers or unexpected trends when evaluating
  - Identify specific errors/weaknesses as random or systematic
  - Identify each source of error as r**andom** or **systematic** (watch this video for help)
  - Explain how each source of error may have **impacted the validity** of collected data

Evaluate **limitations** of the investigation**:**

- ☐ Considers limitations of investigation. These could include:
  - Consider the range of data (independent variable) - a low range might allow for only part of a trend to be identified.
  - Discuss the overall effectiveness of chosen **experimental technique** or the confines of the system
  - Discuss the use of assumptions (e.g. specific heat capacities, pressure systems, solubility of gases when collecting a gas as a product through displacement,…)
- ☐ Consider the impact of limitations by how effectively you have been able to answer your research question.

Explain improvements

- ☐ Suggest improvements based on previously identified errors/weaknesses/limitations.
- ☐ Explain why and how these improvements would help to produce more reliable or accurate results
- ☐ Do not simply suggest more trials especially when number of trials was acceptable.
- ☐ Explicitly provide realistic and specific changes and modifications to the design of data collection, choice of materials, method of analysis by explaining how to implement them.