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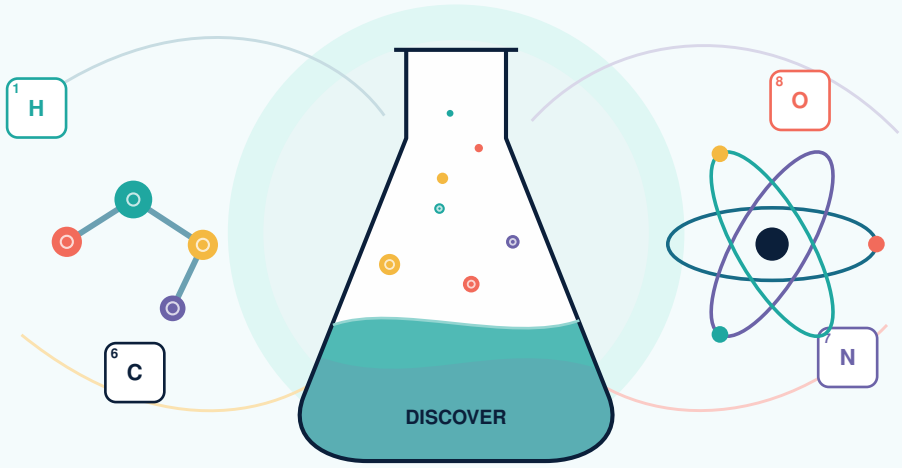
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Chemistry

for Beginners

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Clear explanations • Worked examples • Visual models • Detailed solutions

Reza Nazari

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Chemistry for Beginners

The Ultimate Step by Step Guide to Mastering Chemistry

First edition

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CHAPTER

1

GETTING STARTED

Chemistry and Scientific Problem-Solving

Chemistry connects what you can observe to particles you cannot see and symbols you can use to explain and predict change.

By the end of this chapter, you should be able to:

- ✓ describe a chemical event at macroscopic, particle, and symbolic levels;
- ✓ distinguish observations, inferences, hypotheses, laws, theories, and models;
- ✓ identify independent, dependent, and controlled variables and explain the purpose of a comparison condition; and
- ✓ solve a quantitative chemistry problem by showing units and checking whether the result is reasonable.

1.1 What Chemistry Explains

Chemistry is the study of matter—what it is made of, how its particles are arranged, what properties it has, and how it changes. Chemistry is happening when bread browns, an iron railing rusts, a tablet dissolves, or a battery produces electric current. In each case, observable behavior is connected to particles, energy, and the forces between particles.

Chemistry also connects with other sciences. It overlaps biology when enzymes speed reactions, physics when energy and forces are analyzed, geology when minerals form, and medicine when a drug interacts with the body. Substances and formulas are the vocabulary; the larger purpose is to explain and predict how matter behaves.

Three Ways to Represent One Event

Chemists move among three complementary views:

- The **macroscopic view** describes what can be directly observed or measured.
- The **particle view** explains the atoms, ions, or molecules responsible for the observation.
- The **symbolic view** represents the event with chemical symbols, formulas, equations, graphs, or numbers.

Consider melting ice. Macroscopically, solid water becomes liquid water. At the particle level, the water molecules remain H_2O but become less restricted in their motion and arrangement. Symbolically, the change can be written

$$H_2O(s) \rightarrow H_2O(l).$$

Moving accurately among these three views is one of the central skills of chemistry.

> **Models Are Useful, Not Literal**
>
> A scientific model highlights selected features of a system and leaves others out. A ball-and-stick model shows molecular connectivity and approximate shape, but its sticks are not tiny physical rods. A Bohr diagram helps beginners organize electrons, although electrons in a modern atomic model do not travel like planets on fixed circular tracks. A useful model earns trust by explaining evidence and supporting predictions. Literal resemblance is secondary.

1.2 Evidence, Explanations, and Experiments

An **observation** reports what is detected with the senses or an instrument. An **inference** is an interpretation of what that observation may mean. For example, "a reddish solid formed on the metal" is an observation; "dissolved ions gained electrons" is a particle-level inference.

Observations may be **qualitative**, such as a color change, or **quantitative**, such as a temperature increase of 3.8 °C. Quantitative observations must include units because a number without a unit does not identify the measured quantity.

A **hypothesis** is a tentative, testable explanation for a focused question. It should lead to a prediction that can be compared with evidence. Real investigations loop. Scientists revise questions, improve methods, examine unexpected evidence, and test new predictions as their understanding develops.

Variables and Fair Comparisons

In a controlled investigation, the **independent variable** is deliberately changed and the **dependent variable** is measured in response. **Controlled variables** are other factors kept as constant as practical. A **control condition**, also called a comparison condition, provides the baseline needed to interpret a result.

Repeated trials reveal ordinary variation and make averages more informative. Biased methods stay biased, though, and changing several important variables at once blurs the cause of a result. In a fair test, the plausible competing causes are controlled closely enough for the intended comparison.

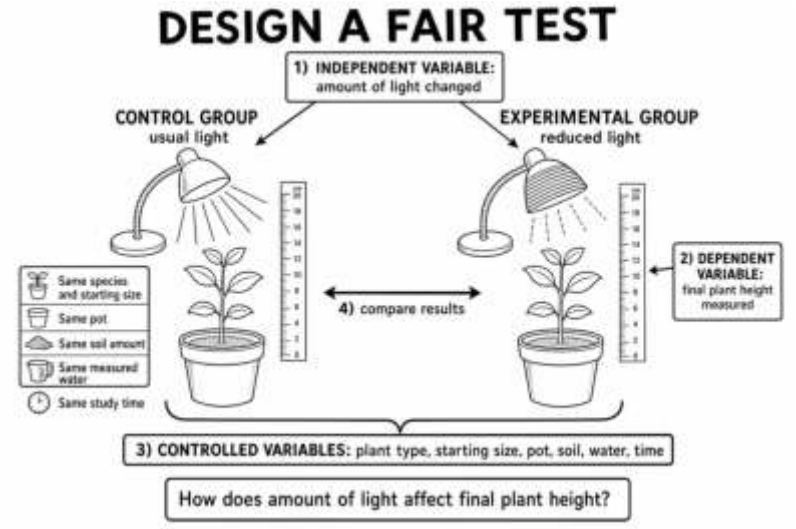


Figure 1.1. A controlled comparison deliberately changes one factor while holding important competing factors steady.

Laws, Theories, and Models

A scientific **law** summarizes a repeatedly observed relationship, often in words or an equation. A **scientific theory** is a broad, evidence-supported explanation that connects many findings and generates new predictions. Laws and theories remain different kinds of scientific knowledge: laws describe patterns, whereas theories explain why those patterns occur. Stronger evidence or a wider range of observations may refine either one.

1.3 A Reliable Quantitative Problem-Solving Routine

A useful routine is **Known–Wanted–Relationship–Solve–Check**.

1. **Known:** Record the given quantities with their units.
2. **Wanted:** State the quantity and unit the problem asks for.
3. **Relationship:** Choose an equation or conversion that connects the known and wanted quantities.
4. **Solve:** Substitute values, keep units visible, and calculate.
5. **Check:** Examine the unit, sign, size, and number of reported digits.

Units carry part of the reasoning. If a density calculation produces grams rather than grams per milliliter, the unit reveals that the setup is incomplete.

Example 1:

A sample has a mass of 18.0 g and a volume of 6.0 mL. What is its density?

☞ Density tells you how much mass is packed into each milliliter, so divide the sample's 18.0 g mass by its 6.0 mL volume:

$$d = \frac{18.0\,\text{g}}{6.0\,\text{mL}} = 3.0\,\text{g/mL}.$$

The units reduce to grams per milliliter, exactly what density requires, and $18 \div 6 = 3$ makes the size of the answer easy to trust. Report two significant figures because the volume, 6.0 mL, has two.

3.0 g/mL

Example 2:

A class suspects that warm water dissolves a sugar cube faster than cold water. What fair test could isolate water temperature as the independent variable and measure dissolving time reliably?

☞ Use sugar cubes of equal mass, equal water volumes, identical containers, and the same stirring procedure. Deliberately change the water temperature, measure dissolving time in seconds, repeat each condition, and compare both the average and the trial-to-trial variation. Water temperature is the independent variable. Dissolving time is the dependent variable.

1.4 Build Explanations from Claims and Evidence

A useful chemistry explanation has three parts. The *claim* answers the question, the *evidence* identifies the relevant observations or data, and the *reasoning* connects that evidence to a particle model or chemical principle. Naming a result without the connection is a conclusion, not yet an explanation.

Three Views of Chemistry

What you observe	What particles do	How chemistry writes it
An effervescent tablet in water shrinks while bubbles form and the sealed container's mass remains constant.	Dissolved reactant particles rearrange into new particles, including gas molecules that remain inside the sealed system.	A balanced equation represents atom conservation; the measured total mass before and after should agree within experimental uncertainty.

✏ **Read the Evidence: Which Claim Is Supported?**

Equal masses of one tablet are added to 100 mL of water at 10, 25, and 40°C. Mean reaction times are 185, 91, and 44 s. The evidence supports the limited claim that reaction time decreased as temperature increased under these conditions. It does not by itself prove that every reaction behaves this way or identify the molecular mechanism.

1.5 Design a Fair and Informative Investigation

Begin with a focused question that names the factor changed and the response measured. Choose a comparison range, keep important conditions controlled, and define how the endpoint will be detected. Repetition reveals variation; it does not rescue a design in which several factors changed together. More decimal places also do not repair a biased method.

Design feature	Question to ask	Why it matters
independent variable	What is deliberately changed?	defines the comparison
dependent variable	What is measured, and in what unit?	makes the response testable
controls	What else could affect the response?	reduces competing explanations
repeats	How variable are trials under one condition?	reveals consistency
comparison condition	What provides the baseline?	gives a result meaning

Example 3:

A metal strip placed in a blue solution becomes coated with a reddish solid, and the blue color fades. "A reddish coating appeared" is an observation. "Metal atoms transferred electrons to dissolved ions" is an inference that must be supported by a redox model and, ideally, further tests. The inference may be strong, but it should not be reported as if it were directly seen.

Report the coating and color change as observations; label the electron-transfer account as the model-based explanation.

2.7 Estimate Before Trusting the Calculator

Estimation catches misplaced decimals, wrong signs, and reversed operations. For

$$\frac{39.8}{4.92},$$

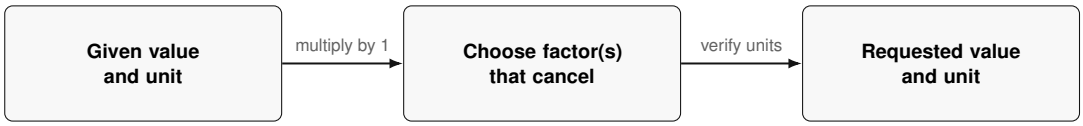
use nearby convenient values:

$$\frac{40}{5} \approx 8.$$

A calculator result near 8 is plausible. A display near 80 points to an entry or decimal-place error. Also check the sign, unit, and whether the operation should make the result larger or smaller. A calculator evaluates a wrong expression perfectly.

2.8 Treat Units as Algebra

Dimensional analysis works because a conversion factor is a ratio of equal quantities. Its value is one, so it changes the unit representation without changing the physical amount. Write the desired unit first, then orient each factor so an unwanted unit cancels.



Unwanted units must appear once above and once below.

Dimensional-analysis road map. The unit path is part of the reasoning: a number is not finished until its units cancel to the quantity requested.

Example 4:

A liquid flows at 35.0 mL/min for 2.50 h. Convert time and multiply:

$$2.50\ \text{h}\left(\frac{60\ \text{min}}{1\ \text{h}}\right)\left(\frac{35.0\ \text{mL}}{1\ \text{min}}\right) = 5.25 \times 10^3\ \text{mL}.$$

Hours and minutes cancel, leaving the requested volume unit. Three significant figures are justified by the measured inputs.

5.25×10^3 mL, or 5.25 L.

2.9 Rearrange Before Substituting

Isolate the requested symbol while the equation is still readable. For $q = mc\Delta T$, where q is energy transferred, m is mass, c is specific heat, and ΔT is temperature change, solving for c gives

$$c = \frac{q}{m\Delta T}.$$

Only then substitute numbers. This reduces calculator-entry errors and makes the expected unit visible. Parentheses matter: $q/(m\Delta T)$ is not the same as $q/m \times \Delta T$.

Powers, roots, and logarithms undo one another. If $10^x = y$, then $x = \log y$. Chemistry uses this relationship in pH and in quantities that span many powers of ten. A difference of 2 on a base-10 logarithmic scale corresponds to a factor of $10^2 = 100$, not a factor of 2.

Example 5:

A measured concentration changes from 0.800 M to 0.620 M. The percent change is

$$\frac{0.620 - 0.800}{0.800} \times 100 = -22.5\%.$$

The negative sign indicates a decrease. Dividing by the final value would answer a different question; the original value is the stated reference.

A 22.5 percent decrease.

2.10 Extract Meaning from a Graph

On a graph of y against x, slope is $\Delta y/\Delta x$ and therefore has units. Intercept is the predicted value of y when $x = 0$, if that point has physical meaning. A straight pattern supports a constant rate of change over the measured range; it does not automatically justify distant extrapolation.

✏ Read the Evidence: Slope with Units

A calibration gives signals 0.12, 0.31, 0.50, and 0.69 for concentrations 0.00, 0.20, 0.40, and 0.60 M. Using the endpoints, the approximate slope is

$$\frac{0.69 - 0.12}{0.60 - 0.00} = 0.95 \text{ signal unit } \mathrm{M}^{-1}.$$

An unknown signal of 0.405 lies between the middle readings, so interpolation is more defensible than extrapolation.

2.11 Round Once and Report Honestly

Keep guard digits during a multi-step calculation and round the final result. Significant figures are not a substitute for measurement uncertainty, but they prevent the answer from claiming more precision than the inputs support. For addition or subtraction, the last reliable decimal place controls; for multiplication or division, the number of significant figures controls.

Operation	Reporting rule	Quick diagnostic
+ or −	round to the least precise decimal place	align decimal points
× or ÷	round to the fewest significant figures	count supported digits
multi-step	keep guard digits; round the final result once	estimate before reporting

Precision decision table. The operation determines the reporting rule; calculator display length does not determine measurement precision.

Three Views of Chemistry

What you observe	What particles do	How chemistry writes it
A measured gas sample occupies 24.0 mL under the stated conditions.	The volume describes space occupied by a large population of moving particles, not the size of one particle.	$24.0 \text{ mL}\left(\frac{1 \text{ L}}{1000 \text{ mL}}\right) = 0.0240 \text{ L}$ preserves the amount and its measurement precision.

✗ Fix the Work: False Calculator Precision

A student reports 12.4 g/3.0 mL = 4.133333333 g/mL. The calculator digits exceed the evidence. Because 3.0 mL has two significant figures, the supported result is 4.1 g/mL. Keep the unrounded value only as an intermediate value when another operation follows.

✓ Memory Check

Before using a calculator, write an estimate for sign and order of magnitude, show a unit-cancellation path, and state the rounding rule that will control the final result.

✓ Quick Review

Carry units from setup to result. Distinguish exact numbers from measurements, match exponents before adding scientific notation, and keep guard digits until the final rounding step. Read graph axes before interpreting slope or trend. An estimate should agree with the final sign and order of magnitude.

Chapter 2 Practice

1. Write 0.00072 in scientific notation.

   A 7.2×10^{-5} **B** 7.2×10^{-4}
   C 72×10^{-4} **D** 0.72×10^{4}

2. How many significant figures are in 0.04050?

   A 2 **B** 3
   C 4 **D** 5

3. A solution contains 12 g of solute in 60 g of solution. What is the mass percent?

   A 5% **B** 20%
   C 48% **D** 72%

4. Rearrange $d = m/V$ to solve for V.

   A $V = m/d$ **B** $V = md$
   C $V = d/m$ **D** $V = m - d$

5. **Select all that apply**

   Which statements are correct?

   □ A. Exact counted numbers do not limit significant figures.
   □ B. Extrapolation stays between measured points.
   □ C. Units can expose a wrong setup.
   □ D. Round every intermediate calculator step aggressively.

6. **Open response**

   A student calculates 24.6 g/3.0 mL and reports 0.122 mL/g. State two reasons to reject the result.

7. A solution cools from 22.5 °C to 17.0 °C. What is $\Delta T = T_{\text{final}} - T_{\text{initial}}$?

   A −5.5 °C **B** +5.5 °C
   C 39.5 °C **D** −39.5 °C

8. Write 4.20×10^{-3} in ordinary notation.

   A 0.000420 **B** 0.00420
   C 4200 **D** 42,000

9. Evaluate and normalize $(4.0 \times 10^{5})(3.0 \times 10^{-2})$.

   A 1.2×10^{4} **B** 12.0×10^{7}
   C 1.2×10^{3} **D** 7.0×10^{3}