

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