

Units and Measurement · Concept 3

Arithmetic Operations with Significant Figures

Governing the precision of mathematical results.

The Absurdity of Calculators

$$4.237 \text{ g} \div 2.51 \text{ cm}^3 =$$

$$1.688047800876 \text{ g/cm}^3$$

A calculated result cannot be more accurate than the original measured values on which it is based.

The Bifurcation of Rules

Multiplication & Division

Count the total
significant figures.

Result matches the input
with the fewest sig figs.

Addition & Subtraction

Count the
decimal places.

Result matches the input
with the fewest decimal
places.

Never mix these two rules.

Worked Example 1.1

Each side of a cube is measured to be 7.203 m. What are the total surface area and volume?

$$\text{Length} = 7.203 \text{ m}$$

4 sig figs

$$6 \times (7.203 \text{ m})^2 = 311.299254... \text{ m}^2$$

$$311.3 \text{ m}^2 \quad (\text{Rounded to 4 sig figs})$$

$$(7.203 \text{ m})^3 = 373.714754... \text{ m}^3$$

$$373.7 \text{ m}^3 \quad (\text{Rounded to 4 sig figs})$$

Key Insight: Exact numbers (like the '6' in the area formula) have infinite sig figs and do not constrain precision.



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$$E=mc^2$$



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Worked Example 1.2

5.74 g of a substance occupies 1.2 cm³. Express its density.

$$\begin{aligned}
 \text{Mass} &= 5.74 \text{ g} && \text{3 sig figs} \\
 \text{Volume} &= 1.2 \text{ cm}^3 && \text{2 sig figs} \leftarrow \text{Limiting Factor} \\
 \text{Density} &= \frac{5.74}{1.2} = 4.78333... \text{ g/cm}^3 \\
 &\downarrow \\
 &4.8 \text{ g/cm}^3 \text{ (Rounded to 2 sig figs)}
 \end{aligned}$$

Key Insight: The least precise measurement (1.2 cm³, 2 sig figs) strictly dictates the precision of the entire result.

The Addition Rule (Decimal Alignment)

436.32	g	(2 decimal places)
+ 227.2	g	(1 decimal place ← Least precise)
+ 0.301	g	(3 decimal places)
663.821	g	(Raw sum) •

Rounds to **663.8 g**

The Subtraction Anomaly

$$\begin{array}{r}
 0.307 \text{ m} \quad (3 \text{ sig figs, 3 decimal places}) \\
 - 0.304 \text{ m} \quad (3 \text{ sig figs, 3 decimal places}) \\
 \hline
 0.003 \text{ m} \quad \left. \vphantom{0.003 \text{ m}} \right\} (1 \text{ sig fig, 3 decimal places})
 \end{array}$$

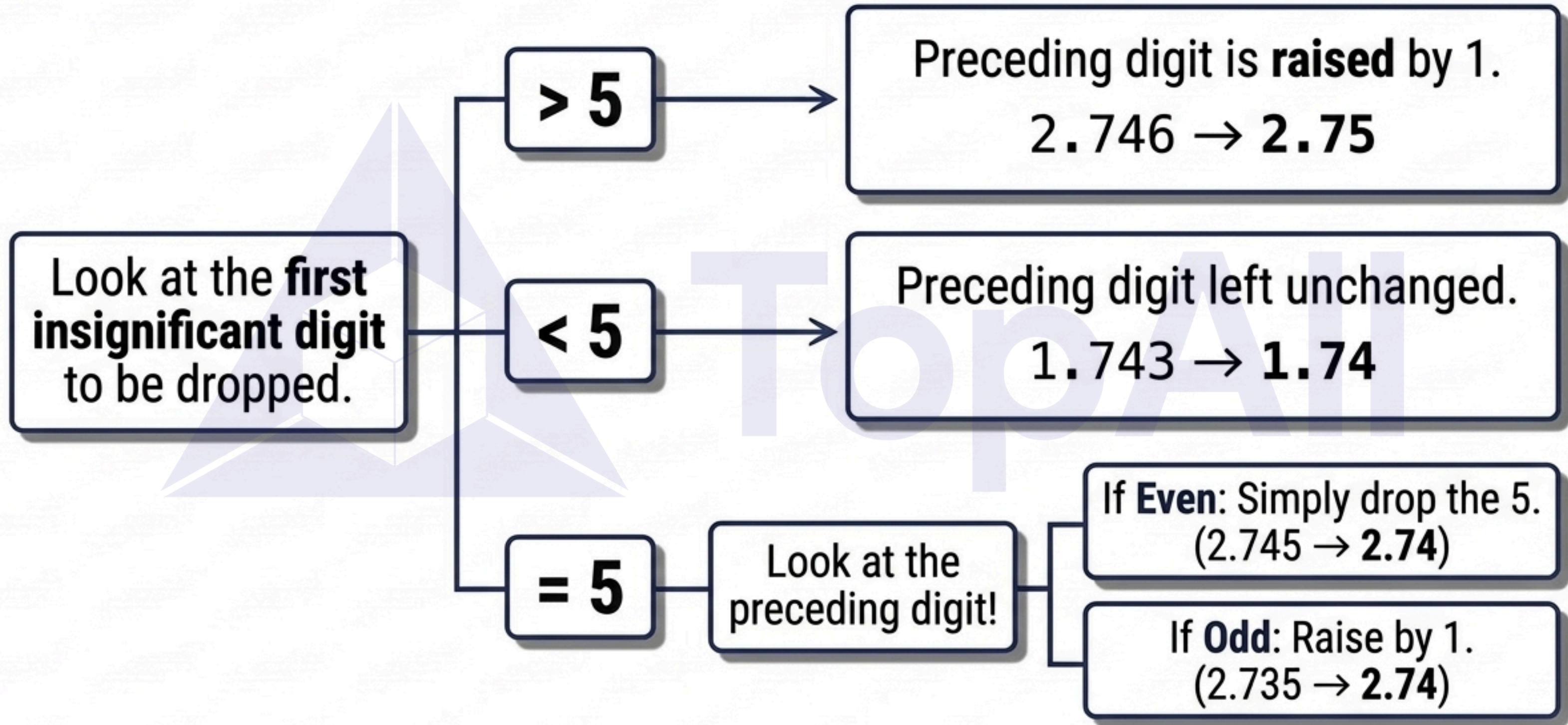
In subtraction, **significant figures** can be **drastically reduced**.



If we blindly applied the multiplication rule (forcing 3 sig figs), we would erroneously write $3.00 \times 10^{-3} \text{ m}$, falsely inventing precision that doesn't exist.

Conclusion: Addition and subtraction must lock to decimal places, not significant figure counts.

Executing the Cut-off: Rounding Rules



Multi-Step Calculations

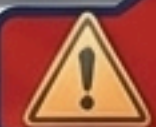
Rule: Retain one extra digit (more than the least precise measurement) in intermediate steps.

Original Value: **9.58** (3 sig figs)

**Path A
(Premature Rounding)**

Round to 3 sig figs → **0.104**

Take reciprocal again:
 $1 / 0.104 = \mathbf{9.62}$



(Error introduced!)

Step 1 (Reciprocal):
 $1 / 9.58 = \mathbf{0.10438...}$

**Path B
(Correct)**

Keep extra digit → **0.1044**

Take reciprocal again:
 $1 / 0.1044 = \mathbf{9.58}$

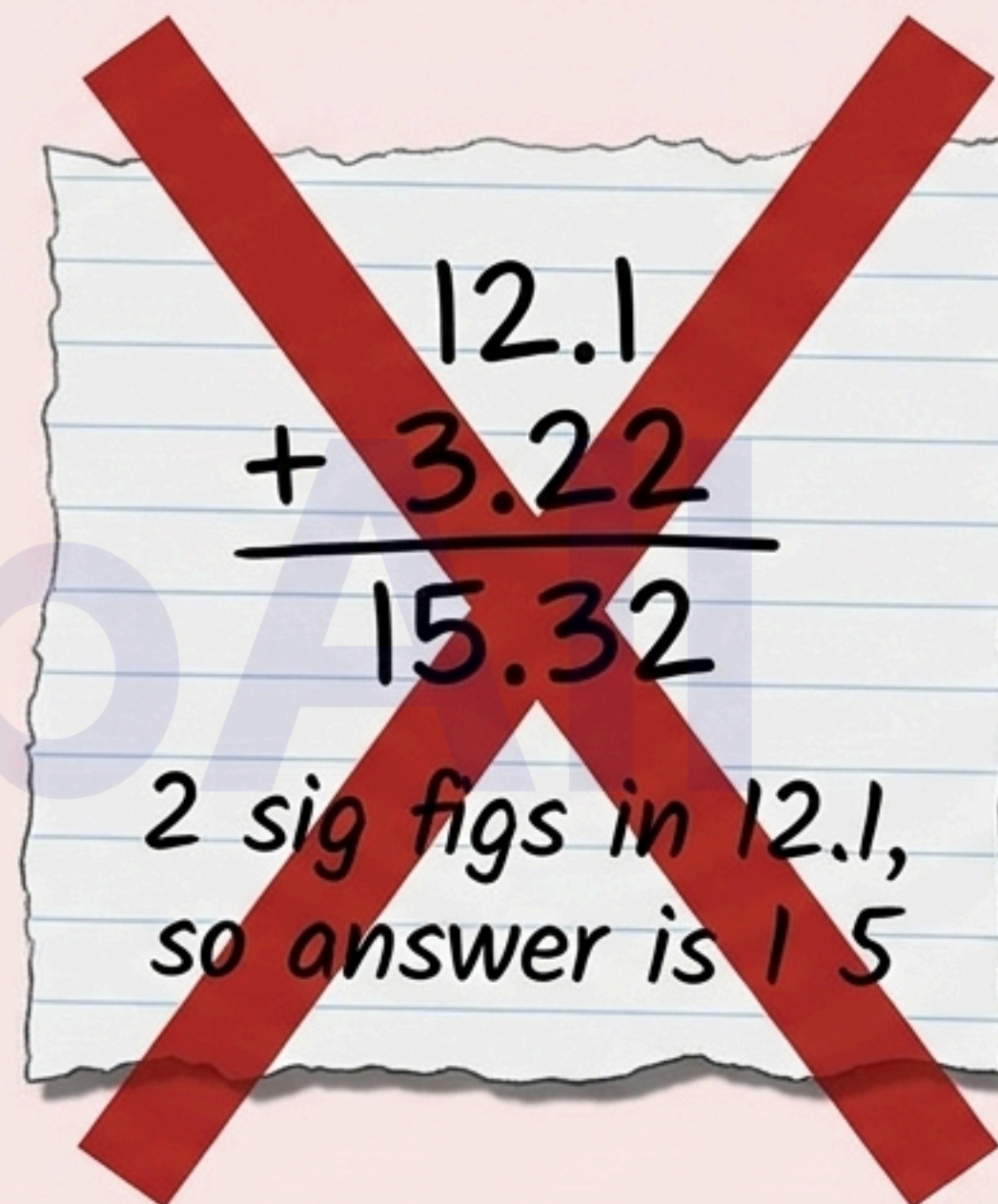


(Original value retrieved)

TRAP ALERT

Don't use the multiplication rule for addition/subtraction.

They are governed by completely different precision laws.


$$\begin{array}{r} 12.1 \\ + 3.22 \\ \hline 15.32 \end{array}$$

2 sig figs in 12.1,
so answer is 15

✓ Key Takeaways

- **Multiply/divide:** count sig figs. Result matches the input with the fewest.
- **Add/subtract:** count decimal places. Result aligns with the least precise decimal column.
- **Never swap** the two rules.
- In **intermediate** calculation steps, **retain one extra digit** to prevent rounding errors.
- **When rounding exactly 5:** round to the nearest even number.



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