THE LEARNED SOCIETIES' GROUP ON STEM EDUCATION

DECEMBER 2015

PRESENTING DATA IN GRAPHS, CHARTS AND TABLES IN SCIENCE SUBJECTS: A RESPONSE TO A CONSULTATION FROM THE SCOTTISH QUALIFICATIONS AUTHORITY

Key points:

- This consultation presents SQA with an opportunity to develop clear policy for providing consistency across SQA documents as well as guiding teachers and learners.
- Data should be presented in line with internationally agreed standards and follow best-practice guidance.
- Data presentation at different levels should be appropriate for each level, but data should be presented consistently within exams and courses at each level.
- There should be a clear distinction between the standards expected of data presentation in documents published by SQA, such as examination papers, and the standards acceptable in student responses to assessments.
- In accordance with best practice advice, tables and graphs should have headings and labels reflecting that they are mathematical devices dealing with pure numbers. They should follow the convention, "*quantity*/units" for example "*mass*/g".

Introduction

The Learned Societies' Group on STEM Education[1] (the LSG) welcomes the opportunity to respond to the Scottish Qualifications Authority's (SQA) consultation on its draft guidance document[2] on the production, use and interpretation of graphs and charts in SQA assessments. This consultation provides a timely opportunity for SQA to develop a clear policy which it can then apply consistently across its own documents as well as giving guidance to teachers and students. We support the SQA rationale for the consultation that, *"[a]s far as possible skills taught in science should be transferable across science subjects to ensure that learners studying more than one science are not disadvantaged".*

The LSG comprises representatives from the: Association for Science Education; BCS, The Chartered Institute for IT; Edinburgh Mathematical Society; Engineering Policy Group in Scotland; Institute of Physics; Royal Society of Biology; Royal Society of Chemistry; Royal Society of Edinburgh; and Scottish Mathematical Council. The LSG collaborative grouping brings together these organisations to discuss and contribute to the major reforms in STEM education in Scottish schools. LSG representatives would be pleased to discuss further our comments with SQA officials.

Following best practice guidance on the presentation of data

All data presented in SQA documents, including examination papers and National Assessment Resource materials should be clear, unambiguous, and follow the best-practice advice and guidance provided in the following authoritative publications. This approach should apply not only to the sciences, but to all subject areas where data is presented, including mathematics, social sciences, humanities and business subjects.

- Swinfen, T.C. et al. (1995) *Signs, Symbols and Systematics: The ASE companion to 5 –16 Science*. Hatfield: ASE.
- Swinfen, T.C. (Ed). (2000) *Signs, Symbols and Systematics: The ASE companion to 16–19 Science.* Hatfield: ASE.
- Campbell, P. (Ed). (2010) *The Language of Measurement: Terminology used in school science investigations.* Hatfield: ASE.

All three of these publications were developed by committees convened by the Association for Science Education, with representatives drawn from across the sciences, including the Institute of Physics, the Royal Society of Chemistry and the Royal Society of Biology (and its predecessor bodies).

1 Information about the LSG is available at: https://www.royalsoced.org.uk/1076_LearnedSocietiesGrouponScottishScienceEducation.html

2 SQA consultation paper on presenting data in graphs, charts and tables – science subjects (November 2015) http://www.sqa.org.uk/sqa/files_ccc/Consultation_PresentingData_Sciences.pdf

In turn, these publications incorporate advice from national and international authoritative bodies responsible for metrology, including the National Physical Laboratory (NPL), the National Institute for Science and Technology (NIST), the Bureau International des Poids et Mesures (BIPM) and the International Union of Pure and Applied Chemistry (IUPAC).

Tables and graphs should have headings and labels that reflect that they are mathematical devices dealing with pure numbers only. However, as a measured quantity has both a numerical value and a unit, axes labels and table headings must be expressed in an appropriate format. Particularly useful sources of advice on expressing quantities and units are exemplified, below.

Rules and style conventions for expressing values and quantities

The value of a quantity is its magnitude expressed as the product of a number and a unit, and the number multiplying the unit is the numerical value of the quantity expressed in that unit. More formally, the value of quantity A can be written as A = {A}[A], where {A} is the numerical value of A when the value of A is expressed in the unit [A]. The numerical value can therefore be written as {A} = A / [A], which is a convenient form for use in figures and tables. Thus, to eliminate the possibility of misunderstanding, an axis of a graph or the heading of a column of a table can be labelled "t/ºC" instead of "t (ºC)" or "Temperature (ºC)."

NIST *Guide for the Use of the International System of Units* (SI) (2008) [3]

Value and numerical value of a quantity, and the use of quantity calculus

Symbols for units are treated as mathematical entities. In expressing the value of a quantity as the product of a numerical value and a unit, both the numerical value and the unit may be treated by the ordinary rules of algebra. This procedure is described as the use of quantity calculus, or the algebra of quantities. For example, the equation T = 293 K may equally be written T/K = 293. It is often convenient to write the quotient of a quantity and a unit in this way for the heading of a column in a table, so that the entries in the table are all simply numbers.

BIPM *The International System of Units SI Brochure* 8th Edition (2006) [4]

Tables of values of physical quantities should be headed by the physical quantities divided by the units (see Example). The entries in the tables are then (pure) numbers and express the ratio of the physical quantities to the unit quantities. The use of the solidus to indicate the division of a physical quantity by its unit has advantages, provided care is taken not to use a solidus in the unit itself. It enables the unit to retain its familiar form, and at an elementary level, may be verbalised as "in" thus allowing correct notation to be used at that level.

The axes of a graph are marked off in numbers. Care should be taken to avoid appearing to plot a graph of anything other than a (pure) number. The correct labelling of axes leads to the correct units for gradients.

Swinfen, T.C. (Ed). *Signs, Symbols and Systematics: The ASE companion to 16–19 Science* (2000) [5]

Example

The data used come from an experiment to find out how the effective force F propelling a boat at constant velocity v is related to the velocity.

If F = 200 N, then F/N = 200.

'F/N = 200' means 'The number of (newton) units of which the force consists = 200.'

Table headings and graph axes are labelled as below:

v/m s^{-1}	F/N
2.0	25
3.0	53
4.0	96
5.0	150
6.0	217

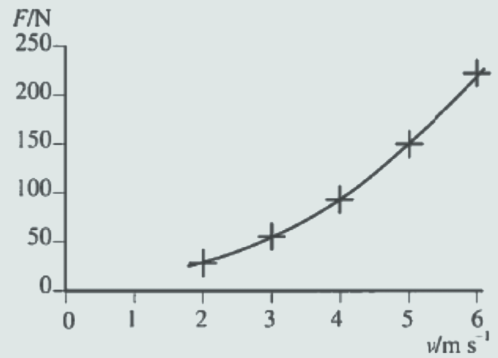


Figure 11.1
Graph of force against velocity.

3 NIST, 2008

4 http://www.bipm.org/en/publications/si-brochure/section5-3.html

5 Swinfen, T.C. (Ed). Signs, Symbols and Systematics: The ASE companion to 16-19 Science (2000). Hatfield: ASE. pp. 144

Overarching comments and main recommendations

Tables and graphs should have headings and labels reflecting that they are mathematical devices dealing with pure numbers. They should follow the convention, "*quantity*/units" for example "*mass*/g".

Where units are expressed in words the format "*quantity* in units" could be used. This format could be used for qualifications at SCQF 4 and below.

The SQA should also ensure that its documents follow the advice on plotting points on graphs as follows:

Points on a graph should not be plotted as dots, although a dot with a circle round it, ⊙, is suitable. Many people favour a vertical cross, +, because the vertical and horizontal lines can be plotted separately, leading to a precise position for the point. The length of the vertical line can be used to indicate the uncertainty of the measured value. The saltire, ×, is not so easy to plot precisely and the Working Party suggests that it not be used.[6]

In addition to recommending the use of + and ⊙ to plot or display points on hand drawn graphs we recommend that the symbols used as the default for points on many electronic graph packages be changed by the user to + or ⊙. All graphs on SQA printed documents should set a good example and follow this convention.

These recommendations are broadly consistent with historic SQA practice in examination data sheets as indicated in Appendix 1.

We recommend that all data presented in SQA documents, including examination papers, data booklets and National Assessment Resource items such as Unit Assessment Support Packs, are consistent with these recommendations. It is in the interest of candidates that they meet a consistent approach in the presentation of quantities and units for data. SQA should ensure that quality assurance procedures relating to all of its published documents are sufficiently robust.

There has been unfortunate variation in recent years in the presentation of data in assessment items, both in examinations and unit assessments. For example, some of the 2015 physics examinations used different formats within a paper, including many different from the best-practice advice as used in the data sheets. See Appendix 2 for specific examples of this. We recommend that SQA should ensure that data is presented consistently across questions within any single assessment instrument. It is potentially confusing for candidates to meet a variety of presentations within the same instrument.

6 Swinfen (2000), pp. 144

Additional and subject-specific comments

Mark allocation

We support the intention that not all graph questions should have the same mark allocation, with the number of marks allocated depending upon the level of input required from the learner and the complexity of the data.

Assignments/Projects (National 4-Advanced Higher)

We strongly support the intention that the correct type of graph is used for all appropriate data and the clear specification of the use of different graph and chart types given.

A stick or spike graph is referred to in the line graph section along with mention of graphs with one continuous and one discrete variable. No example is then given of this type of presentation in any of the subsequent examples. Perhaps an example such as the *relative abundance* against *atomic number* from a mass spectrometer could be included to illustrate this.

Biology and Human Biology specific section (pages 5–9)

Units in all examples are given in brackets and are therefore not consistent with best practice advice, as is the case in the Chemistry and Physics examples. We recommend using the solidus notation where there is no likelihood of confusion with the unit.

Line graphs

We recommend that points are plotted with + (plus) as points on a graph should not be plotted as dots. While a point-to-point graph may be acceptable in very specific circumstances, the blood glucose concentration (page 5) is not a good example of this and better data to use to illustrate this type of graph may be the frequencies of neutral alleles in the population against time, owing to genetic drift.

In relation to the line of best fit example on page 6, this is not a good example as the line of best fit has been drawn in the absence of any plotted data points.

Chemistry specific section (pages 10 – 11)

Line graphs

In relation to the paragraph which states, "Due to uncertainty in measurements, all data points will not normally lie on a single straight line or curve. By examining the scatter of points candidates are expected to form a judgement as to whether a best fit straight line or curve is appropriate. No line should be drawn if the data points do not support either a straight line or curve." We would recommend that this point should be further clarified with the addition of the text, *"It will never be appropriate for a candidate to adopt a dot-to-dot approach joining adjacent points with a series of straight lines."*

Bar charts
In the example depicting a bar chart, clear gaps between bars should be visible, in line with the general guidance on the drawing of bar charts on page 4 of the document.

SQA data booklets
The current editions of the SQA data booklets for Chemistry tend to follow best practice in their representation of units, however in both the National 5 data booklet and the Higher and Advanced Higher data booklet, where density is listed, the incorrect format has been used. We recommend that the table on page 7 of the National 5 data booklet and on page 5 of the H/AH data booklet are amended to match the *quantity*/units format used elsewhere in these documents, i.e. "*Density* / g cm^{-3}".

Physics specific section (pages 12–14)

Line graphs
We recommend that points are plotted with + (plus) signs rather than × signs. Plus signs are good precursors to error bars and their intersections can be plotted and read more accurately than a cross as the lines are parallel to the graph gridlines.

Both line graph examples have zeroes marked on both axes. This may give the impression that a zero on both axes is required to indicate the origin. A single zero is adequate in many cases to indicate the origin on a graph and including a suitable example to indicate this would be advisable.

Bar chart
We consider this to be a very poor example of the use of a bar chart. The example does not have discrete bars with gaps in between, which contradicts the advice given regarding bar charts on page 4 of the document. The plotting of data points (using × rather than +) at the centre of the top of the bars and fitting a trend line is inappropriate. Assuming the elastic bands used are identical it would be more sensible to plot a line graph of "*acceleration*/m s^{-2}" against "*force*/number of elastic bands" with a resulting line of best fit. The line of best fit is likely to pass close to the origin unlike the rather confusing outcome of the bar chart example given.
A better example of a bar chart should be included in the exemplar, such as height of bounce for a ball dropped on to different surface materials.

Appendix 1

Higher and Advanced Higher Physics

PROPERTIES OF SELECTED MATERIALS

Substance	*Density*/ kg m^{-3}	*Melting Point*/ K	*Boiling Point*/K	*Specific Heat Capacity*/ J kg^{-1} K^{-1}	*Specific Latent Heat of Fusion*/ J kg^{-1}	*Specific Latent Heat of Vaporisation*/ J kg^{-1}
Aluminium	$2{\cdot}70 \times 10^3$	933	2623	$9{\cdot}02 \times 10^2$	$3{\cdot}95 \times 10^5$	. . . .
Copper	$8{\cdot}96 \times 10^3$	1357	2853	$3{\cdot}86 \times 10^2$	$2{\cdot}05 \times 10^5$	. . . .
Glass	$2{\cdot}60 \times 10^3$	1400	. . . .	$6{\cdot}70 \times 10^2$	. . . .	. . . .

Standard Grade Credit, Intermediate 2 and National 5

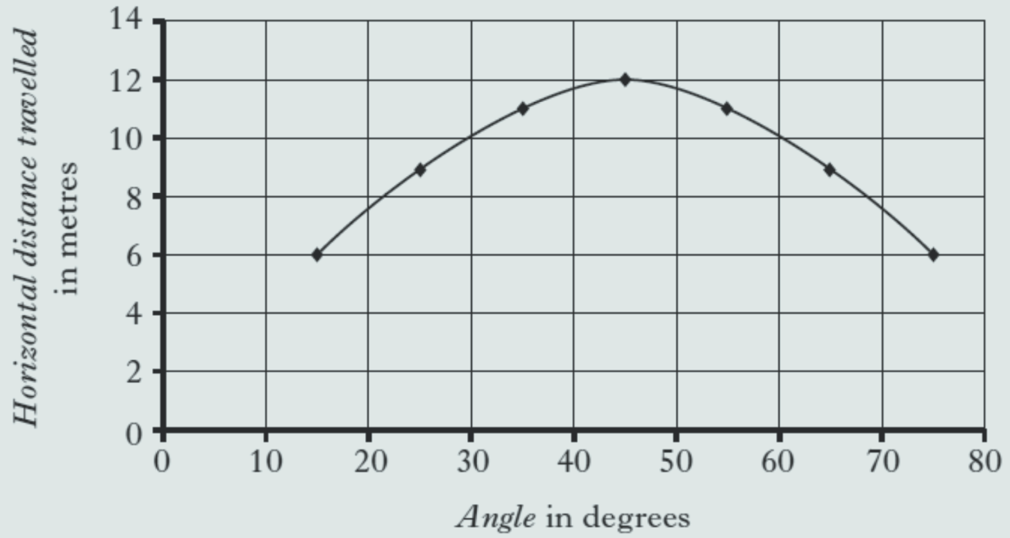
Speed of light in materials

Material	*Speed in* m/s
Air	$3{\cdot}0 \times 10^8$
Carbon dioxide	$3{\cdot}0 \times 10^8$
Diamond	$1{\cdot}2 \times 10^8$

Speed of sound in materials

Material	*Speed in* m/s
Aluminium	5200
Air	340
Bone	4100

For lower levels without a data sheet, historically the "*quantity* in units" format has been used, e.g. Intermediate 1 Physics, 27 May 2013 p10:



Appendix 2

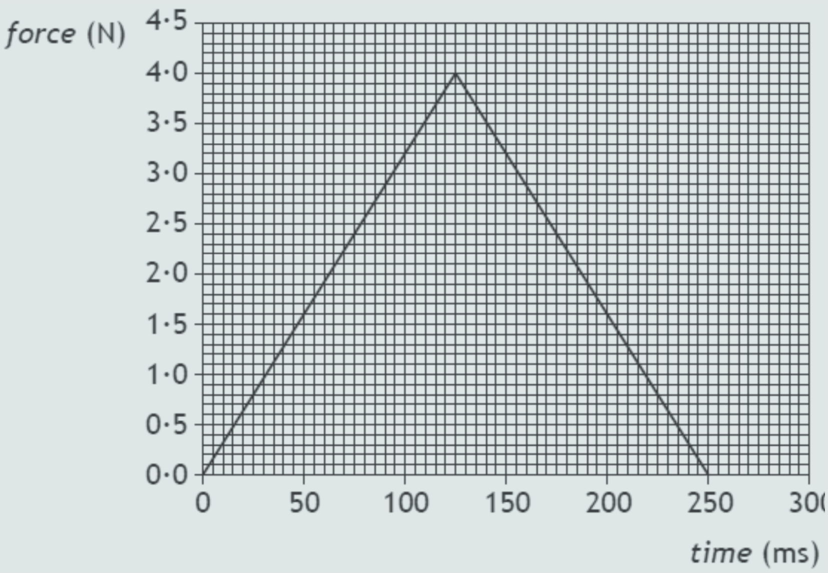
Higher Physics, 5 May 2015

Data Sheet Table on Section 1 p2

PROPERTIES OF SELECTED MATERIALS

Substance	*Density*/kg m^{-3}	*Melting Point*/K	*Boiling Point*/K
Aluminium	$2{\cdot}70 \times 10^3$	933	2623
Copper	$8{\cdot}96 \times 10^3$	1357	2853
Ice	$9{\cdot}20 \times 10^2$	273	. . . .

Graph on Section 2 p10



Physics National 5, 5 May 2015

Data Sheet Table on Section 1 p2

DATA SHEET

Speed of light in materials

Material	*Speed* in $m\,s^{-1}$
Air	$3{\cdot}0 \times 10^8$
Carbon dioxide	$3{\cdot}0 \times 10^8$

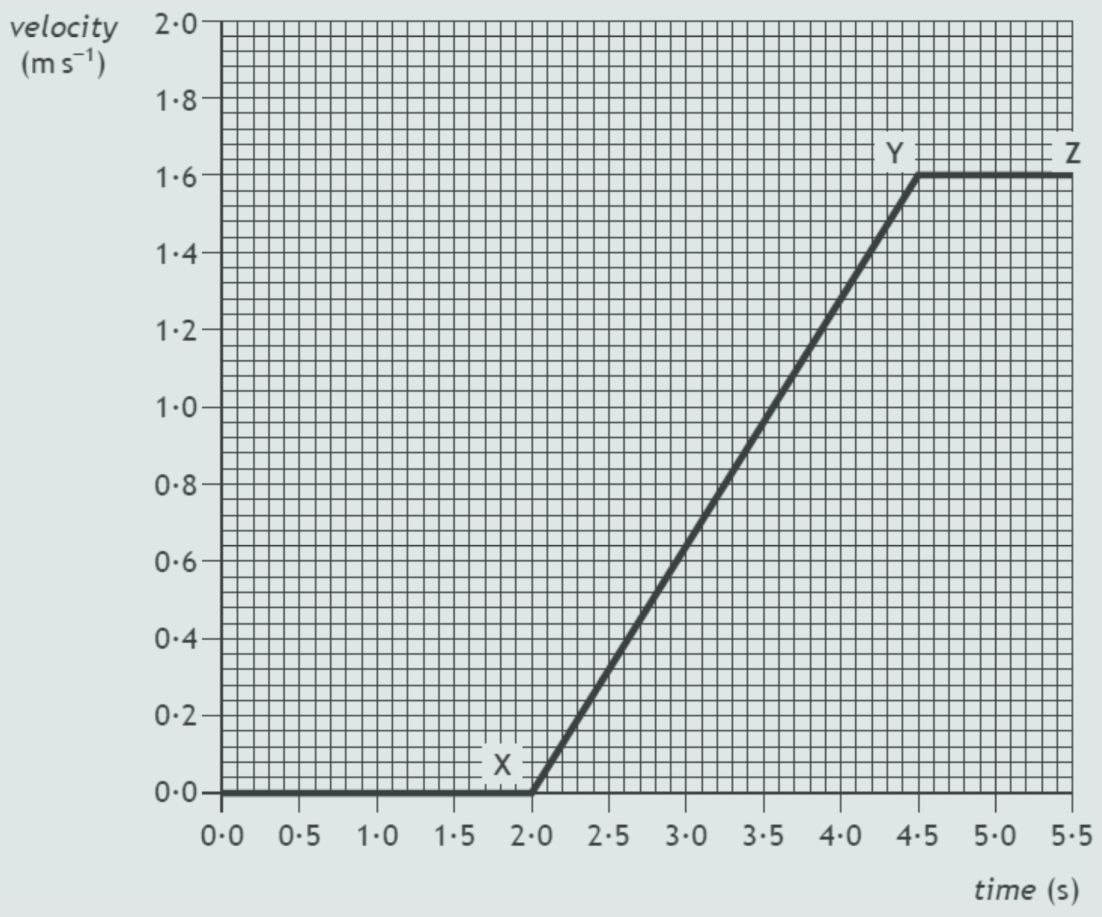
Speed of sound in materials

Material	*Speed* in $m\,s^{-1}$
Aluminium	5200
Air	340

Table on Section 1 p9

Time (s)	0	1	2	3
Velocity of X ($m\,s^{-1}$)	2	4	6	8
Velocity of Y ($m\,s^{-1}$)	0	1	2	3
Velocity of Z ($m\,s^{-1}$)	0	2	5	9

Graph on p21



For further information about the Learned Societies' Group, contact William Hardie, Secretariat (whardie@royalsoced.org.uk)

The Association for Science Education
Promoting Excellence in Science Teaching and Learning

bcs The Chartered Institute for IT
Academy of Computing

Edinburgh Mathematical Society

EPGS Engineering Policy Group Scotland

IOP Institute of Physics In Scotland

Royal Society of Biology

Royal Society of Chemistry

The Royal Society of Edinburgh

Scottish Mathematical Council

The Learned Societies' Group on STEM Education *December 2015*