3.2 Measurement, recording and uncertainty

Name: _____ Class: _____ Date: _____ **Total: 23 marks**

KEY WORDS Accuracy • Precision • Repeatability • Reproducibility • Random effects • Systematic error • Uncertainty • parallax • anomalous reading • half range

Objective

Practise the WPH13 skills in measurement, recording and uncertainty. These are original training tasks grounded in the specification and reviewed assessment demand.

1 Key knowledge and worked examples

Accuracy describes closeness to the true value. **Precision** describes how closely repeated values cluster. Closely clustered results can still all share a systematic offset.

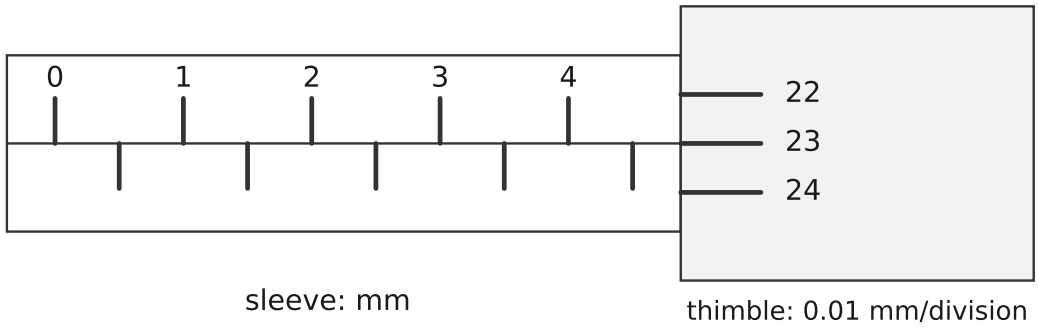
- **Repeatability** concerns similar results using the same operator and method over a short time.
- **Reproducibility** concerns similar results from different operators, apparatus or methods.
- **Random effects** cause unpredictable variation. Repeating and taking a mean can reduce their influence.
- **Systematic error** shifts results in a consistent way. Correct the cause or known offset; repeating does not remove it.
- **Uncertainty** is a reasonable interval associated with a measurement. It is not automatically a mistake or the known size of the error.

■ Read instruments at their resolution

A millimetre ruler has a smallest interval of 1 mm. The specification's standard Vernier calipers resolve 0.1 mm, and its standard micrometer resolves 0.01 mm. Check the instrument shown: a digital display or a different scale may have a different resolution.

For a micrometer, add the visible sleeve reading and the thimble reading. Include a visible half-millimetre sleeve mark when appropriate. Use the ratchet for consistent contact pressure, rather than overtightening the jaws.

For Vernier calipers, read the main scale just before the Vernier zero, then add the aligned Vernier division times its resolution. Check that the jaws contact the intended surfaces without tilting. Do not infer a missing scale from an extracted text description: read the instrument diagram itself.



Read the sleeve before adding the aligned thimble division.

Worked example. The last visible sleeve mark is 4.5 mm. Thimble division 23 aligns with the reference line. Resolution is 0.01 mm and zero error is +0.02 mm.

$$d_{\text{indicated}} = d_{\text{sleeve}} + d_{\text{thimble}} = 4.5 \text{ mm} + 23 \times 0.01 \text{ mm} = 4.73 \text{ mm}$$

$$d_{\text{corrected}} = d_{\text{indicated}} - d_{\text{zero}} = 4.73 \text{ mm} - 0.02 \text{ mm} = 4.71 \text{ mm}$$

Geometry and timing techniques

Avoid **parallax** by viewing a scale along the correct line of sight. Use a set square to transfer a height or position onto a ruler. Keep the ruler parallel to the distance being measured; a sloping ruler measures a different distance.

A light gate measures the blocking time of an interrupting object. With known interrupting length l, speed is $v = l/t$. That gives speed during passage, not acceleration by itself. To find acceleration, measure a change of speed over known time, or use a justified motion equation with additional measured quantities. Do not call l/t acceleration.

A video with known frame rate can reduce reaction-time uncertainty. Count frames between clearly defined start and end events, then use $t = N/f_{\text{frame}}$. The frame interval limits timing resolution. Blurred images or unclear event positions can still limit the result.

■ Tables and significant figures

Put quantity and unit together in each column heading, for example l/mm. Record raw measurements with decimal places matching instrument resolution. Do not add extra digits that the instrument cannot resolve.

Reading	Time / s
1	5.12
2	5.24
3	5.18
4	5.20

These all have the same two decimal places. A calculated mean can be kept with extra digits during working, then reported sensibly. Processed values for plotting are commonly given to three significant figures, unless the question or data requires otherwise. Do not mix 5.1, 5.24 and 5.180 as if they came from one unchanged display.

An **anomalous reading** does not fit the pattern. Check the reading, method and repeat measurement if possible. Do not silently delete the least convenient value. A suspected anomaly needs a reason and a recorded decision.

For one reading, this specification uses half the instrument resolution as the basic absolute uncertainty estimate. This does not mean resolution is the only source of uncertainty. A poorly defined endpoint, reaction time or alignment may make the uncertainty larger.

$$\text{percentage uncertainty} = \frac{\text{absolute uncertainty}}{\text{measured value}} \times 100\%$$

Worked example. A balance displays 135.0 g with resolution 0.1 g.

$$\Delta m = \frac{0.1\ \text{g}}{2} = 0.05\ \text{g}$$

$$\text{percentage uncertainty} = \frac{0.05\ \text{g}}{135.0\ \text{g}} \times 100\% = 0.037\%$$

For repeated values, the specification uses **half range** as an uncertainty estimate:

$$\bar{x} = \frac{\sum x}{N} \qquad \Delta x = \frac{x_{\max} - x_{\min}}{2}$$

Worked example. Repeated times are 5.12, 5.24, 5.18, 5.20 s.

$$\bar{t} = \frac{5.12 + 5.24 + 5.18 + 5.20}{4}\ \text{s} = 5.185\ \text{s}$$

$$\Delta t = \frac{5.24 - 5.12}{2}\ \text{s} = 0.06\ \text{s}$$

$$\text{percentage uncertainty} = \frac{\Delta t}{\bar{t}} \times 100\% = \frac{0.06}{5.185} \times 100\% = 1.2\%$$

Report about (5.19±0.06) s. Keep the unrounded mean in the percentage calculation. The repeat spread is much larger than half a hundredth of a second, so quoting display resolution alone would miss the observed variation.

Unit 3 does not require compounding percentage uncertainties in a calculated quantity. If an uncertainty for that quantity is supplied, use it directly. Do not introduce an advanced propagation rule as a requirement here.

2 Practice

2.1 Distinguish accuracy from precision. Explain why a zero error can give precise but inaccurate results. [3]

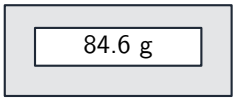
accuracy

precision

2.2 A micrometer sleeve reads 3.5 mm and thimble division 18 aligns with the reference. Its resolution is 0.01 mm and closed-jaw reading is +0.02 mm. Find indicated and corrected values, then the basic single-reading absolute uncertainty. [3]

sleeve: 3.5 mm
thimble: division 18
resolution: 0.01 mm
zero error: +0.02 mm

2.3 A balance reads 84.6 g with 0.1 g resolution. Calculate absolute and percentage uncertainty using this specification's single-reading convention. [3]



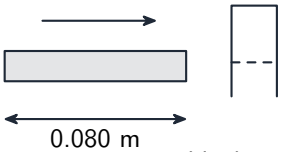
resolution 0.1 g

3 Exam-style questions

3.1 Repeated times are 6.12, 6.24, 6.18, 6.20 s. Calculate the mean, half range and percentage uncertainty. A student reports 6.18500 ± 0.005 s. Give two criticisms. [5]

time / s			
6.12	6.24	6.18	6.20

3.2 A light gate records a car blocking time of 0.040 s. Its interrupting length is 0.080 m. Find the passage speed. Explain why this alone does not give acceleration, and describe an additional measurement route. [4]



blocking time 0.040 s

3.3 A group gets five closely clustered wire diameters with one micrometer. Another group using a different micrometer obtains a consistently larger mean. Explain which quality the first group shows and which wider check is being made. Suggest a cause, a check and why deleting the larger mean is unsuitable. [5]

Solutions

Original-task allocations: B1 = one point, M1 = one method mark, A1 = one accuracy mark.

2.1 Accuracy concerns closeness to the true value. Precision concerns clustering of repeated values. A fixed zero offset can shift all closely clustered results away from the true value.

2.2 $d_{ind} = 3.5 + 18 \times 0.01 = 3.68$ mm. Subtract the positive zero error: $d = 3.68 - 0.02 = 3.66$ mm. Half resolution gives $\Delta d = 0.005$ mm, before considering other method uncertainties.

2.3 Half resolution: $\Delta m = 0.1/2 = 0.05$ g. Percentage $= (\Delta m/m) \times 100\%$. $0.05/84.6 \times 100 = 0.059\%$.

3.1 Mean $\bar{t} = (6.12 + 6.24 + 6.18 + 6.20)/4 = 6.185$ s. Half range $\Delta t = (6.24 - 6.12)/2 = 0.06$ s. Percentage $= 0.06/6.185 \times 100 = 0.97\%$. The quoted mean has unjustified extra digits for the readings; 0.005 s uses half resolution but ignores the much larger repeat spread. Report about (6.19 ± 0.06) s.

3.2 $v = l/t = 0.080/0.040 = 2.0$ m s^{-1}. One speed is not a change in speed per time. Use two gates to find two passage speeds and measure the elapsed time between the corresponding speed positions/events, then $a = \Delta v/\Delta t$ for the stated mean acceleration.

3.3 Within-group clustering demonstrates precision/repeatability under the same method. Comparison across operators/apparatus examines reproducibility. A micrometer zero offset or different contact pressure could cause the discrepancy. Check both zeros/calibration or use a controlled ratchet technique on the same positions. A difference is evidence to investigate, not a reason to discard the inconvenient group without justification.