Chapter 3

Forming a Hypothesis

All scientific enquiries start from a question that the scientist has in his/her mind. The question is related to some event or phenomenon that occurs in nature or society. He asks questions like “How did it happen?”, “When did it happen?”, “Why does it happen?” etc. The whole enterprise of science is to find answers to questions like this.

Given such a question, the usual method of science is to form intelligent guesses about the possible answer, and then to test the correctness of the guesses. This makes the method of scientific investigation quite similar to the method adopted by a detective, called in to find the perpetrator of a crime. On the first day the detective visits the crime scene and looks for clues—footprints, fingerprints, items misplaced, narratives of witnesses, etc. Then he forms intelligent guesses about the course of events leading to the crime. These are not wild guesses: each has to satisfy the clues he has found. So long as the clues are insufficient, a number of guesses can be formed that are consistent with the clues. Now the detective faces the task of eliminating the wrong guesses by looking for more clues. But now he searches in a directed way: If the guess number 1 is correct, an object A should be found in a particular place; if the guess number 2 is correct, then the person B should visit a particular spot, etc. The detective then checks these out, and that way he eliminates the wrong guesses. Finally, when he has eliminated all but one guess, he is ready to identify the criminal.

Scientific investigation proceeds in much the same way. Faced with a scientific question, scientists form intelligent guesses, called hypotheses (plural of the word ‘hypothesis’). These are scientifically formulated guesses about the possible answer to the question. A hypothesis is the proposed explanation of a phenomenon, obtained by indicating a possible causation or correlation.

In order to propose a hypothesis, a scientist has to follow a procedure.

3.1 To look for clues

Faced a question, a scientist first looks for clues. Either he performs observation of the object in question, performs some experimental measurements, or simply reads up facts about the object or phenomenon that other people have found. These form the primary clues. For example, when a patient visits a doctor, he reports the manifestations of the ailment that he or she feels, i.e., the symptoms. For the doctor, these form the ‘clues’.

3.2 The requirements for a hypothesis to be ‘scientific’

The scientist then proceeds to guess what possible answers to the question could be. But in order for a guess answer to be scientific, certain necessary criteria have to be satisfied. Only then a guess answer is called a ‘hypothesis’.

3.2.1 It should be consistent with the clues

The hypothesis should account for the facts regarding the event or phenomenon that have been found already. If some aspect of the available information contradicts the proposed explanation, the hypothesis is not considered to be scientifically formulated.

However, it is possible that at the time of formulation some causal pathway is not known and due to that missing knowledge, an available clue may appear to contradict the hypothesis. In such a situation the scientist has to clearly state that the hypothesis is inconsistent with one of the clues, and the hypothesis will pass the test only after the contradiction is resolved. Till then, science can proceed with that 'provisional' hypothesis.

3.2.2 It should satisfy the demand of materialism

The hypothesis must explain the event or phenomenon in terms of material processes and phenomena. One cannot invoke the idea of magic, miracle, or supernatural power to explain some event or phenomenon.

3.2.3 It should have some testable predictions

The way to eliminate the wrong hypotheses it to test them through further observation and/or experimentation. In order for this programme to work, each hypothesis must be amenable to objective tests, that is, it should have clearly stated predictions that can be observationally or experimentally checked.

3.2.4 It should be falsifiable

A hypothesis is not considered scientific unless it is falsifiable. Falsifiability of a hypothesis is the inherent possibility that it can be proved false. A statement is considered falsifiable if it is possible to conceive of an observation or a specific outcome of an experiment which negates the statement in question.

This implies that, while proposing the hypothesis, the scientist should clearly state which observations or experimental outcomes will definitely prove the hypothesis to be false. If these are really observed, the hypothesis will be rejected.

Note that the whole programme of science is to formulate as many hypotheses as possible that are consistent with the clues, and then to perform directed tests to detect and reject the wrong ones. Therefore it is vitally important to know under what circumstances a particular hypothesis can be proved false.

Note also that under no circumstances a hypothesis can really be proved absolutely true. This is because of the possibility that a future observation can reveal information that will be inconsistent with the explanation that the hypothesis offers. That is why science is based not on 'proving' hypotheses, but on *rejecting* wrong hypotheses.

3.3 The desirable criteria

The above are mandatory conditions of proposing a hypothesis. In addition there are a few characters that a hypothesis should preferably have. Where there are a few alternative hypotheses to explain a phenomenon, these are the issues one checks in order to form an order of preference in performing checks.

Fruitfulness: It is desirable that a hypothesis should be testable using a number of alternative experiments. Theorefore, other things being equal, the best hypothesis is the one that makes the largest number of testable predictions that are not obtainable from background theory alone.

Scope: If you are proposing a hypothesis to explain some event or phenomenon, and it helps explain only that event and nothing else, it will not be very useful. A good hypothesis should throw light on more than what it is intended to explain. That is why, other things being equal, the best hypothesis is the one that explains and predicts the most diverse phenomena.

Simplicity: In many situations scientists propose many hypotheses, some of which are simple, and some complex. Here 'simplicity' implies that the hypothesis makes very few a-priori assumptions. Other things being equal, the best hypothesis is the one that makes the fewest assumptions.

Conservatism: Science has already built up considerable knowledge about the material world, and a hypothesis should be based on that knowledge. However, there may be situations where a hypothesis may rest on a premise that we do not yet know to be true. Such hypotheses would naturally be seen with suspicion. This does not mean that such hypothesis should not be proposed, because in the end that assumption may turn out to be true. Still the general undestanding is that, other things being equal, the best hypothesis is the one that fits best with established knowledge.

3.4 Null and alternative hypothesis

Hypotheses are always formulated in pairs: the null hypothesis and the alternative hypothesis. The null hypothesis is the statement that the proposed effect does not occur and the alternative is that the proposed effect occurs. These are denoted by the symbols H_0 and H_1 respectively.

3.5 Testing of hypothesis

As we have seen above, the proponent of each hypothesis has to state the predictions of the hypothesis, in particular which observations would render the hypothesis false. The testing of each hypothesis, for obvious reasons, depends on these predictions.

Most hypotheses are tested using statistical techniques. We shall learn the techniques of statistical hypothesis testing in Chapter **??**.

3.6 An example: Origin of the solar system

In the 18th century people started asking the question “How did the solar system originate?” By then people had noticed the outstanding ‘orderliness’ of the solar system. The members of the solar system move in a common direction in elliptical orbits. The orbits for all the planets lie in almost the same plane. Thus, the solar system is practically ‘flat’. In addition to that the Kepler’s laws regarding the motion of planets were also known. Thus when scientists started pondering on the issue of the origin of the solar system, these formed the initial ‘clues’.

On that basis, two major hypotheses were proposed: the catastrophic hypothesis and the evolutionary hypothesis. The catastrophic hypothesis, initially proposed by the French naturalist George Buffon (1707–1788), said that a pre-existing sun was hit by a celestial body, which tore a number of ‘drops’ from the sun, which went spinning about the sun due to the gravitational attraction, and later condensed into planets. The hypothesis was later modified by the British physicists James Jeans (1877–1946) and Harold Jeffries (1891–1989) who envisioned that another star passed very close to the sun and its gravitational pull tore away parts of the sun’s body like a ribbon. As the star went away from the sun, the ribbon-like structure went spinning round the sun, and slowly condensed to form the planets.

In contrast the evolutionary hypothesis propounded by the German philosopher Immanuel Kant (1724–1804) and enriched by the French physicist Pierre-Simon Laplace (1749–1827) said that the whole solar system—including the sun, planets, satellites, asteroids and comets—formed together out of a cloud of gas and dust, i.e., a nebula. If the nebula had a slight rotational motion, as it shrunk due to its own gravity, it would spin faster since angular momentum is conserved. This would give the nebula the shape of a flattened disc. They envisioned that the sun formed through gravitational collapse of the central mass while the planets and other bodies formed in the outer part of the disc.

It may be noticed that these two hypotheses differed in their answers to the questions:

1. Were the sun and the planets formed at the same time, in other words, are they co-genetic?

2. Were the planets formed from interstellar material or from stellar material (i.e., material that was part of a star)?

What would be the testable predictions of these two hypotheses? It is known that most elements have isotopes. Deuterium, an isotope of hydrogen, is rare, but is extremely stable unless subjected to great heat, as inside the stars. Thus, a prediction of the catastrophic hypothesis would be that the deuterium-to-hydrogen ratio in the planets would be the same as in the sun (because the material of the planets was once inside the sun). In contrast, a prediction of the evolutionary theory would be that the D/H ratio would be higher in the planets than in the sun (because the planetary material was not subjected to the heat inside the sun).

In the 1970s we acquired the ability to measure these ratios through spectroscopic analysis. It was found that in the sun the D/H ratio is around 3×10^{-7} while on Earth it is 2×10^{-5}, i.e., they are different by two orders of magnitude. This was a good ground for rejecting the catastrophic hypothesis. With that, the evolutionary hypothesis became the currently accepted ‘theory’ of the origin of the solar system.