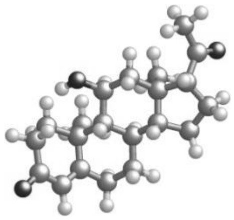

Chem!stry

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<u>Guide to the Design of Scientific Experiments</u>

1. Read the information through several times. Make sure that you are *clear* about the objective of the experiment that you are designing. It is useful to think about which topic(s) in Chemistry the experiment is related to, for example, rate of reaction or chemical energetics – you can then recall your prior knowledge of that topic. Think *very carefully* about how you will perform the experiment. If there is more than one way, then consider which is the *best* method, the one for which you can write straight forward instructions that you are familiar with.

2. Identify the *independent variable* (input variable). This is the variable that will be purposefully changed during the experiment. Be careful how you define the independent variable. For example, if you are investigating the reactivities of two different metals, then the independent variable is *not* the *type* of metal used for the experiment, but the *reactivity* of the metal used for the experiment.

3. Identify the dependent variable (output variable). This is the variable that will be measured during the experiment. For Science, you should ideally collect *quantitative data*. This is *numerical data* which has *units*, for example, mass in grams, temperature in degrees Celsius and volume in cubic centimetres. It is not advised to collect data that is *subjective*, for example, the number of bubbles formed (a few or many) or how fast a precipitate is formed (slow or fast, is the precipitate faint or thick).

4. If you are required to write a hypothesis, then this is best written as the expected relationship between the independent variable and the dependent variable.

5. Identify variables that should be kept *constant* throughout the experiment, variables that should not change when the experiment is repeated with new values for the independent variable. In scientific experiments, there should only be *one independent variable*, *i.e.* only one variable should be changed at a time. If variable **A** and variable **B** are both changed at the same time, and we obtain a different set of results, it is difficult to know which variable influenced the system and caused the change – was it mostly **A** or was it mostly **B**?

6. When writing the step-by-step method for the experiment, consider how the independent variable will be changed or manipulated, how the dependent variable will be measured and how the other important variables will be kept constant. This needs to be clearly described in the method.

7. It is useful, but not always essential, to include a list of apparatus for the experiment. Thinking about the apparatus that is required and writing it down can help with the planning and design of the experiment.

8. (a) It is useful, but not always essential, to include an annotated diagram of the experimental set-up. If you are required to draw a diagram as part of the design, then it *must* be labelled. Diagrams should be two-dimensional scientific diagrams of the apparatus, not artistic three-dimensional sketches. Diagrams should be drawn in pencil and labelled in pen.

(b) An annotated diagram can help you visualise the experiment which can help you plan the step-by-step procedure. A diagram can also save time when explaining how the apparatus should be arranged and can also be used as a reference to show which essential pieces of apparatus are required for the experiment to succeed. Note: if drawing apparatus to produce and collect gases, ensure that the glassware is airtight, *i.e.* there are no gaps shown. Pay attention to other important information, such as the exact location of the bulb of a thermometer when the experiment requires temperatures to be taken.

9. Always state appropriate volumes of the solutions to be used, and name the glasswear that will be used to measure and store these solutions. For example, *A 50 cm^3 measuring cylinder was used to measure 40 cm^3 of dilute sulfuric acid into a 250 cm^3 conical flask*.

10. (a) Be careful when using the term *amount* while describing an experiment. Amount refers to the number of moles of chemical present, and should not be confused with mass and volume. For example, *The volume of carbon dioxide gas produced by the reaction after five minutes was recorded* – this is correct. *The amount of carbon dioxide gas produced by the reaction after five minutes was recorded – this is incorrect.*

(b) Sometimes an experiment requires the *same mass* or *volume* of a reagent to be used, for example, when comparing the effect of surface area to volume ratio on the rate of a chemical reaction, one experiment might use 10.0 g of granular calcium carbonate while another experiment uses 10.0 g of powdered calcium carbonate. For other experiments, it might be important to use the same number of *moles* of a reagent. This might be important if the experiment is comparing different elements with different A_r or different compounds with different M_r. For example, reacting 10.0 g of magnesium carbonate (M_r = 84.3) and 10.0 g of calcium carbonate (M_r = 100.1) with excess nitric acid would result in different volumes of carbon dioxide gas being produced because a different number of moles of each carbonate is being used. If it is important that the same volume of carbon dioxide gas is produced by each reaction, then the same number of moles of each carbonate must be used, which requires a different mass of each carbonate being weighed out.

11. (a) Ensure that the volumes of the solutions used, and the glasswear that is used to measure and store them, are appropriate for the experiment. For example, the volume of solution that a test tube can safely hold is approximately 10 cm^3, so avoid statements like *50 cm^3 of dilute sodium hydroxide were poured into a test tube* – the volume of the solution clearly exceeds the volume of the glasswear.

(b) For qualitative analysis, 1 cm^3 or 2 cm^3 of the unknown solution in a test tube is sufficient. The test reagent is then usually dropwise until no further change is observed.

(c) For experiments that require quantitative data, such as measuring volumes of gases and temperature changes, 50 cm^3 to 100 cm^3 of solution in a beaker / conical flask or Styrofoam cup should be sufficient.

(d) Remember that some solutions need to be *acidified* for the results to be conclusive. For example, nitric acid should be added to unknown solutions before adding aqueous silver nitrate (to test for chloride) or aqueous barium nitrate (to test for sulfate). The oxidising agent potassium manganate(VII) also needs to be acidified before it can be used.

(e) Be mindful of your choice of acid used for a reaction. Some acids will react to form *unwanted precipitates* that will slow down the reaction and eventually prevent the reaction from taking place. For example:

$$Ca(s) + H_2SO_4(aq) \rightarrow \mathbf{CaSO_4(s)} + H_2(g)$$

$$PbCO_3(s) + 2HCl(aq) \rightarrow \mathbf{PbCl_2(s)} + CO_2(g) + H_2O(l)$$

A better choice might be nitric acid, because *all nitrates are soluble in water* :

$$Ca(s) + 2HNO_3(aq) \rightarrow \mathbf{Ca(NO_3)_2(aq)} + H_2(g)$$

$$PbCO_3(s) + 2HNO_3(aq) \rightarrow \mathbf{Pb(NO_3)_2(aq)} + CO_2(g) + H_2O(l)$$

(f) When investigating the effect of a *catalyst* on the rate of a chemical reaction, only a small volume or mass of the catalyst needs to be used, for example 0.5 g (for mass of solid) or 1.0 or 2.0 cm^3 (for volume of solution). Adding 10 g of a catalyst to only 25 cm^3 of solution is excessive.

(g) Consider whether any of the reagents should be used in *excess*, or used as a *limiting reagent*. For example, when comparing the reactions of two different metal carbonates with a dilute acid and measuring the volume of carbon dioxide gas produced – *excess* of the dilute acid should be used to ensure that both of the metal carbonates *react completely*.

12. (a) Place steps in the correct *chronological order*. For example, if a strip of metal needs cleaning (maybe a strip of magnesium needs cleaning before it reacts with an acid or a copper strip needs cleaning before it is used in electrolysis) then this should be done *before* weighing it. In addition, remember to include when important readings should be taken. For example, the *initial* mass of a solid, the *initial* temperature of a solution and the *initial* reading of a burette. Reactions should also run for an appropriate amount of time.

(b) At the start of some quantitative experiments there might be specific pieces of apparatus that need to be set to zero. For example, an electronic balance might need to be set to zero before weighing a conical flask, or the plunger of a gas syringe might need to be pushed in to zero before measuring the volume of a gas.

(c) Some parts of the experiment may need to be done at the same time, for example, mixing two reagents together and stating a stopwatch. In the procedure, this can be emphasised by using the word *immediately*, for example, *The calcium carbonate was added to the beaker of dilute hydrochloric acid and the stopwatch started immediately*.

13. Be carful with the language that you use. Your choice of words can have significantly different meanings. For example, if a reaction exothermic then you might want to measure the *maximum* temperature reached in order to calculate the change in temperature. However, it is wrong to say that you measure the *final* temperature – in reality the *final* temperature would be room temperature which is reached once the reaction has cooled down. Likewise, avoid saying *the time is faster* – you cannot speed up time! What you mean to say is either *the time taken is shorter* or *the reaction is faster*.

14. **(a)** For experiments involving qualitative analysis, remember to add reagents such as aqueous sodium hydroxide and aqueous ammonia dropwise until no further change is seen. Describe the *colours* of *precipitates* and describe the *colour* of the *solution* formed if the precipitate dissolves in excess of the reagent.

(b) If the reaction produces a gas, then you should describe the *test* for the gas, for example *Damp red litmus paper turns blue*, and *name* the gas responsible – in this case it is *ammonia*.

15. Describe how the data collected should be processed to fulfil the purpose of the investigation.

(a) This could be manipulating / transforming the data through calculations, analysing the data using tables, graphs or diagrams and making sense of the data so that meaningful deductions and conclusions can be made.

(b) If you sketch a graph to illustrate the results, consider whether it should be a straight line or a smooth curve and whether or not it should pass through the origin (0,0). Graphs should have titles, and the axes should be clearly labelled, including the correct units. The *x-axis* is the *independent variable* and the *y-axis* is the *dependent variable*.

(c) State the final conclusion based upon the quantitative data that you collect. For example, *If adding 0.1 g of compound **X** to the reaction causes 20 cm^3 of gas to be produced in a shorter space of time compared to the reaction where **X** is not added, then **X** functions as a catalyst*.

16. If asked to suggest experimental errors, then suggest errors that are due to limitations of the apparatus or reagents. Avoid suggesting human errors, such as parallax errors, which are within your control to avoid. Be specific when describing errors, and avoid terms such as *The results will be inaccurate* – state *how* and *why* they will be inaccurate.