Chapter 1: The Nature of Science

A scientific theory is a structured explanation of a set of facts or a phenomenon, arrived at by thorough examination and tested in accordance with the scientific method.

A scientific law is a statement that has been deduced from empirical evidence.

- A scientific theory sets out to provide an explanation for how or why an aspect of nature behaves as it does.
- A law describes what always happens under certain circumstances.
- **Laws do not change much unless an experimental error is discovered**
- **Theories are always provisional or incomplete and they are refined and improved as new data becomes available.**

The Scientific Method

The scientific method is a systematic, evidence-based approach that scientists use to gather, analyse and interpret data.

Scientists…..

1. Make observations.
2. Develop and refine a research question.
3. Research.
4. Formulate a hypothesis.
5. Develop a testable prediction.
6. Design, plan and carry out an experiment to gather data.
   - *The experiment must be a fair test.*
   - *Safety considerations must be taken into account.*
   - *Suitable equipment should be chosen.*
   - *Troubleshoot along the way – make changes if necessary.*
   - *Carry out the same experiment multiple times to ensure reliable, accurate results.*
7. Analyse data.
8. Draw conclusions.
9. Accept or reject hypothesis.
10. Communicate results.

The purpose of carrying out an experiment is to **find data to either support or reject a hypothesis.**

Science as a global enterprise

Science is a global enterprise in which scientists from all over the world collaborate to share knowledge, solve problems and advance our understanding of the world.

It is important for scientists to **publish their research** so that others can learn from their work and build on it.

Scientists **communicate** in a variety of ways:

- Academic journals (e.g. *Nature, Science, The New England Journal of Medicine).*
- Presentations at scientific conferences.
- Media (including social media).

International conventions

1. International convention can refer to **internationally agreed systems or standards.** e.g. SI units in measurement.

2. However, international conventions can also refer to **international agreements about a specific issue**, e.g. The Paris Agreement.

Peer review

Peer review is the process by which scholarly work of all kinds is evaluated by experts.

Scientists:

- Conduct research (an experimental investigation or a different type of study, e.g. a survey) to gather data.
- After analysing their findings, they then write a research article and submit it to a scientific journal.
- The editor of the journal may reject the article immediately, or, if considering publication, will send this article to other scientists (who work in the same field) for peer review.

Peer review involves other scientists reading the article, evaluating it and providing feedback to the editor. If the article is not appropriate for publication it is rejected.

Although peer review is time-consuming, it is an **important safeguard** to ensure the validity and reliability of research and to protect against the spreading of inaccurate information.

Repeatability & Reproducibility

Repeatability: Having obtained a result from an experiment, scientists can conduct the same experiment again, in the same location, with the same setup, and produce the exact same (or very similar) results.

Reproducibility: Different scientists, in different locations, using different instruments can produce the same (or very similar) results as the original scientists.

Evaluating sources of information

C – Credibility (Is the source trustworthy? Does it come from a reputable journal, institution, or organisation? Who are the authors? Are they experts in this field?)

A – Accuracy (Are the claims backed by evidence? Is the data reliable, consistent, and free from errors?)

R – Relevance (Is the information directly related to your question or research?)

D – Date (When was it published? Science evolves quickly, so older information may no longer be valid or accurate).

S – Sources (Are references provided? Reliable information cites evidence or secondary sources to back up claims).

Bias

Scientific bias refers to a lack of objectivity or a tendency to see or interpret evidence in ways that do not match what can be observed or concluded scientifically.

- **Reporting bias:** Occurs when certain evidence is ignored or not reported..
- **Selection bias:** Occurs when a sample is chosen that doesn't represent the target population.
- **Confirmation bias:** Occurs when researchers focus only on information that supports their beliefs or expectations and ignore other information.
- **Researcher bias:** Occurs when the personal views or interests of the researcher influence the outcome.
- **Social or cultural bias:** Bias that is due to the researcher's social or cultural point of view.

The Impact of Science on Society

	Positive	Negative
Health	Pharmaceuticals, e.g. antibiotics. Water treatment. Surfactants, e.g. soap,	Chemicals in plastics and pesticides affect human and animal health. Medicines can have negative side-effects. Chemical warfare is fatal.
Technology	Lithium-ion batteries e.g. in electric vehicles, smartphones, laptops etc. New materials, e.g. fullerenes and carbon nanotubes	The production of lithium-ion batteries is not yet environmentally friendly
Sustainability	Environmentally friendly materials Energy-efficient processes Renewable alternatives to fossil fuels Advanced recycling techniques	Hazardous waste, pesticides and plastic pollution (including microplastics) can lead to habitat loss.

The Impact of Society on Science

Society directly influences scientific research and scientists engage in research that reflects societal needs, challenges and priorities, e.g. COVID-19 pandemic, climate change.

Models

A model is a simplified representation of reality that is used to understand, explain or predict phenomena.

Models can be:

- **Diagrams**
- **Equations** (e.g. the ideal gas equation)
- **Simulations** are all examples of models.
- **Physical models**
- **Conceptual models** (e.g. Bohr's model of the atom).

As more experiments are carried out and more data becomes available, **models can be refined or modified.** This is a fundamental part of science.

Limitations of models

All models have limitations.

- **Oversimplification:** Models often simplify complex systems by leaving out important details. This makes them easier to understand, but can make them less accurate. We must remember when using them that models are usually approximations.

- **Assumptions:** Many models make assumptions (which can lead to inaccuracies and errors).

- **Static vs. Dynamic:** Diagrams and physical models cannot accurately capture the dynamic, 3-D nature of molecules.

Chemical phenomena

Chemists (and you!) must be able to **relate observable phenomena** to the **chemical processes at the atomic, sub-atomic or molecular level,** i.e. link the macroscopic world with the microscopic.

	Macroscopic	Microscopic
Evaporation	The water 'disappears'.	Water molecules gain enough energy to change state (liquid → gas).
Filtration	The residue is caught on the filter paper and the filtrate passes into the conical flask.	We can visualise the residue and filtrate being made of particles; insoluble solid particles are unable to pass through the filter paper, while the liquid particles are able to pass through.
Chemical reactions	A product is formed.	Particles collide with sufficient energy and proper orientation, leading to effective collisions and reactions.