Index

accuracy, 1, 2, 8, 89, 148, 167, 175
through calibration, 141
versus precision, 15

calibration
error on a calibration curve, 272
introduction, 142, 234
set up, 142

calibration error, 138

determination of, 147
for volumetric glassware, 321
from manufacturer, 150
from rule of thumb, 149
introduction, 142
special considerations, 152
user-defined, 151
volumetric glassware, 160
working with, 155
worksheet, 321

Cannon–Fenske viscometer, 86, 213, 214

coefficient of determination, 80, 295
defined, 242
limitations, 307
when of value $R^2 = 1$, 358
confidence intervals
of the mean, 55

covariance, 263, see variance
covariance matrix, 257
definition, 184, 264
of least-squares slope and intercept, 264, 353

data sampling, 26, 29, 32
data supplied
$Q$ versus $\Delta p$, 146
Bourdon gauge pairs, 229

commuting time, 23, 27
density of Blue Fluid, 63
DP meter calibration, 172
flow-loop raw DP, 144
flowering crab leaves, 96
heat-transfer coefficients, 269
lilac bush leaves, 95
maple leaves, 94
pail and scale, 79
plastic cups, 97
rheological (Bagley), 254, 258
rotameter, 83
sugar solutions density, 309
sugar solutions viscosity, 311
systematic error, 309


temperatures in bath, 138

temperatures on two indicators, 101

viscometer efflux times, 214
deviation, 41
between true value and sample mean, 40
maximum, 47
population standard, 37
sample standard, 21, 22
scaled, $t$, 43
scaled maximum, $t_{lim}$, 48

error limits, 5, 7, 9, 12
basic, 46
replicate, 46
significant figures, 73
error propagation, 181
how to perform, 183
introduction, 182
working with, 197
worksheet, 321

370
errors, 1. see error limits, reading error,
calibration error, replicate error
calibration, 138
combined, 125
propagation of, 181
replicate, 20
Type A, 107
Type B, 107
estimating errors, 109
examples, see linked examples
introductory, 14
linked examples roadmap, 11
Excel, 22, 192, 193, 240, 325
functions, 325
least-squares calls, 251
LINEST, 300

homoscedacity, 246, 247, 249, 250, 266, 268,
274, 281, 283, 291, 354

least squares
CI and PI on fits, 292
confidence interval, 249, 251, 253, 257
covariance of slope and intercept, 353
error on model parameters, 246
error on the value of the function, 262
Excel commands, 251
fix intercept to zero, 284, 286
introduction, 234
linear models, 235
MATLAB commands, 328
ordinary, 237
other models, 298
physics-based models, 303
polynomial models, 283
prediction interval, 266
R², 295
residuals, 80, 85, 247, 283
software tools, 236
SSE, 238
SST, 243
SSxx, 239
SSyy, 239
SSxy, 243
table of LINEST commands, 300
x not assumed certain, 244
least squares (LS), 235
limit of determination (LOD), xi, 12, 14, 18,
152–154, 177, 180, 186, 232, 276, 277,
279, 300, 302, 306, 362

linear regression, see least squares
LINEST, 240
arguments of the function, 325
commands, 251
equivalent MATLAB commands, 328
linked examples
Example 4.2, 144
Example 4.8, 172
Example 5.6, 200
Example 5.7, 208
Example 5.9, 222
Example 6.1, 241
Example 6.2, 249
Example 6.6, 272
Example 6.7, 279
Example 6.8, 280
roadmap, 11

manometer operation, 172, 174, 201, 202, 204
mathematics
dummy variable of integration, 33
ero error function, 35, 325
Gamma function, 44, 348
linear algebra, 283
logarithmic scaling, 359
matrices, 283
partial derivative, 197
MATLAB, 11, 22, 192, 197, 328
commands, 328
equivalent LINEST commands, 328
functions, 328
table of arrays for least squares, 298
models
choosing, 355
certainty of interval and prediction interval
don fits, 292
cubes, 355
error on fit parameters, 290
exponential, 298, 359
first-order response, 300, 363
fitting process, 233
linear fits, 283
logarithmic, 298
parabolas, 355
power-law, 298, 363
second-order fits, 286
uncertainty on, 269

normal distribution, 40, 347, see probability
density functions
Index

- performance limits
  - upper and lower, 152
- piezoelectric sensor, 172
- precision, 2, 3
- versus accuracy, 15
- prediction intervals, 72, 76
- next value of $x$, 70
- of least-squares fit, 269
- probability density function (pdf), 32, 346
  - normal, 7, 37, 39, 397, 348, 350, 352
  - Student’s $t$, 44, 48, 348
- pycnometer, 128, 159, 161, 183

- random error, see replicate error
- random variable, see stochastic variable
- randomization, 78, 82, 83, 86, 161
- reading error, 101
  - determining sensitivity, 112
  - from fluctuations, 113
  - from scale markings, 113
  - from sensitivity, 106
  - sensitivity defined, 107
  - sources, 104
  - standard, 117
  - working with, 126
- worksheet, 321
- rectangular distribution, 120, 121, 351
- regression, see least squares
- replicate error, 20, 43, 46, 59, 66, 67, 69, 70, 77, 78, 89, 91
  - basics, 20
  - worksheet, 321
- resistance temperature detector (RTD), 167, 169, 179, 300
- roundoff error, 4, 90, 322
- rules of thumb
  - calibration error, 7, 10, 149
  - calibration standards, 148
  - limit of determination, 14, 154, 177
  - reading error, 108
  - sensitivity, 108
  - standard error, 6
- sampling distribution, 11, 38, 43, 45, 46, 48, 51, 54, 55
- saturation, 154, 177
- significant figures, 3, 321
  - definition, 321
  - determine with statistics, 50
  - for logarithms, 323
  - limitations, 323
- on error limits, 89
- rounding, 90
- rules, 322
- standard error
  - combining, 123, 157
  - definition, 6
- GUM guidance, 349
- how to standardize, 6
- of replicates, 43
- standard calibration error, 150
- standard reading error, 104, 117
- standard replicate error, 23, 105, 122, 123
- types, 349
- statistics, see stochastic variable
  - basics, 20
- Bessel’s correction, 22
- combined uncertainty, 349
- degrees of freedom, 44
- determining number of significant figures, 50
- GUM, 349
- introduction, 21
- level of confidence, 61
- miscellaneous topics, 346
- population variance, 22, 23
- $s_{y,x}$, 13, 85, 223, 247, 248
- sample mean defined, 21
- sample variance, 22, 23
- sampling, 29
- Type A uncertainty, 107
- Type B uncertainty, 107
- stochastic variable, 28–30
  - continuous, 29
  - discrete, 31
- Student’s $t$ distribution, 44, 46, 52, 91, 117, 327, 348
  - mean and variance of, 352
  - $t_{0.025,v}$ values, 61
- thermocouples, 5, 138, 141, 151, 154, 163
- special limits wire, 164
- standard limits wire, 164, 165
- total sum of squares $SS_{T}$, 243
  - definition, 243
  - truncation, 4, 322
- uncertainty, see errors
  - expanded, 350, see Problem 4.23
  - types, 7, 107
### Index

<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>variance</td>
<td>347</td>
</tr>
<tr>
<td>covariance</td>
<td>184, 263</td>
</tr>
<tr>
<td>covariance matrix</td>
<td>257</td>
</tr>
<tr>
<td>of a sample</td>
<td>22</td>
</tr>
<tr>
<td>variance defined</td>
<td>247</td>
</tr>
<tr>
<td>worksheets</td>
<td></td>
</tr>
<tr>
<td>calibration error</td>
<td>321</td>
</tr>
<tr>
<td>error propagation</td>
<td>192, 321</td>
</tr>
<tr>
<td>reading error</td>
<td>315, 321</td>
</tr>
<tr>
<td>replicate error</td>
<td>321</td>
</tr>
</tbody>
</table>