Guidance Notes

In general, you should be able to:

- apply investigative approaches and methods to practical work and think independently when undertaking practical work**;**

- use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification.

Methods of data collection and analysis

You should be able to:

- describe with the aid of a clearly labelled diagram, the arrangement of apparatus for the experiment and the procedures to be followed;
- describe how the data should be used in order to reach a conclusion, including details of derived quantities and graphs to be drawn where appropriate;
- select appropriate apparatus and record the instrument resolution used i.e. the smallest measurable division on the instrument;
- set up apparatus correctly without assistance and follow instructions given in the form of written instructions, diagrams or circuit diagrams;
- undertake and record trial readings to determine the suitability of ranges and intervals;
- take repeat readings where appropriate;
- make and record accurate measurements;
- evaluate experimental methods and suggest improvements.

Safety considerations

You should be able to:

- assess the risks of your experiment;

Hazard	Risk	Control measure

Hazard - an object or chemical and the nature of the hazard

Risk - an 'action' in the method that can create a risk from a hazard

Control measure - must be practicable in the context of the practical

- describe precautions that should be taken to keep risks to a minimum.

Table of results

You should be able to:

- present numerical data and values in a single clear table of results;
- produce column headings which have both a quantity and unit e.g. I/mA;
- include columns for all the initial data and values calculated from them;
- record initial data to the same number of decimal places as the instrument resolution e.g. if length is measured to the nearest mm then all lengths in the column should be recorded to the nearest mm;
- use the correct number of significant figures for calculated quantities. For example, if values of pd and current are measured to 2 and 4 significant figures then the corresponding resistance should be given to 2 or 3 significant figures. The number of significant figures may, if necessary, vary down a column of values for a calculated quantity.

Recording readings and significant figures

All raw data should be recorded to the resolution of the instrument used. Any data processed (calculated) from the raw data should be to the same number of significant figures (or a maximum of one extra) as the raw data. The number of significant figures should be consistent within a column of data.

To simplify things a general rule is that:

Processed data should be given to the same number of significant figures as raw data and raw data should always be quoted to the resolution of the instrument used to measure it

Approach to data analysis

You should be able to:

- rearrange expressions into the form $y = mx + c$;
- plot a graph of y against x and use the graph to find constants m and c in an equation in the form $y = mx + c$.

Graphs

You should be able to:

- include a title and axes which are labelled with scales and units;
- make sure the scales are convenient to use, so that readings may easily be taken from the graph – avoid scales which use factors of 3 – and that the plotted points occupy at least half of both the vertical and horizontal extent of the graph grid;
- first consider carefully whether your plotted points suggest a straight line or a curve - then draw in your best fit line either with the aid of a ruler or (if a curve) by a freehand sketch;
- when extracting data from a graph, use the best-fit line rather than the original data;
- when determining the gradient of a graph, show clearly on your graph the readings you use. This is most conveniently done by drawing a right angled triangle – this should be large so that accuracy is preserved.

Estimating uncertainties

You should be able to:

1. Express uncertainties

Use the form $x \pm u$, where x is the quantity being measured and u its estimated uncertainty.

2. Estimate uncertainties using the resolution of an instrument

If a single reading is taken and there is no reason to believe that the uncertainty is greater, take the uncertainty to be the instrument resolution.

3. Estimate uncertainties using the spread of readings

Take the best estimate of the quantity you are determining as the mean of your readings and the estimated uncertainty to be half the spread in the readings, discounting any suspect readings: i.e. $u = \frac{x_{\text{max}} - x_{\text{min}}}{2}$

4. Percentage uncertainties

The percentage uncertainty, p, is calculated from:

$$p = \frac{\text{estimated uncertainty}}{\text{mean value}} \text{x} 100\%$$

Uncertainties in calculated quantities

1. If a quantity is calculated by **multiplying and/or dividing** two or more other quantities, each of which has its own uncertainty, the percentage uncertainty in the result is found by adding the percentage uncertainties in the quantities from which it is derived.

   e.g. If λ is calculated using $\lambda = \frac{ay}{D}$, the percentage uncertainty in λ is:

$$p_\lambda = p_a + p_y + p_D$$

2. If a quantity is calculated by multiplying by a **constant**, the percentage uncertainty is unchanged.

3. If a quantity is **raised to a power**, e.g. x^2, x^3 or $\sqrt{x}$, the percentage uncertainty is **multiplied** by the same power.

   Example of 2 and 3: The energy, E, stored in a stretched spring is given by $E = \frac{1}{2}kx^2$. Both k and x have uncertainties, but $\frac{1}{2}$ has no uncertainty.
   So: $p_E = p_k + 2p_x$

Conclusions and evaluations

You should be able to:

- draw conclusions from an experiment, including determining the values of constants, considering whether experimental data supports a given hypothesis, and making predictions;

- suggest modifications to the experimental arrangement that will improve the accuracy of the experiment or to extend the investigation to answer a new question.

A LEVEL ONLY:

Approach to data analysis

You should be able to:

- rearrange expressions into the forms: $y = ax^n$ and $y = ae^{kx}$;
- plot a graph of $\log y$ against $\log x$ and use the graph to find the constants a and n in an equation in the form $y = ax^n$;
- plot a graph of $\ln y$ against x and use the graph to find the constants a and k in an equation of the form $y = ae^{kx}$.

Graphs

The following remarks apply to linear graphs.

Error bars

The points should be plotted with error bars. These should be centred on the plotted point and have a total length equal to $y_{max} - y_{min}$, for uncertainties in the y values of the points, and $x_{max} - x_{min}$, for uncertainties in the x values of the points. If identical results are obtained the precision of the instrument could be used. If the error bars are too small to plot this should be stated. This will almost certainly be the case for log graphs.

Maximum and minimum gradients

If calculating a quantity such as the gradient or the intercept a line of maximum gradient and a line of minimum gradient should be drawn which are consistent with the error bars. It is often convenient to plot the centroid of the points to help this process. This is the point,$(\overline{x},\ \overline{y})$ the mean x value against the mean y value. The line of maximum gradient and the line of minimum gradient should both pass through this point.

Values for the maximum and minimum gradients, m_{max} and m_{min}, [or intercepts, c_{max} and c_{min}] can now be found and the results quoted as:

$$\text{gradient} = \frac{m_{\max} + m_{\min}}{2} \pm \frac{m_{\max} - m_{\min}}{2}$$

$$\text{intercept} = \frac{c_{\max} + c_{\min}}{2} \pm \frac{c_{\max} - c_{\min}}{2}$$

The following remarks apply to curved graphs.

If the graph is curved error bars should still be plotted (on both axes if possible) and a curve of best fit drawn to enable a tangent to be constructed if the gradient of any point is needed.

Example of good practice

The following results were obtained when the resistance of a coil of wire was measured at different temperatures. The resistance was measured when both heating and cooling the wire so giving two sets of readings. The mean resistance was calculated using:

$$\text{mean resistance} = \frac{R_{\text{max}} + R_{\text{min}}}{2}$$

and the absolute uncertainty calculated using:

$$\text{absolute uncertainty} = \frac{R_{\text{max}} - R_{\text{min}}}{2}$$

Systematic presentation

Consistent sig figs within each column

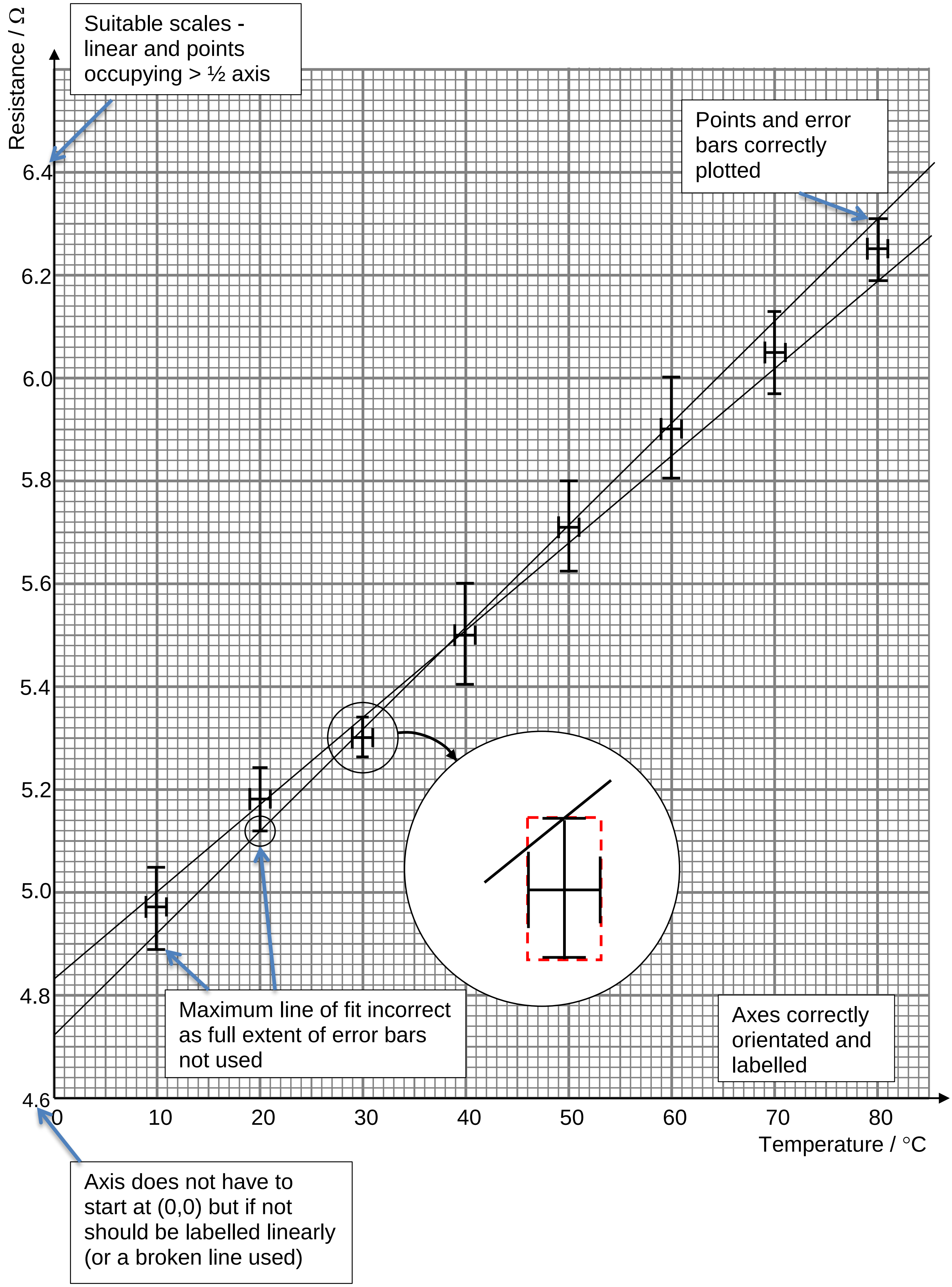
Headings given with units

Temperature ± 1 / ^{o}C	Resistance heating / Ω	Resistance cooling / Ω	Mean resistance / Ω	Absolute uncertainty / Ω
10	4.89	5.05	4.97	0.08
20	5.12	5.24	5.18	0.06
30	5.26	5.34	5.30	0.04
40	5.40	5.60	5.50	0.10
50	5.62	5.80	5.71	0.09
60	5.80	6.00	5.90	0.10
70	5.97	6.13	6.05	0.08
80	6.19	6.31	6.25	0.06

Uncertainty to 1/2 sig figs **max**

All raw data to the resolution of the instruments used

Processed data to the same number of sig. figs as the raw data



Suitable scales - linear and points occupying > ½ axis
Points and error bars correctly plotted
Resistance / Ω
6.4
6.2
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
0
10
20
30
40
50
60
70
80
Temperature / °C
Maximum line of fit incorrect as full extent of error bars not used
Axes correctly orientated and labelled
Axis does not have to start at (0,0) but if not should be labelled linearly (or a broken line used)