Chapter 2

Logical Reasoning

All human activities are conducted following logical reasoning. Most of the time we apply logic unconsciously, but there is always some logic ingrained in the decisions we make in order to conduct day-to-day life. Unfortunately we also do sometimes think illogically or engage in bad reasoning. Since science is based on logical thinking, one has to learn how to reason logically.

The discipline of logic is the systematization of reasoning. It explicitly articulates principles of good reasoning, and systematizes them. Equipped with this knowledge, we can distinguish between good reasoning and bad reasoning, and can develop our own reasoning capacity.

Philosophers have shown that logical reasoning can be broadly divided into two categories—inductive, and deductive.

Suppose you are going out of your home, and upon seeing a cloudy sky, you take an umbrella along. What was the logic behind this commonplace action? It is that, you have seen from your childhood that the sky becomes cloudy before it rains. You have seen it once, twice, thrice, and then your mind has constructed the link “If there is dark cloud in the sky, it may rain”. This is an example of *inductive logic*, where we reach a general conclusion by repeated observation of particular events. The repeated occurrence of a particular truth leads you to reach a general truth.

What do you do next? On a particular day, if you see dark cloud in the sky, you think 'today it may rain'. You take an umbrella along. What was the line of reasoning behind this action? This is called *deductive logic*, where, starting from a general truth, you reach the particular truth about a specific situation.

All human reasoning falls into one of these two categories. Man cannot proceed a single step without applying these two lines of reasoning—from the particular to the general, and then from the general to the particular. The first one is inductive, and the second one is deductive.

2.1 Inductive logic

Inductive logic, thus, is the method of going from the particular to the general. No human action is possible without forming inductive inferences. In ancient times people saw a seed growing into a tree. He saw it repeatedly, and then formed an inductive connection: seeds grow into trees. That was the basis of the invention of agriculture: Where you want the tree, plant the seed there.

Modern science developed through large-scale application of inductive logic. During the Renaissance, the British philosopher Francis Bacon (1561–1626) urged people to look at nature with open mind, without the prejudices remnant of the Dark Age, and to make large-scale observation. To facilitate such large-scale observation and recording of data about nature, he advocated the formation of associations of scientists (the Royal Societies formed as a result of that prescription). Then he recommended that scientists should try to extract the general properties and laws governing nature by applying inductive logic.

Many different branches of science developed by applying this procedure. That is why, in the 19th century, much of the sciences were called 'inductive sciences'. For example, people observed the character of different types of animals and categorised them into mammals, reptiles, birds, fishes, insects, etc., based on some common characteristics that members of each category share. Likewise in chemistry, elements were categorised as metals, non-metals, semiconductors, etc.; compounds were categorised as acidic, basic, etc. These are examples of application of inductive logic.

2.1.1 Method of inductive reasoning

Let us give examples of a few conclusions in science that have been reached through inductive logic.

1. All insects have six legs
2. Copper turns green when dipped in vinegar
3. All planets have elliptical orbits
4. Volcanoes are located close to the boundaries between tectonic plates

Now let us carefully analyze how such conclusions are reached. Notice that nobody has counted the legs of *all* insects. We have counted legs of a *sample* taken from the population of insects, and have found that in all the samples the number of legs was six. We then say that, unless we find evidence on the contrary, it is reasonable to conclude that all insects have six legs.

Tycho Brahe had observed the motion of the known planets: Mercury, Venus, Mars, Jupiter, and Saturn, and on the basis of these observational data, Kepler had deduced mathematically that the orbits of these planets around the sun are ellipses. We then concluded, using inductive logic, that *all* planets have elliptic orbits. Newton developed his theory of gravitation on the basis of that general premise.

The other two examples can also be seen in a similar way. The general characteristics of this line of reasoning is that, knowing the properties of a sample, we are trying to infer the properties of the population. This is a very important component of scientific reasoning.

2.1.2 Philosophical questions on inductive logic

Yet, in the 20th century, some philosophers raised questions about the usefulness of inductive logic. They said, ‘suppose you have observed ten instances of an event A leading to an event B and you infer that event A always leads to event B. But can you rely on that? It is always possible that later you will find *one* instance where B does not happen following A. A single counter-instance will then destroy your inductive inference. Can science consider such inductively obtained inferences as dependable?

Let us cite an example. 99.99% of humans have their heart on the left side of the chest. If one collected a sample of 10,000 humans and studied the location of their hearts, it is possible that all people in the sample would be found to have hearts on the left side. Thus a scientist would conclude, with a high degree of confidence, that *all* humans have hearts on the left side. Such a conclusion would actually be false, because some people do exist whose hearts are located on the right side.

In spite of the possibility of falsehood of inductive conclusions, science has continued to proceed using inductive logic, because in many cases there is no other method at hand.

Let us give a couple of examples.

Field biologists have noticed that many different animals live in the same geographical region and share the same habitat. For example, zebra, wildebeest, Tomson’s gazelles and many other grazing animals live in the African savannas. But when the biologists critically studied their livelihood, food habits, predator-prey relationships, etc., they found that each species always occupies a unique ‘niche’ even when many different species live in the same area. Thus they concluded, inductively, that all species occupy unique niches.

This conclusion has proved to be of great advantage. Whenever field biologists encounter a situation where two or more organisms live together, they deliberately look for the differences in niches, and they have always found it. Thus, the inductive inference has given direction to research.

The second example comes from astronomy. How do we measure the distances to astronomical objects? The distances to nearby objects like the moon and the planets can be measured by the method of parallax—by observing the object from two widely separated points on Earth. The angle between the lines of sight, the parallax angle, is measured by comparing the positions of the distant stars that are in the background. But this method does not work for even the nearby stars. For that, the pictures are taken from two different times of the year, so that the distance between the points of observation is comparable to the diameter of the Earth's orbit. This way the distances to hundreds of nearby stars could be measured. But for more distant stars, this method does not work because the parallax angle becomes too small.

Astronomers had noticed that there are a few stars whose luminosity varies periodically. These are called Cepheid variables. Some of them are very luminous and some are less luminous. In 1908 the American astronomer Henrietta Swan Leavitt took a careful look at Cepheid variables whose distances could be measured by the parallax method. She found a relationship: The longer the pulsation period, the more luminous is the star.

Now, the pulsation period of any star can be directly measured by observation, whatever the distance. If this is related to the absolute luminosity, then the latter can also be found. The distance to the star can then be found by measuring the apparent luminosity. This provided a new way of measuring distances to even further astronomical objects.

When Edwin Hubble looked at the Andromeda galaxy through the new 100 inch telescope at the Mount Wilson observatory, he managed to locate a few Cepheid variable stars. Then he used the relationship discovered by Leavitt and measured the distance to the galaxy. He used the same method to measure the distances to many other galaxies, and established the famous Hubble Law on which the whole of cosmology depends today.

Now notice the line of reasoning. Leavitt had observed a few *particular* Cepheid variables and established a relationship between their period and luminosity. Then scientists applied inductive logic and assumed that this is a general law, applicable to *all* Cepheid variables. When Hubble noticed a *particular* Cepheid variable star in the Andromeda galaxy, he applied deductive logic from the inductive premise, to obtain the distance to that star. The whole exercise would have been impossible without the combination of inductive and deductive reasoning.

That is why science still productively uses inductive logic, even though it knows that a future counter observation can make an inductive inference invalid.

The established practice in science is not to state the conclusion in an absolutist sense, implying that it cannot be false. The practice is to state the premises that has led one to reach the inductive conclusion, so that an independent enquirer can check the validity of the premises and the line of reasoning. It should be presented in a manner that convinces a community of sceptical rational inquirers that the conclusion is correct.

2.1.3 Probabilistic inductive logic

We understand that there would always be a lack of certainty in inductive conclusions. Even if the premises are true, there is a possibility that conclusion can still be false.

To guard against possible logical errors, two types of statements are generally made.

Suppose we have obtained a large sample of insects from the population of all insects and have found that all of them have six legs. The two types of statements are as follows.

Probabilistic inductive reasoning: We can say, with a high degree of confidence, that all insects have six legs. Here we are effectively stating that the probability that the conclusion is correct is very high.

Deterministic inductive reasoning: Until we find an insect with number of legs other than six, we conclude that all insects have six legs. We generally phrase such statements as "in absence of evidence on the contrary, we conclude that $\cdots$".

In the later chapters we will see how to make probabilistic inductive inferences with quantitatively defined degree of confidence.

2.1.4 Quantitative inductive logic

In some situations, the property in question concerns a quantity. Suppose a scientist wants to make a statement regarding the body-weight of adult male sparrows. She obtains a reasonably large sample of adult male sparrows and weighs them. From the data she can reach some conclusions regarding the *sample*. Then she would like to make a statement regarding the *population* of all adult male sparrows. Here also it is the application of inductive logic. But in order to be logically correct, she has to specify the conclusion as "the body weight of all adult male sparrows lies in the range between w_1 and w_2, and I can state this with 95% confidence".

In some situations, the property in question may concern a proportion of two quantities. For example, Gregor Mendel crossed a tall variety of pea plants with a short variety and observed that in the first generation all the plants are tall, but in the second generation one third of the plants are short. Obviously he did the experiment with a *sample* of plants but tried to reach a general conclusion that would be applicable to all similar situations. And the property in question was the proportion of tall and short plants in the 2nd generation. In such situations also the scientific statement would be of the form "with 95% confidence I can state that the proportion of tall and short plants lie in the range p_1 to p_2".

The method of applying such quantitative probabilistic inductive logic will be discussed in a later Chapter.

2.2 Deductive logic

When one has a set of general statements, and tries to reason what will happen in a particular situation, the line of logic is called deductive logic. Thus, deductive logic provides a way of going from the general to the particular.

The methods of applying deductive logic were developed by ancient philosophers, most notably by Aristotle. During the period of Renaissance, the philosopher René Descartes (1596–1650) underscored its importance in the method that science should follow. Since then, deductive logic has formed one of the structural foundations of scientific thinking.

Much of the application of deductive logic today happens in mathematics. In this course, instead of going into the methods of mathematical deduction, we shall focus on a few essential concepts of deductive reasoning.

2.2.1 Propositional logic

Modus Ponens

Suppose we make the statement: "*If* copper is dipped in vinegar, *then* it turns green". Then you know that if a particular piece of copper is dipped in vinegar, it will turn green. In this example, you are given a premise, and the application of logic allows you to reach a conclusion.

Let us analyze the structure of this logic. It is

If A then B
A
$\therefore B$.

In this particular case, A is "copper is dipped in vinegar", B is "it turns green". You are also given the premise that A is true. So you conclude that B must be true.

This line of logical inference is called *modus ponens*. Its structure is "A implies B and A is asserted to be true, therefore B must be true."

Now suppose you are given that "If A then B", and it is asserted that B is true. Can you conclude from this that A is true? No. The rules of logical deduction does not permit that. For the example above, you are given the premise "If copper is dipped in vinegar, it turns green", and also the fact that a piece of copper turned green. The laws of logic does not allow you to conclude that the piece of copper was dipped in vinegar. The event of turning green could also be caused by a different factor.

Modus Tollens

Now consider another logical structure. Suppose we have the premise "if P is a charged particle, then its trajectory will bend in presence of a transverse electric field". Now we have a situation that the trajectory of a particle P did *not* bend in presence of an electric field. We infer that P was not a charged particle.

This is also a valid inference, and the logical structure, called *modus tollens*, is

If A then B
Not B
$\therefore$ not A.

In some literature the symbols '$\neg$' or '$\sim$' are used to imply 'not'. In this text we shall simply write 'not'. In this particular example, A is "P is a charged particle", and B is "its trajectory bends in presence of a transverse electric field". The second premise asserts that B is not true. We conclude that A is not true.

In the above examples, two given premises allowed one to reach a valid conclusion, i.e., premise #1 and premise #2 $\rightarrow$ conclusion. For example, in modus tollens,

$$\{\text{If } A \text{ then } B\} \;\text{ and }\; \{\text{not } B\} \;\rightarrow\; \text{not } A$$

In many situations a conclusion many have to be reached based on many premises:

$$P_1 \text{ and } P_2 \text{ and } P_3 \text{ and } \cdots \rightarrow \text{ conclusion}$$

If all premises are true, and the rules of logical inference are followed, then the conclusion reached is necessarily true. This is normally done by combining two premises at a time to arrive at an intermediate conclusion, which is then combined with the next premise to derive the next conclusion, and so forth:

$$\begin{array}{rcl} P_1 \text{ and } P_2 & \to & \text{conclusion 1} \\ \text{conclusion 1 and } P_3 & \to & \text{conclusion 2} \\ & \vdots & \\ \text{conclusion } n-1 \text{ and } P_n & \to & \text{conclusion} \end{array}$$

In each step we apply either modus ponens or modus tollens.

2.2.2 Probabilistic deductive logic

Note that in the logical structures discussed in the last section, if the premises are true, and the rules are applied properly, the conclusions must necessarily be true. But in real life conclusions are not so black-and-white, in the sense of being either 'true' or 'false'.

The premises on the basis of which the conclusions are drawn are derived by inductive logic. And we have seen earlier that an inductive conclusion may also be probabilistic. For example, consider the statement "99.99% of humans have heart in the left side of the chest". Now if the second premise is that Venu is a human, what conclusion can we drive? It is that there is a 99.99% probability that Venu has heart on the left of his chest. The logical structure, called probabilistic modus ponens, is as follows.

If A then B with probability p
A
$\therefore B$ with probability p.

Here the probability p is a number between 0 and 1. If its value is above 0.5, we might say that B is 'most probably true', and if its value is between 0 and 0.5, we might say that B is most probably false.

Suppose a scientist has measured the body weight of a sample of adult male sparrows and, based on inductive logic, has stated that the body weight of adult male sparrows lie between m_1 and m_2 with 95% probability. Now, you want to reach a conclusion about a particular adult male sparrow that you have caught, without actually measuring it. You will conclude, based on probabilistic modus ponens, that there is a 95% probability that this particular sparrow's weight lies between m_1 and m_2.

Can we apply modus tollens in a probabilistic sense? Consider the following line of argument.

Premise 1: If it is an adult male sparrow, its body weight lies between m_1 and m_2 with 95% probability

Premise 2: Venu's body weight is above m_2.

Here A is 'it is an adult male sparrow', and B is 'its body weight lies between m_1 and m_2'. The second premise is 'not-B'. Can we conclude that Venu is not an adult male sparrow, or that premise 1 was wrong? No. Since premise 1 assigns a non-zero probability to not-B, you cannot reach such a conclusion.

Suppose you again do the experiment by collecting a reasonably large sample of adult male sparrows, measure them, and obtain a mean value above m_2. Then also the premise 1 goes not stand negated. It will only cast doubt about the earlier inductive conclusion. We will come to these issues in a later chapter that deals with statistical reasoning.

2.2.3 Defeasible deductive reasoning

Consider the statements:

Premise 1: If a patient has more than 95% heart blockage, one should perform surgery to remove the blockage.

Premise 2: Venu has more than 95% blockage in his heart.

In this situation, the application of modus ponens would enable the physician to conclude that the right course of action is to perform a surgery.

But then, a blood test reveals that Venu has haemophilia. And it is known that haemophilia patients cannot be operated upon (as the bleeding may not stop). So the doctor advises against operation and decides to try medication.

This example shows that there are situations where, when additional information becomes available, a conclusion that was accepted earlier as correct can be rejected as incorrect.

Let us now analyze the line of reasoning formally.

Here the statement A is 'a patient has more than 95% heart blockage'; statement B is 'one should perform surgery'; statement C is 'the patient has haemophilia'.

Then the line of reasoning is

Premise 1: If A then B
Premise 2: If C then not-B
Premise 3: A is true
Premise 4: C is true
Premise 5: Premise 2 is stronger than premise 1

Conclusion: not-B is true and B is false.

In such situations, direct application of modus ponens leads to a logical contradiction—Premises 1 and 3 leads to B, and premises 2 and 4 leads to not-B. One has to find all the possible inter-contradictory conclusions coming out of the premises, and has to choose the strongest one. The choice should not be based on subjective judgement; it has to have a basis that is acceptable to the scientific community. Such arguments are called defeasible deductive reasoning.

Scientists often face ethical dilemmas, and have to decide the correct course of action through defeasible deductive reasoning. For example, if you have scientific knowledge, you should try to apply it in practice. But you find that the specific application demanded by your employer causes harm to the society, directly or indirectly. In such a situation, what should you do?

Ethics of science imposes a over-riding premise that scientists should not engage in any activity that causes harm to humanity. That is a stronger demand compared to all other considerations a scientist may have. Inability to apply it properly has led to many so-called scientific inventions — ranging from development food adulterants to biological weapons — that have caused immense harm to the society.

2.2.4 Syllogistic logic

A syllogism is a kind of logical argument that applies deductive reasoning to arrive at a conclusion based on two or more propositions that are asserted or assumed to be true.

Aristotle proposed a form of syllogistic logic in which a general statement (obtained earlier using inductive logic) and a specific statement embodying a particular situation allows one to derive a valid conclusion. The general statement is called a 'major premise' and the specific statement is called the 'minor premise'. A categorical syllogism consists of three parts:

1. Major premise
2. Minor premise
3. Conclusion

For example, knowing that all mammals are hot-blooded animals (major premise) and that leopard is a mammal (minor premise), we may validly conclude that leopards are hot-blooded animals. Syllogistic arguments are usually represented in a three-line form (without sentence-terminating periods):

All mammals have hot blood
Leopard is a mammal
Therefore leopards have hot blood.

Aristotle showed that such statements can have four types of structures, which allow them to be expressed in abbreviated form:

aAb or Aab	=	"every a is b"
aEb or Eab	=	"No a is b"
aIb or Iab	=	"Some a is b"
aOb or Oab	=	"Some a are not b"

Here A, E, I, and O denote the kind of relationship between the terms a and b.

"All a are b," and "No a are b" are termed universal propositions; "Some a are b" and "Some a are not b" are termed particular propositions. Each of the premises has one term in common with the conclusion: in a major premise, this is the major term (i.e., the predicate of the conclusion); in a minor premise, this is the minor term (i.e., the subject of the conclusion). For example:

Major premise: All spin-half particles are Fermions
Minor premise: All electrons are spin-half particles
Conclusion: All electrons are Fermions

Each of the three distinct terms represents a category: In the above example, Fermions, electrons, and spin-half particles. Fermions is the major term, electrons the minor term. The premises also have one term in common with each other, which is known as the middle term; in this example, spin-half particles. Both of the premises are universal, and so the conclusion is also universal.

Another example:
Major premise: All mortals die.
Minor premise: All men are mortals.
Conclusion: All men die.

Here, the major term is die, the minor term is men, and the middle term is mortals. Again, both premises are universal, hence so is the conclusion.

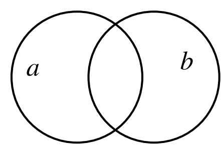
One can also form a series of incomplete syllogisms, so arranged that the predicate of each premise forms the subject of the next until the subject of the first is joined with the predicate of the last in the conclusion. Thus one can form a chain of deductions. For example, one might argue that all lions are big cats, all big cats are predators, and all predators are carnivores. By joining these statements serially, one can conclude that all lions are carnivores.

Aristotle and other ancient logicians clearly stated, given a pair of statements, which conclusions are valid and which are not. Today we can get a clearer picture using Venn diagrams.

Let us now illustrate some of the valid syllogistic conclusions.

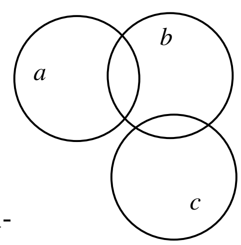
Premise $a\mathrm{I}b$:
Some a are b

Possible conclusion:
Some b are a



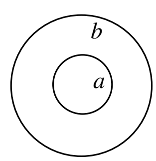
Premise $a\mathrm{I}b$ and $b\mathrm{I}c$:
Some a are b, Some b are c

Possible conclusions:
Between a and b: Some b are a
Between b and c: Some c are b
It is not possible to derive any conclusion between A and C.

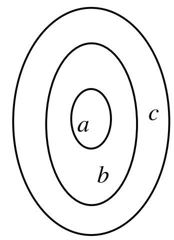


Premise $a\mathrm{A}b$:
All a is b

Possible conclusions:
Some a are b, Some b are a

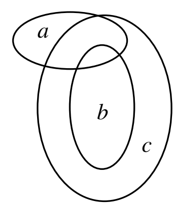


Premise aAb and bAc:
All a are b, All b are c



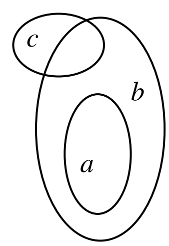
Possible conclusions:
Between a and b: Some a are b, Some b are a
Between b and c: Some b are c, Some c are b
Between a and c:
All a is c, Some a are c, Some c are a

Premise aIb and bAc:
Some a are b, All b are c



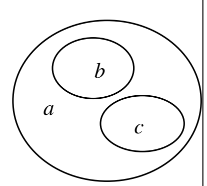
Possible conclusions:
Between a and b: Some b are a
Between b and c: Some b are c, Some c are b
Between a and c: Some a are c, Some c are a

Premise aAb and bIc:
All a is b, some b are c



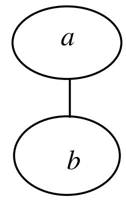
Possible conclusions:
Between a and b: Some a are b, Some b are a
Between b and c: Some c are b
Between a and c: No conclusion

Premise bAa and cAa:
All b is a, All c is a



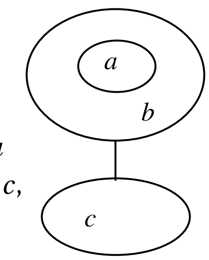
Possible conclusions:
Between a and b: Some a are b, Some b are a
Between a and c: Some a are c, Some c are a
Between b and c: No conclusion

Premise bEa and cEa:
No b is a, No c is a



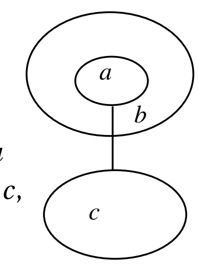
Possible conclusions:
No a is b, No b is a
Some a are not b, Some b are not a
Note: When NO comes in statement, some-not should follow in conclusion

Premise aAb and bEc:
All a is b, No b is c



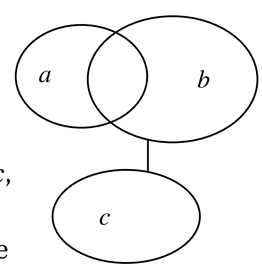
Possible conclusions:
Between a and b: Some a are b, Some b are a
Between b and c: No b is c, Some b are not c, Some c are not b
Between a and c: No a is c, Some a are not c

Premise aAb and aEc:
All a is b, No a is c



Possible conclusions:
Between a and b: Some a are b, Some b are a
Between a and c: No c is a, Some a are not c, Some c are not a
Between b and c: Some b are not c

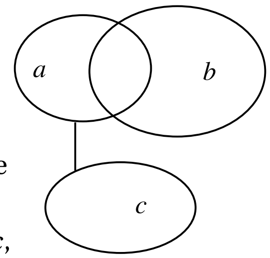
Premise aIb and bEc:
Some a is b, No b is c



Possible conclusions:
Between a and b: Some b are a
Between a and c: Some a are not c, Some c are not a
Between b and c: No c is b, Some b are not c, Some c are not b

Premise $a\text{I}b$ and $a\text{E}c$:
Some a is b, No a is c

Possible conclusions:
Between a and b: Some b are a
Between a and c: No c is a, Some a are not c, Some c are not a
Between b and c: Some b are not c, Some c are not b



Sometimes one needs to figure out whether a certain conclusion is possible or not. Whenever the term 'Possibility' or 'Can' comes in Conclusion, one needs to check the entries in Table 2.1.

Given	Desired	Possibility
Some	All	Yes
No relation	Some / All	Yes

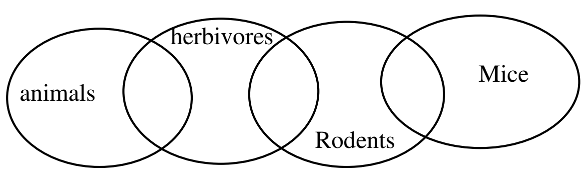
Table 2.1: Table of possibilities

Let me explain with an example.
Statements: Some animals are herbivores; Some rodents are herbivores; Some mice are rodents

You are asked to check if the following conclusions are true or false:

1. Some animals are rodents
2. Some mice being herbivores is a possibility
3. Some mice are animals
4. All herbivores being animals is a possibility

The first step is to draw a Venn diagram.



- Conclusion 1: It is False. (no direct connection between them).
- Conclusion 2: No relation between mice and herbivores. ‘Possibility’ is there. (check table) (It is True)
- Conclusion 3: It is False (No direct relation)
- Conclusion 4: Between Apples and Mangoes ‘Some’ can come. Possibility is there’ (check table). It is also true.

Note that you should not derive the conclusions based on your prior knowledge. The conclusions must be based on the statements provided.

Now we come to some examples of combinatorial logical structures.

Structure: AAA, M: men, S: Greeks, P: mortal
All men are mortal (MAP)
All Greeks are men (SAM)
$\therefore$ All Greeks are mortal. (SAP)

Structure: EAE, M: reptile, S: snake, P: fur
No reptiles have fur (MEP)
All snakes are reptiles (SAM)
$\therefore$ No snakes have fur. (SEP)

Structure: AII, M: tiger, S: mammal, P: retractable claws
All tigers have retractable claws (MAP)
Some mammals are tigers (SIM)
$\therefore$ Some mammals have retractable claws. (SIP)

Structure: EIO, M: metal, S: element, P: insulator
No metal is insulator (MEP)
Some elements are metals (SIM)
$\therefore$ Some elements are not insulators. (SOP)

Structure: AOO, M: infectious, S: bacteria, P: harmful
All harmful organisms are infectious (PAM)
Some bacteria are not infectious (SOM)
$\therefore$ Some bacteria are not harmful. (SOP)

Structure: OAO, M: cat, S: mammal, P: tail
Some monkeys have no tails (MOP)
All monkeys are mammals (MAS)
$\therefore$ Some mammals have no tails. (SOP)

Structure: AAI, M: square, S: rhombus, P: rectangle
All squares are rectangles. (MAP)
All squares are rhombuses. (MAS)
$\therefore$ Some rhombuses are rectangles. (SIP)

Structure: EAO, M: reptile, S: snake, P: protruded ears
No reptiles have protruded ears. (MEP)
All snakes are reptiles. (SAM)
$\therefore$ Some snakes have no protruded ears. (SOP)

Structure: AEO, M: lay eggs, S: mammal, P: reptile
All reptiles lay eggs (PAM)
No mammal lays eggs (SEM)
$\therefore$ Some mammals are not reptiles. (SOP)

The above list is not exhaustive, and there can be many more logical structures. The purpose was to acquaint the reader with the formal methods of logic. In modern science, we do use the above styles of logical reasoning, but often do so unconsciously. It is better to learn how to reason logically in order to do better science.

2.3 Use and misuse of logic

Deductive logic allows one to derive valid inference from a set of premises. But that does not mean the inference will be true. Valid inference means, if the premises are true the conclusion must necessarily follow. If the given premises are false (or meaningless), still one can derive a valid inference.

That is why one has to make distinction between truth and validity. Only after a logical reasoning is valid, one should proceed to check its truth.

This has great importance in the way science works. In many situations it is difficult (or impossible) to directly check the truth of a statement or a set of statements. But it is possible to derive some new statement by logically valid reasoning based on the set of premises. And it may be possible to check the truth of the conclusion by observation or experiment. If the conclusion is tested and is found to be false, we know the premises (or at least some of them) must be false.

However if the conclusion is tested and is found to be true, it does not mean that the premises are true. People often make logical error by making such inference. It is possible to derive perfectly correct conclusion based on false premises. Consider the following statements:

All dinosaurs are mammals
All cats are dinosaurs
$\therefore$ All cats are mammals.

It is obvious that the premises are false, yet the conclusion, derived by valid deductive reasoning, is correct. This implies syllogistic logic does not work both ways. A true conclusion can be derived from false premises, but a false conclusion cannot be derived from true ones. Therefore

- The conclusion is false implies that the starting premises are wrong

- The conclusion is true does *not* imply that the starting premises are true.

Sometimes, when the conclusion appears to be true, we tend to believe that the line of reasoning is valid. Yet, it may not be so. For example, consider the sentences:

All particles with integer-valued spin are bosons
Electrons do not have integer-valued spin
∴ Electrons are not bosons.

The fact that the conclusion is right can easily confuse an untrained mind into believing that the reasoning is valid. Yet, it is not. To illustrate, let me change the subjects and predicates, keeping the structure the same:

All insects are living organisms
Tigers are not insects
∴ Tigers are not living organisms.

Now it is obvious that the reasoning was faulty.

In learning to do science, one has to learn valid reasoning, and has to practice it to make it one's natural thought process. Only then can one hope to make a mark in science which depends greatly on one's ability of logical reasoning.