

## Index

- abscissa, 25
- absolute uncertainty, 67
- accuracy, 68
- accuracy and precision, 68
  - summary of difference, 70
  - worked example, 69
- acronyms, 142
- AD548, 188
  - input resistance, 188
  - layout of connections, 188
- ADC, 186, 190
  - resolution, 190
- analogue to digital converter, 186, 190
- analogue voltage, 186
- Analysis ToolPak
  - descriptive statistics, 183
  - Histogram, 183
  - Random Number Generation, 183
  - Regression, 183
  - summary, 182
  - t-Test, 183
- answers, 202
- Arduino, 192
- Arduino Uno
  - circuit board, 193
  - example program, 194
- best estimate
  - of a quantity, 60
  - the mean, 63
- best estimate of true value
  - standard error of the mean, 89
- best line through  $x$ - $y$  data, 111
- BIPM, 10
- Bluetooth, 195
- C programming language, 194
- calculator apps for
  - smartphones, 87
- calibration uncertainty, 62
- charts, 169
- citing references, 147
- coefficient of linear expansion, 38
- combining uncertainties, 74–81
  - difference, 79
  - example, 79–80
  - Method I, 74
  - Method II, 77
  - product, 79
  - quotient, 79
  - sum, 78
  - when errors are uncorrelated, 101–102
- computer-aided data capture, 185
- confidence interval, 98–99
- confidence limits, 98–99
- continuous and discrete quantities, 103
- continuously varying quantities
  - examples, 103
- CSV file, 182
- DAQ, 190
- data
  - selection and rejection, 81
  - tabulation, 12
  - scientific notation, 13
- data acquisition system, 190
- data gathering
  - using a computer, 185
  - using a plug and play system, 191
  - using a smartphone, 194
  - using an Arduino, 192
- degrees of freedom, 197
- dependent variable, 26
- derived units, 10
- deviation, 86
- discrete quantities, 103
- distributions
  - normal, 94, 198
  - Poisson, 104
  - $t$ , 198
- documenting your work, 4–8
- Einstein, 1
- electronic notebook, 5
- equations
  - linearisation, 44
- error
  - gain, 71
  - how it differs from uncertainty, 61
  - in measurement, 60
  - offset, 71
  - random, 70, 73
  - systematic, 63, 70
  - detection, 70
  - systematic and random, 70–74
- error bars, 29–30
- estimation, 20
- event, 104
- Excel, 168
  - Analysis ToolPak, 182
  - charts, 169
  - Solver, 183
- experimental data
  - important features, 9
- experiments
  - importance in science and engineering, 1
  - stages, 2–4
- extrapolation, 36
- Fermi, 21
- Fermi problems, 20
  - example, 21
- fitting a line to  $x$ - $y$  data
  - difficulties, 111
  - using least squares, 111
- flexi-curve, 31
- fractional uncertainty, 67
- further reading, 218
- Gaussian distribution, 94
- gradient of a line, 34
- Graph (software)
  - free graph plotting program, 52

- graphs
  - abscissa, 25
  - axes, 24
  - dependent and independent variables, 25
  - dependent variables, 26
  - error bars, 29
  - extrapolation, 36
  - importance, 24
  - independent variable, 25
  - interpolation, 36
  - key, 28
  - labels, 26
  - line of best fit, 34–36
  - linear, 33
    - importance of, 34
  - logarithmic, 48–50
  - logarithmic scales, 48
  - log–linear, 48
  - log–log, 50
  - ordinate, 25
  - origin, 29
  - outliers, 36
  - plotting, 24
  - rise, 38
  - run, 38
  - scales, 28
  - semi-log, 48
  - symbols, 28
  - title, 26
  - units, 26
  - when to plot, 32
  - $x$ - $y$ , 24
- Hall probe, 187
- Harvard referencing, 148
- histogram, 91
  - bin, 91
  - guide to plotting, 93
- importing (a file), 182
- independent variable, 25
- intercept, 34, 37, 40
  - calculation, 40
  - uncertainty, 41
  - weighted, 123
- intercept of best line through  $x$ - $y$  data, 114
- interfacing, 185
- International System of Units, 10
- interpolation, 36
- LabJack, 194
- laboratory notebook, 5–7
  - description of contents, 6–7
  - documenting open-ended experiments/projects, 7
  - example of pages from a notebook, 8
- least squares, 112
  - calculation difficulties, 117
  - comparison of weighted and unweighted fit, 125
  - example of calculation of uncertainty in  $m$  and  $c$ , 119
  - example of fitting a line to  $x$ - $y$  data, 115
  - example of weighted fit, 123
  - example where transformation requires weighted fit, 126
  - interpretation of uncertainties in  $m$  and  $c$ , 121
  - linear correlation coefficient,  $r$ , 129
  - non-linear, 182
  - standard errors in slope and intercept, 118
  - weighted, 121–127
  - weighting the fit, 121
- line of best fit, 34
  - how to draw it, 36
- linear correlation coefficient, 129
- linear regression, 112
- linear  $x$ - $y$  graphs, 33
- linearising equations
  - examples, 45
- LINEST, 176
  - example of application, 177
- logarithmic graphs, 48–51
- logbook, 5
- Logger Lite, 191
- log–linear graphs, 48
- log–log graphs, 50
- map
  - example, 153
  - to assist in report writing, 150
- mean, 63
  - best estimate of true value, 90
  - calculating, 63
- measurand, 9
- measurements
  - repeatable, 61
- microcontroller, 186
  - Arduino, 192
- Microsoft
  - PowerPoint, 161
  - Publisher, 161
- non-linear least squares, 182
- normal distribution, 82, 94
  - properties, 94
  - shape, 95
- notebook
  - electronic, 5
- op-amp, 188
  - example, 188
- open-ended experiments, 7
- open-source, 193
- operational amplifier, 187
- oral presentations, 163
  - answering questions, 165
  - body of talk, 165
  - conclusion, 165
  - delivery of presentation, 166
  - introduction, 165
  - preparation, 163
  - presentation practice, 166
  - technical aspects, 167
  - visual aids, 166
- order of magnitude, 20
- ordinate, 25
- origin (of graph), 29
- Origin (software), 184
- outliers, 34, 36
- partial differentiation, 77
- PASCO, 191
- percentage uncertainty, 67
- plotting graphs, 24
- plug and play systems, 191
- Poisson distribution, 104
- population, 96
- population and sample, 96
- population mean, 97
- population parameter, 96
- posters, 160
  - example, 161
  - free templates, 161
  - preparation, 161
  - sizes, 161
- PowerPoint, 166
- powers of 10 notation, 13
- precision, 68
- predictor variable, 25

- prefixes, 11
- preliminary experiment, 3
- Prezi, 166
- principle of maximum likelihood, 113
- probability distribution
  - normal, 94
  - Poisson, 104
  - $t$ , 100, 198
- propagation of uncertainties, 74
  - where errors are uncorrelated, 101, 200
- quantities
  - continuous, 103
  - discrete, 103
- $r$ , 129
- random errors, 73, 85
  - some causes, 73
- range, 65
- reading uncertainty, 62
- references, 147, 220
  - citing, 147
- repeatable measurements, 61
- report writing, 139
  - overview, 139
- reports,
  - abstract, 143
  - acknowledgements, 147
  - acronyms, 142
  - appendices, 149
  - background theory, 145
  - choice of tense, 142
  - conclusion, 147
  - discussion, 146
  - example, 153–160
  - introduction, 144
  - map to aid report
    - preparation, 150
  - materials and methods, 145
  - planning, 149
  - preparation aid, 149
  - references, 147
  - results, 146
  - sections, 143
  - section of a map, 151
  - sentence length, 142
  - stages of report writing, 149
  - structure, 141
  - use of English, 141
- residuals, 113
- resolution uncertainty, 62
- response variable, 26
- rise, 38
- rounding numbers, 17
- run, 38
- $s$ 
  - estimate of population standard deviation, 97
- safety, 3
- sample, 97
- scatter plots, 24
- scientific notation, 13, 18, 66
  - examples, 20
- scientific reports, 139
- SciGen Technologies Poster
  - Genius, 161
- selection and rejection of data, 81
- sensor, 185
- SI
  - derived units, 10
  - fundamental units, 10
  - prefixes, 11
- SI system, 10
- SI units, 10
- signal conditioning, 186–187
- significant figures, 15, 17
  - and scientific notation, 18
  - rules, 18
- Skypaw, 195
- slope, 34, 37, 40
  - uncertainty, 41
  - weighted, 122
- slope of best line through  $x$ - $y$  data, 114
- smart sensor, 186
- smartphone, 87, 194–195
- Solver, 183
- spreadsheets, 168–184
  - active cell, 172
  - alternatives, 184
  - Apache OpenOffice, 168
  - array functions, 176
  - AVERAGE function, 176
  - basics, 169
  - calculations involving columns of data, 170
  - cells, 169
  - CORREL function, 175
  - example using statistical functions, 175
  - Excel, 168
  - FILL command, 172
  - histogram, 179
  - illustration of application, 169
  - LibreOffice, 168
  - LINEST function, 176
  - MAX function, 176
  - MIN function, 176
  - non-linear least squares, 182
  - statistical functions, 175
  - STDEV.S function, 176
  - transferring data, 182
  - visualising data, 179
  - what if calculations, 181
  - $x$ - $y$  graph, 180
- SSR, 113
- standard deviation, 85–88, 119
  - of points about a line of best fit, 119
  - population, 96
- standard error
  - in intercept, 119
  - in intercept (weighted), 123
  - in slope, 119
  - in slope (weighted), 122
- standard error of the mean, 88–89, 97
- statistics
  - quantifying variability
    - caused by random errors, 85
- sum of squares of residuals, 113
- systematic and random errors, 70–74
- systematic error, 63
- systematic errors
  - caused by instruments, 73
- tables
  - containing data, 12
- tabulation of data, 12
- $t$  distribution, 100, 198
- thermoelectric generator, 180, 191
- transducers, 185–187
  - examples, 187
- transforming equations
  - to the form  $y = mx + c$ , 43–47
- Trendline, 176
- true value, 60, 68
- uncertainties
  - what are they?, 59
- uncertainties in slope and intercept, 41

uncertainty, 6, 14, 59	in single measurement, 61–63	variable
absolute, 67	in values obtained through measurement, 14	dependent, 26
combining when errors are uncorrelated, 101	percentage, 67	independent, 25
due to calibration, 62	review, 100	predictor, 25
due to reading, 62	units, 9	response, 26
due to resolution, 62	of slope and intercept, 40	variance, 87
estimating using statistics, 85	prefixes, 11	variance and standard deviation, 85
fractional, 67	value of a quantity	Vernier, 191
how it differs from error, 61	how to quote, 66	
how to quote, 66		‘what if’ calculations using a spreadsheet, 181
in best estimate, 64, 90		