NATURE OF MODELS IN NATURAL SCIENCES:

A STUDY 0F THEIR NATURE AND ROLE

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CERTIFICATE

This is to certify that the dissertation entitled MODELS IN NATURAL SCIENCES: A STUDY OF THEIR NATURE AND ROLE being submitted By Mr. Anil.N in -partial fulfilment of the requirements for the award of the. degree of Master of philosophy is a record of bona fide work carried out By him under my supervision.

The dissertation has not Been suBmitted previously either in part or in full to any other university or institute of learning for the award of any degree or diploma.

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Presented to My Parents

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and

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PREFACE

This dissertation seeks to understand the nature and significance of models as they figure in natural sciences. In the execution of this task the thesis focuses its attention on issues pertaining to the logical features of models, the role of models in theorising and the relation between models and reality.

The various questions that philosophy of science raises and grapples with in its attempt to understand the nature of science as a cognitive enterprise can be classified into three domains. The first domain which one might call the domain of conceptual questions consists of questions like "What is observation?", "What is theory?" "What is explanation?" etc. In this domain an attempt is made to provide analyses of the various concepts that figure in scientific discourse. The second domain which may be called the domain of methodological questions consists of questions like "How are scientific theories generated?", "How are scientific theories evaluated?' and "How are two successive scientific theories related?". In the domain of axiological questions, the third domain, we seek to critically evaluate certain value judgements made on behalf of science such as "scientific knowledge is rational, objective and progressive". Thus, in this domain, we deal with questions like whether, and if so how, science is objective, rational and progressive.

The questions concerning the nature and significance of models fall in the first domain, namely, the domain of conceptual questions. By riseing certain questions about models we seek to understand, in epist emological terms, the character and significance of models. In other words, we try to provide the 'logical geography', to use Gilbert Ryle's expression, of the concept of model. The thesis is a humble attempt at such an epistemological exercise.

After making some preliminary remarks concerning the philosophical significance of models and issues concerning them, the thesis, in chapter 1 attempts to give a typology of models and a brief description of various kinds of models. This is followed by an attempt to delineate certain important logical features of models as cognitive artifacts. In chapter 2 the question that is dealt with is whether models are intrinsic or extrinsic to theorising. The dissertation seeks to substaniate the claim that models are not mere heurisitic devices but are built in the very texture of theorising,

with the result the theories and models are related in an essential way. In the third and final chapter, a realistic constual of scientific models is sought to be substantiated in explaining the relation between the model and thing modelled. While providing such a representationalist account of models the thesis rejects the idea that our cognitive artifacts like models represent reality in the sense of 'mirroring'. The version of realism espoused here underscores the point that models create reality while representing it. Such a creative role of models is taken as a clue to understand the nature of scientific creativity that is involved in the construction of models.

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CHAPTER 1

PROBLEM OF MODELS

Human activity, theoretical or practical involves representation, in the sense we first make some sort of picture of what we want to do or what we want to know. It is this commonality of representation that makes it difficult to draw a hard and fast line between practice and theory. That we picture to ourselves what we want to do before doing it, is very well brought out by Karl Marx, who says:

> a spider conducts operations that resemble those of a weaver and a bee puts to shame many an architect, in the construction of her cells. But what distinguishes the worst architect from the best of bees is this, that the architect raises his structure in imagination before he erects it in reality.'

Theoretical activity is directed at understanding and explaining the world and it involves representation in terms of cognitive artifacts like theories, models, analogies etc. Models are, therefore, one species belonging to the genus which we call representation. Representation constitutes the essence of what we call knowledge or cognition. Hence, the philosophical significance of any attempt to understand the nature and function of models consists in its ability to shed light on the nature and function of representation in knowledge-acquisition or epistemic activity. One should not lose sight of this epistemic motive and significance while dealing with the technical issues and details pertaining to the philosophical discussions about models. So an articulation or construal of the concept of model, if it involves only the technical matters instead of illuminating the concept of representation, is highly inadequate. This is the problem of the ordinary understanding of the concept of model, according to which a model is a selective or abstractive duplication of some aspects of the world such that it is a construction in which we organise symbols of our. experience or of our thought in such a way that we effect a systematic representation of our experience as a means of understanding it.

Philosophy of science has tried to provide an analysis of or a logical geography of concept of model so as to shed light on the question whether, and if so how, knowledge involves representation of reality.

The concept of model, which has emerged as a crucial concept in the discussions related to the method of science, is as old as science itself despite some differences in the modern concept and use of model and the ancient concept and use of model. Even though there are many differences between the ancient and the present day science regarding the method and the aim, the similarity between them lies in the use of analogies (here the word "analogy" is used instead of "model" because model has a complex texture with the result the term "model" has become excessively technical in the present day scientific discourse). Whatever may be the historical period, any scientific practice tries to describe the reality in terms of analogies drawn from the events or processes which are familiar and felt to be better understood. The analogies that are used in Greek science might be mythological and aimed at satisfying the logical requirements of a metaphysics, but their role in epistemic activity is same as the role of models in present day science. It clearly shows that any cognitive activity presupposes the use of familiar concepts. To put it in the words of Mary Hesse:

> This is not merely the most obvious and convenient way to proceed, but that it is an essential ingredient of intelligible scientific explanation.[2]

In recent years the analysis of the role of models, (especially in the sciences) came to the fore in the philosophy of science due to the failure of the logicist programme of positivism. Positivism which dominated the first half of this century considers science as a distinct human activity and that all sciences have only one method which is the method of induction. To them philosophy of science is logic of science. Its tasks are:

1. giving a logical clarification of scientific concepts and theories

2. to provide justification of the principle of induction by working out an inductive logic

3. to specify and elaborate 'the logical form' of all scientific explanations, and

4. to work out the logical relation between the theoretical super-structure and observational sub-structure.

In the development of their 'logicist programme' positivism did not bother,how science is actually done and only showed interest in the final products like theories and explanations.

The collapse of this programme of positivism led many philosophers of science to search for intellectual processes which actually take place in scientific activity and which have nothing to do with formal analysis. Construction of models is one of these intellectual processes.Rom Harre in his paper'The constructive roleof models', describes the intellectual processes involved in the construction of models, as follows:

> These processes involve the disciplined scientific imagination, in its task of constructing conceptions of processes and structures that are immune from empirical investigation, and yet, they must be assumed to underlie and be productive of those patterns which can be studied empirically. In the attempt to understand the imaginative processes that are involved in creative scientific thinking the notion of models has turned to be particularly illuminating.[3]

The significance of the analysis of models is not confined to calling into question the basic assumptions of positivist programme in philosophy of science. The analysis of the role of models is also a conscious attempt to expose and remedy the short comings of other views of science like Hypothetico-deductivism.

The hypothetico-Deductivist view of science sought to replace positivist view of science and philosophy of science . Central to this view is the dichotomy between Discovery and Justification. Hypothetico-Deductivism maintains that theoretical explanations or hypotheses are not products of a logical or rational processes. Theories are guesses or conjectures and are tested by deducing their

consequences and comparing these with observation-statements. Here conjecturing theories is a creative discovery and any kind of logical or rational account of it is not possible. The processes of deducing consequences from these guessed theories and testing them constitute the act of justification - a perfectly logical or rational processes.

The questions that are to be answered by this account of science are :

1. Are the theoretical entities only a part of deductive system or real entities?

2. How can the theories be productive? That is,If theories are constructed signs and embedded with imagined strange entities, how can they be productive? In other words, how is the passage from theoretical language to observational language possible?

Some philosophers of science like Campbell, Marshall Spector, Mary Hesse tried to answer these questions with the help of the analysis of the role *Of-* models in science. According to Mary Hesse **A** these questions can be answered in terms of the use of material models, at the cost of some modification of the original deductive account. She says that theoretical concepts can be understood as derived by analogy from familiar situations and describable in observational terms.Sometimes models give a basis for analogical argument and prediction from actual physcial systems.

The above discussion brings to fore the crucial role played by the analysis of the role of models in evaluating or modifying the different accounts of the method *of* science. Not only this, there **A** is a growing consciousness in the philosophers of science that the account of method of science which is given by philosophers of science should not be remote from the actual scientific practice. Hence,the philosophers of science have to consider the processes and concepts that actually figure in scientific practice. One of these important concepts is 'the concept of model'.

In the processes of producing an analysis of models the significant questions that can be delineated out of many are :

1. What is a model?

2. What is the role of models in theory construction? In other words, are models extrinsic to theorising in the sense that they are only heuristic devices for learning and teaching theories or are they intrinsic to theorising in the sense that they are constitutive of theories?

3. How are models and reality related? That is, do models represent reality and if so, how?

In this chapter I try to give an account of what model is and thus seek to provide a brief answer to the first question. The use of the term 'model' became very common in scientific disciplines despite the differences in their methods and subject matter. Though they differ in their mode of procedure and subject matter they seem to agree in one respect, namely, the employment of models in developing theories. My discussion of models is confined to models in natural science though models figure in non-natural sciences and even non-scientific discourses also. The use of the models is prevalent in all scientific disciplines. However since the character of models varies from discipline to discipline any compact definition of model will probably be unsatisfactory. This is what Groenewold means when he says:

I know of no model of a model.[4]

Hence, I will try to bring out the meaning of 'model' as it is used in natural sciences by illustrating it with some examples before discussing the relevant philosophical issues.

To begin with, it is necessary to clarify that a simple definition of 'model' is philosophically misleading since such a definition assumes that all models in science are of the same kind (apart from the fact that, as we have pointed out, models exhibit different characterstics in different disciplines). In actual scientific practice one comes across different kinds of models. Hence, to understand what a model is it is better to elucidate different kinds of model, individually. The most important kinds of model are: 1. Scale model 2. Analogue model 3. Mathemetical model 4.

Simplifying model, and 5. Theoretical model. In what follows a few words about each of these kinds of models with certain illustrations are in order.

Before we do this let us note the relation between logical models and scientific models.We can say that most uses of models in science carry over from logic the idea of interpretation of a deductive system. Let us see what is model in logicians sense.[5]

Formal logic is concerned with sets of axioms and their deductive consequences and also with the interpretation of these axioms and theorems through a model. Here the term 'model' means any set of entities that constitute an interpretation of all the axioms and theorems of a system and in which those axioms and theorems hold true Tarski defines model thus:

> A possible realisation in which all valid sentences of a theory T are satisfied is called a model of T.[6]

The following example makes clear the sense of the above definition. In the formalised system of geometry we can find the axiom 'Any two points lie on one and only one straight line'. In the deductive system of geometry we cannot find any exact definition of terms like 'point' or 'straight line'. The definition of these terms can only be undertood by their relationships that are given by axioms and their deductive consequences.But it should not be considered that the above mentioned geometric example is the only possible 'model'in which the axiom can be realised. The same axiom can be realised in terms of 'sets' and 'elements' also. Then the axiom will be 'Any two individuals are co-members of one and only one set'. Here the set of entities of geometry and the set of entities of set theory are the models of the same uninterpreted calculus.

Though most of the uses of 'model' in science carry over from logic the idea of interpretation of a deductive system, there is little else common between the scientist's sense of model and the logician's sense of model. With these words let us briefly describe the various kinds of models.

1. Scale Models:

General examples of models in the literal sense of the word 'model' include three-dimensional miniatures. The miniature house built by the architect before constructing the intended one, small toy aeroplane, etc, are examples of scale models. These models are 'more or less true to scale' of the original. But restricting ourselves to only something smaller than the original is not logical. We have to take into consideration the magnification also. As a natural extension we can widen the above concept of model as:

proportional change of scale in any relevant dimension, such as time.[7]

Now the title 'scale model' includes even the chemical or biological processes, which are artificially accelarated or decelerated. Mainly these models are used in science for expository purpose. E.H.Hutten says:

In this use, the model has mainly a psychological function: it gives visual representation of something which is not easily visualised. For example because of its size. This is also described as the heuristic and pragmatic use of the model[8].

Max Black in his article' Models and Archetypes' lists the following characteristics of scale Models.[9]

A. A scale model is always a model of something. The notion of a scale model is relational and indeed, asymmetrically so. If A is a scale model of B, B is not a scale model of A.

B. A scale model is designed to serve a purpose, to be a means to some end.

C. A scale model is a representation of the real or imaginary thing for which it stands. Its use is for "reading off" properties of the original from the directly presented properties of the model.

D. Some features of the scale model are irrelevant while others are pertinent and essential to representation in question. There is no such thing as a perfectly faithful model. Only by being unfaithful in some respects can a sacle model represent its original.

E. As with all the representations, there are underlying conventions of interpretation-correct ways for "reading" the scale model.

F. The conventions of interpretation rest upon partial identity of properties coupled with invariance of proportionality.

It is also important to take note of the demerits in representing something by scale models. Change of scale might introduce irrelevance and distortion. Mere change in the scale may change the balance of factors in the original. For example, small model of a uranium bomb fails to explode as there is a need to have more than the critical mass for explosion. Hence, inferences from scale models are potentially dangerous and are in need of supplementary validation and correction.

2. Analogue Models:

An analogue model is some material object, system or processes designed to reproduce as faithfully as possible in some new medium, the structure of web of relationships in the original.[10]

Models in this sense are widely used in science and are also nearer to ordinary sense though further away from the logician's sense. These are not straightforward replicas like scale models. They do not resemble in substance the thing modelled but are merely similar in certain relations between it parts. In these models representation involves change of medium.

For example:

A. The use of diagrams for electric **circuits.**

B. Hydraulic models for economic supply and demand.

Diagrams of electric circuit only represent the relations and economic supply and demand does lot consist of pipes of carrying fluids. Unlike the scale models, which rely upon identity and aim it imitating the original, analogue models aim at reproducing the structure of the original. It is not

something like a material or pictorial replica but a" structural echo"."

A

As there is a possibility for building the same structural relations in many contents the possibilities of construction of analogue models are endless. The use of different media in which the structure of the original is reproduced increases the chances for fallacious inference from irrelevences and distortion that are invetably present in the model.

3. Mathematical Models:

Unlike in the case of above two kinds of models there is disagreement regarding the existence of mathematical models. Hutten argues that there is no mathematical model in science, especially in physics, where as Mary Hesse[12] strongly argues in her article 'Model in physics' that mathematical formalisms may also function like other types of scientific models, which are used for theorising. She calls these mathemetical formalisms, 'Mathematical Models'. In Social sciences the term 'Mathematical model' became very common but it differs from the sense of mathematical model that is used in developing theories in natural sciences. Hesse says that advent of modern physics necessitated the acceptance of mathematical formalisms as models. She argues that any hypothesis can be satisfactory if it is possible to deduce the data from the hypothesis and the hypothesis itself is capable of being thought about, modified and generalised without referring to experiments done in relation to mechanical models. But in case of modern physics especially fields like quantum mechanics we must not ask for picturable or mechanical models. Only formal mathematical hypotheses can be used. She argues that even a mathematical formalism has its own ways of suggesting modifications and generalizations. As a mathematical formalism behaves like a model, it can be accepted as a model. Let us look at the following examples.Recent world-models, such as Einstein's finite but unbounded space, can not be physically imagined but only expressed mathematically. Same is the case with the conception of curvature of three dimensional space, we can also find models which are hybrids in the sense that mechanical models fused with mathematical models.

The dangers that are involed in using mathematical models are[13] :

1. Drastic similifications that are involed in representing a physical phenomenon as a mathematical formalism causes serious problem of transferring the accuracy of mathem tical formalism to physical phenomenen.

2. Mathem«itical models cannot give explanations though they provide the 'form' of an explanation in terms of functions and equations, they cannot provide causal explanations. Hence, they differ from the mechanical models or theoretical models.

4. Simplifying Models :

The term 'model'is sometimes used to denote systems that deliberately simplify a physical phenomenon. Here the purpose is only to make the particular phenomenon intelligible or to make our understanding or expression easier. This kind of models are called simplifying model. These models are generally, used in applied sciences rather than **pure** sciences as convenient approximations.

For example:

1. Electric current is considered as a flow from positive terminal to negative terminal of an electric source, though the flow of electrons is from negative charge to positive charge.

2. Idealisation of gases.

3. Smoothed out universe in cosmology.

5. Theoretical Models or Mechanical Models:

Theoretical models or mechnical models are the most crucial type of models in natural sciences. The controversies regarding the use of models are none other than the disagreements

regarding the function of theoretical models as these models are very closely connected with the theories themselves. For example, the explanations for the phenomenon of light were given in terms of 'corpuscles'and 'waves' are known as 'corpuscular model of light' and 'wave model of light'. So are 'planetary model of atom' and 'Double helix model of DNA'. But once a theory is fully developed and accepted it is not called a model. Thus, we cannot find anywhere explanation of sound phenomenon being called a'wave model of sound' as wave theory of sound is fully established and there are no alternatives.

Wave model of Christian Huygens (proposed to explain light propagation), Corpusclar model of light put forth by Newton, planatory model of atom, Billiard balls model of gas molecules used in Kinetic theory of gases are examples of this category of models.

Let us see the properties of these theoretical models. Theoretical models are like logical models, interpretations of a semiformal or a formal system. For example, mechanical corpuscular interpretation is an interpretation of Newton's laws of motion. From this interpretation corpuscular model of light propagation is deduced. But it may some times happen that the model may be developed without any formal theory. For example, DNA model can't be said to be interpretation of a formal theory.

Theoretical models are dependent on some familiar system which is epistemologically prior in the sense theoretical model provides the explanation of a physical phenomenon in terms of something which is already known. Hutten in his paper 'The role of Models in Physics' says that a model must be familiar to us to be an aid to explain an unfamiliar phenomenon. We must know how to use it and how to describe it. Otherwise the purpose of using a model, to make clear the meaning of an obscure expression, will be defeated. A theoretical model exploits some other familiar system in order to explain the less established system. This less established system is called explanandum. Max Black though agrees that the model must belong to a more familiar system says:

familiarity is to be taken to mean belonging to well established and throughly explored

theory. Familiarity need not be common experience.[14]

A theoretical model should be richer than the explanandum so as to import concepts and relations into the explanandum. This kind of richness is called by mary Hesse 'opentexture' or 'surplus meaning'. According to her any kind of model generally has this surplus meaning. But what makes a theoietical model different from others and more useful in theory development is that the surplus meaning of the model can be exploited in predictions and explanations. Max Black says:

> A promising model is one with implications rich enough to suggest novel hypotheses and speculations in the primary field of investigation.[15]

According to Hesse's analysis of models,[16] the relation between model and the theory modelled is analogy that includes identites as well as differences. She calls the identites 'positive analogy' and the differences 'negative analogy'. Apart from these positive and negative analogies there is a set of properties in whose case it is not known whether they are positive or negative analogies. This is called 'neutral analogy'. The model is proposed because of the positive analogy. The negative analogy is conveniently ignored. The actual use of a theoretical model involves the exploitation of the neutral analogy which consists of suggestions. These suggestions will be tested by observations. The following examples may make it more clear the use of the theoretical models in theory development.

The use of a model[17] in explanation by Maxwell resulted in a very important theory namely electro-magnetic theory in physics. At that time there were two different schools of thought regarding the electric and magnetic effects. One school considered the electrical and magnetic effects as similar to gravitational atraction. That means, it considered this effect as 'action at a distance". For them the space between the magnetic or electric poles was not important. Other school, mainly represented by Michal Farady, considered magnetic and electric poles to be the starting points of lines of forces which fill the surrounding space and play the role of agents in producing the magnetic and electric effects.

Maxwell accepted Faraday's account of electric and magnetic effects and from this he developed his electromagnetic field theory in which he assumes that in space there is matter in motion, by which the observed phenomenon is produced. Though at first he hesitated to accept Faraday's lines of force as substative he later comitted himself to the view that the lines of force were not mere mathematical abstrations but are:

> the directions in which the medium is exerting a tension like that of a rope or rather like that of our own muscles.[18]

Thus Maxwell gives a model of magnetic field to illustrate Faraday's concept of magnetic induction. According to this model the lines of magnetic force were represented by cylinders rotating around these lines as axes. The magnitude of the magnetic force is represented by the speed of rotation and its direction by the axis of rotation. In a uniform magnetic field, where lines of force are to be parallel straight lines, the cylinders are to rotate in the same direction. To bring out this, Maxwell introduces small spheres like ball bearings between these cylinders. These newly introduced balls are to be given corresponding interpretation as the cylinders are interpreted as magnetic forces. Maxwell considered these balls as corresponding to the flow of an electric current. Thus Maxwell showed with the help of above model that charges in magnetic field can bring out production of electric currents. Apart from this Maxwell's idea of the existence of electric waves led to the discoveries of wireless and radar etc.

The widely known planetary model of atom can also be given as an example of theoretical model. The substantial evidence for the existence of positvely charged and negatively charged particles in atom demanded an account of the arrangement of these particles in the atom. Rutherford's x-ray scattering experiment showed that all the positively charged particles are together forming a point mass, namely, nucleus. Basing on these facts Rutherford imagined the structure of atom by taking solar system as the model. In this the sun is compared with the nucleus and planets with negatively charged electrons. Taking the stability as common point between these

two systems it is established that electrons must be revolving in stable orbits to overcome the attractive force of nucleus,like plantes revolve in stable orbits to overcome the gravitational force of the sun.

The above examples, of course, do not exhaustively represent all the possible theoretical models. However they are sufficient to give us a feel of the essential nature of this most 'important kind of models'. With this brief discussion of some important kinds of models we may now proceed to specify the various features that scientific models as cognitive artifacts exhibit.

One of the central philosophical questions concerning models pertains to the relations between model and thing modelled. Answer to this question from logical point of view obviously makes clear our understanding of the concept 'model' which I tried to explicate with the help of some illustrations. By and large it is agreed that the relation is analogical. The best articulation of this widely held view can be found in Mary Hesse's book, Models and Analogies in Science.

Mary Hesse says[9] that any account of analogy should give the justification for the validity of an argument from analogy. She gives a comprehensive account of analogy by comparing it with mathematical proportionality. According to her

  neither the analysis of types of analogy of classical and medieval logic nor the vaguely
  defined analogies of modern logic.[20]

are adequate to give justification for the reasoning from scientific models. She says that these accounts never considered 'analogy' as problematic, as they took only few cases which are camparitively simple and in which models of scientific enquiry cannot be placed.

The relation of analogy can be fully understood by considering identites and differences.[21] The set of properties which are similar are said to be 'Positive analogy' and the set of differences 'Negative analogy'.
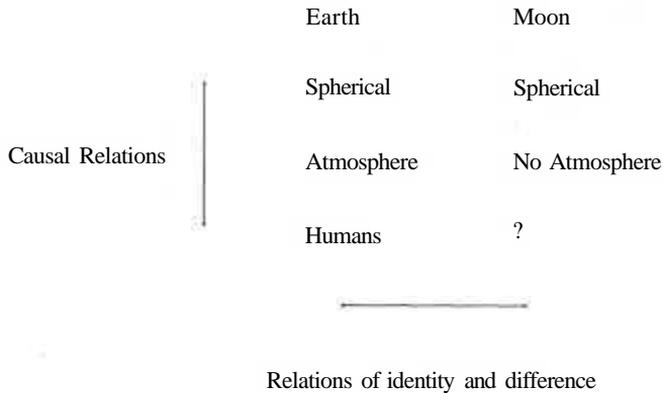
For example, we compare the Earth and the Moon, both are spherical, spatial, opaque,

receiving heat and light from the sun, revolving in orbits and gravitating towards other bodies. These properties can be said to be 'positive analogy'. At the same time the moon is smaller than the Earth, and there is no atmosphere and water on the moon. This is negative analogy between them. Apart from these positive and negative analogies there can be a set of properties of the analogue whose positive or negative analogy is not yet known. This can be called 'neutral analogy'. Actually it is the neutral analogy which only plays crucial role in developing and extending theories with the help of models.

Making the point that similarity relation includes identites and differences Mary Hesse classifies analogy into two types, namely, 'formal analogy' and 'material analogy'. In case of logical models of formal system there will be 'isomorphism' or 'similarity in structure' between the model and the system. Here the same formal axiomatic and deductive relations connect individuals and predicates of both the system and its model. This isomorphism consists of the correspondence between individuals and the predicates of the system and the terms. The terms are their interpretations in the model. In other words, model and the system are two interpretations of the same calculus. Hence, such a kind of analogy is formal analogy. This kind of analogy we can see between a swinging pendulum and an oscillating elecrtic circuit. These two are analogous by virtue of the formal relations described in a wave equation satisfied by both.

In case of some other analogies there will be something more than the formal analogy. This lies in the similarity between the observable properties. Here similarity exibited by the two systems *h* **A** is not merely the similarity by virtue of being logical models of the same formal system. We can find material similarities between the parent system and its replica.Such an analogy is called material analogy. The notion of material analogy is the root of many controversies about models. Agreeing with modellists, who maintain that models are intrinsic to theories and material analogy shall be present between theories and models, Hesse argues that material analogy is very much required for the prediction from models. She characterizes, material analogy by two types of dyadic

relations namely 'similarity relation and "causality relation". Consider once again the above mentioned example of the Earth and athe Moon. If we write the properties of both schematically. You get the following scheme:[22]

	Earth	Moon
Causal Relations	Spherical	Spherical
	Atmosphere	No Atmosphere
	Humans	?

Relations of identity and difference

From the above comparison between the properties of the Earth and the Moon the following two features of the analogy can be noted.

1. one to one relation of identify or difference between a property of one of the analogues and a corresponding property of the other.
2. The relation between properties of the some object.[23]

We find the first feature across the horizontal properties and the second feature along the vertical properties. The horizontal relations are concerned with similarity and vertical relations, at least in most of the cases, are concerned with causality.

Hesse makes this distinction to analyse the argument from analogy. For example, when can we argue for the presence of human beings on the Earth, the validity of the arguments depends on (1) the extent of the positive analogy compared with the negative analogy, and (2) the relation

between the new property (neutral analogy) and the properties already known to be parts of the positive or negative •analogy. If we have reason to think that the properties in the positive analogies are causally related, in a favourable sense, to the presence of humans on the earth, the argument will be strong! If the properties of the moon which are parts of negative analogy tend causally to prevent the presence of humans on the moon the argument will be weak or invalid.

It is very important to note the point made by Marry Hesse regarding the authenticity of the causal relation. She says:

> The use of analogical argument presupposes a stronger causal relation than mere co-occurrence. It does not presuppose that the actual causal relation is known.[24]

Properties of analogical relation[25]:

Comparing 'anal ogical relation' with mathematical proportionality helps to bring out the properties of analogy as these two kinds of relations are closely connected.

Consider the relation 'a is to b' as 'c is to d' is represented by $\overset{o}{V}$: : -jr\ If we consider a and b as the properties of the same analogue and c and d as the corresponding properties of another analogue, respectively, we can express these properties in the manner above just mentioned.

For example 'pitch is to sound as colour is to light' can be written as

$$\frac{pitch}{sound} \; : \bullet \; \frac{colour}{light}$$

By writing the corresponding properties of the analogues in the above form which is generally used to express numerical proportionality, we can see the following properties of analogical relation.

1. The analogical relation is "reflexive".

    i.e, $\frac{a}{b}$: : $\frac{c}{d}$

2. The analogical relation is 'symmetrical'.

i.e, $\frac{a}{b} :: \frac{c}{d}$ then $\frac{c}{d} :: \frac{a}{b}$

3. The analogical relation can be inverted

i.e, Iff $:: |$ then £ : :£

4. There is similarity between the additive property of numerical proportion and the results of taking the logical sum of terms of an analogy. We know that if $\frac{a}{b} :: 4$ then $\frac{a}{b} t \frac{b}{a} = \frac{c}{u} t \frac{d}{u}$. Similarly we can say

$$\frac{\text{Properties of sound}}{\text{pitch}} = \frac{\text{Properties of light}}{\text{colour}}$$

Here properties of sound and properties of light are taken to be just logical sum of terms.

5. There is some resemblance between locating a corresponding term in an analogy and finding the fourth term of a proportionality when the other three terms are known.

For example, take three terms of analogy a,b,c. The relation between 'a' and 'b' (a R b) and c as corresponding to 'a' are given. We can find out the fourth term 'd' in two ways (i) We can find 'd'such that (c R d). (ii) We can find 'd' as related to 'b' is such a way as 'a' is related to 'c'. We can extend this example to an analogical relation . Following the above mode of reasoning we can find out the property,'colour', if we know the relations between pitch and other properties of sound and other properties of light. Other wise following the second mode of reasoning, that means by using similarity, we can find the unknown property, namely, colour.

In this kind of finding unknown terms, the difference between numerical proportionality and analogy is that numerical proportionality gives the unique fourth term, whereas the unknown term given by anology need not be unique.

6. In the analogical relation the horizontal and vertical relations are not of same kind. One is similarity relation and other is causal, whereas in the numerical proportionality both relations are of the same type.

7. In analogy there is no transitivity between three pairs of terms. That means if $\frac{T}{b} : \frac{j}{e}$ and $\frac{t}{a} : \frac{?}{i}$ then there many not be any analogical relation between $\frac{T}{b}$ and $\bullet\frac{}{i}$. Even if there is it may not be the same as the relation between the first two pairs. But in case of numerical proportionaliaty transitivity holds.

Swanson[26] though agrees with the analogical constnTal of model and thing modelled relation questions one of above mentioned properties, namely symmetrycaHty which was accepted by many philosophers like Mary Hesse, May Broadbeck, Braithwaitae etc. Despite many differences regarding the role of models in developing and extending theories it is widely accepted that there exists an isomorphism of structure between model and its interpretation (ie theory or thing modelled). Mary Hesse says:

> most obvious property of a statisfactory model is that it exhibits an analogy with the phenomenon to be explained, that is, that there is some identity of structure between the model and the phenomenon[27].

However, against Swanson and supporting Mary Hesse, Max Black says:

> . . . .the key to understanding the entire transaction (i.e, use of model) is the identity of structure that in favorable cases permits assertions made about the secondary domain to yield insight into the original field of interest.[28]

According to Swanson, philosophers like Mary Hesse have assumed that symmerty is self evident in such a relation between the model and thing modelled. Responding to the above accounts by Hesse and Black he says:

> the crux of these separate accounts is contained in the key phrase 'identity of structure'.[2']

Swanson argues:

this expression is misleading in the sense that it obliterates the essential asymmetry of model and theory, an asymmetry which is the chief source of insight in the use of models.[30]

We know that the general mathemetical definition of isomorphism as a one-to-one correspondence is symmetrical. Swanson defines it thus:

Two theories T, and T_2 are said to be isomorphic if there exists a one-one function 'g' mapping the structure (i.e, the relations and function) of T, and T_2 such that the inverse g^1. Here again whatever x and y you pick, I_{iy} if and only if 1^ (using T for the dyadic relation of Isomorphism).[31]

Swanson says that despite the wider use of the above definition of isomorphism there is another definition of isomorphism which is so framed to show that the relation is not symmetrical. This definition was given by Nelson Goodman in his work The Structure of Appearance in terms of ultimate factors. Swanson says that though Goodman is aware of classical definition of isomorphism, as Goodman:

is concerned with theory construction, not with uninterpreted calculi[32],

he frames his definition of isomorphism in such a fashion that:

the posible sub-structures of the relations in a given theory are not lost sight of in, what is for his purposes, the excessive abstraction of mathematical characterisation of isomorphism.[33]

Let us look at the account of isomorphism by Nelson Good man.[34] Goodman defines relations as ordered n-tuples of elements. A very important character of these relations is that the elements of these relations need not be simple elements or ultimate factors.

For example (a, b) and ((a, b), b) both are examples of dyadic relations, though one of the elements of the second ordered pair it self is an ordered pair i.e, a complex one. From this Goodman says that the extentions of these dyadic relations are sets of ordered couples, the members of which are decomposeable into further n-tuples. These are again decomposeable and so on. This process goes on till we get ultimate factors. Making the point that the elements of a dyadic relation

need not be ultimate elements Goodman states his definition of isomorphism in the following way:

> A relation R is isomorphic to a relation S, in the sense here intended, if and only if R can be obtained by consistently replacing the ultimate factors in S.[35]

Consider S as a set which consists of 1-tuples, A,B,C,D and R to be a set that consists of ordered pairs or 2-tuples (a, 1), (a, 2), (b, 1), (b, 2). By replacing elements A, B, C, D of S with (a, 1), (a, 2), (b, 1), (b, 2) respectively we can get R. According to the above definition R is isomorphic to S. But S is not isomophic to R as we can't get the ultimate factors of S, when we replace A, B, C, D with (a,l), (a, 2), (b, 1), (b, 2). It follows from Goodman's definition that from R is isomorphic to S" it does not follow "S is isomorphic to R".

Now extend the above definition of isomorphism to explain the relation between a model and a theory. We say T_2 (the model) is isomorphic to T, (The interpretation or theory). We cannot say T,, is isomorphic to T_2. If we say so it indicates the existence of the ultimate factors or simple elements in T_2 (The model).

Swanson[36] argues that it should not be the case as a model should have 'deeper structure' than its interpretation in order to be pregnant. He says that it is strange that though:

> a number of philosophers have admitted the need for assuming greater complexity for the model than for its interpretation, they claim for the identity of structure between the model and its interpretation[37]

i.e, theory.He also says that modellists' view that models are intrinsic to theories but not conceptually vacuous devices can't be substantiated unless they accept Goodman's definition of isomorphism. Criticising Mary Hesse's stand that the use of model involves the exploitation of neutral analogy or abstraction from excess meaning, Swanson asks if, as Mary Hesse says, our use of models depends only on the excess meaning of model only and thus discount the richer sub-structure, how can we deny the view that models are only "props for feeble minds or surrogates for some procedure"?[38] He says:

> the notion of a model is non-trivial only if we impute deeper structure to the model than

to its interpretation.[39]

It seems that Swanson's position is quite convinsing and has not been rebuffed by Mary Hesse and has been virtually accepted by Max Black. Hence from our list of the logical features of models we have to exclude symmetricality.

It should also be noted that, though anything can be related with anything including itself, in scientific practice scientists do not use a theory or a system as a model to itself. Hence, the relation between a model and the thing modelled can never be reflexive.

The aim of this chapter was to provide a preliminary account of the concept of the model. This was sought to be done by mentioning the different kinds of models on the one hand and the logical features of scientific models on the other hand . No doubt, the logical features that have been mentioned are exhibited or claimed to be exhibited mostly by one type of models namely 'Theoretical models'. However this does not render our discussion to be partisan. For, theoretical models constitute the paradigm of scientific models. This is borne out by the fact that the important philosophical questions about models concern primarily the theoretical models. The rest of the two chapters pertain to two of those philosophical issues, namely, l.The relation between model and theory, and 2. The relation between model and reality.

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4. Groenewold, H.J.: 'The Models in Physics', *Vie Concept and the Role of the Model in Mathematics and Natural and Social Science,* edited by Kazemier.B.H. and Vuysje.D. P.98.

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6. Tarski, A. : 'A General Method in Proofs of Undecidability' *Undecidable Theories,* edited by A.Tarski, A.Mostowarki and R.M.Robin son, P. 11.

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9. cf. Black, Max: op cit, P.220.

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11. Deshpande, V.N : *Models in Science,* P.5.

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13. cf. Max, Black : op cit, P.225.

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15. Ibid , P.223.

16. Hesse, Mary.B : *Models and Analogies in Science* ,pp.9-10.

17. Deshpande, V.N : op cit, pp. 15-22.

18. Maxwell, James Clerk : *Vie Scientific Papers of James Clerk Maxwell,pp.* 155-156.

19. Hesse, May. B : *Models and Analogies in Science,* P.64.

20. Ibid , P.63.

21. cf. Ibid ,pp.64-70.

22. Ibid , P.65.

23. Ibid , P.65.

24. Ibid , P.93.

25. cf. Ibid , pp.70 - 74.

26. Swanson, J.W.: 'On Models', **British** *Journal for the Philosophy of science, Volume:!7, Nov-1966,* pp.299 - 300.

27. Hesse Mary B: *Forces and Fields,* P.22.

28. Black, Max : op cit, pp.230 - 231.

29. Swanson, J.W : op cit, pp.300.

30. Ibid , P.300.

31. Ibid, P.300.

32. Ibid , P.302.

33. Ibid , P.302.

34. cf Goodman, Nelson: Chap 1, Sec 3 and 4, *Tlie Structure of Appear*p,ce*

35. Ibid, P. 12.

36. Swanson, J. W.: op cit, P.297.

37. Ibid , P.303.

38. Black, Max.: op cit, pp.235-236.

39. Swanson, J. W.: op cit, P.303.

CHAPTER 2

MODELS AND THEORIES

In the history of scientific practice many philosophers and scientists with strong empiricist predilections objected to the use of theories. They wanted scientific activity to confine itself to observations and empirical generalizations based on them. Despite such views, which gradually became feeble, scientific community has continued to theorize and undoubtedly theories are central to scientific practice. The centrality of theories in scientific practice forced philosophers of science to understand the role of theories in the epistemic activity called science.

Though all the major schools of philosophy of science accept the place and role of theories in scientific practice they differ in their conception of theory. Their conception of theory is framed to satisfy their conception of explanation since a scientific theory is considered to give an 'explanation'. Let us briefly look at the different conceptions of theories before understanding the relation between theories and models.

According to positivists the aim of science is to gain predictive and explanatory knowledge of the external world. They hold that explaining an event means showing that the event is an instance of a well-supported regularity expressible in the form of laws. As theories are instrumental in achieving this predictability and explanation, it is necessary to construct theories in scientific practice. Positivists maintain that a scientific theory is a set of highly generalised universal statements, whose truth or falsity can be assessed by means of systematic observation and experiment. These testable statements are labelled as laws. Only these laws enable us to provide prediction and explanation of the discovered phenomenon by means of systematic observation and experiment. Positivists say that the truth of these universal statements is not one of logical necessity. If you say they are true means they are true contingently only. For them there are no necessary connections in nature except regularities. Hence the laws of science are only systematic

representations of the successions of events. These laws must be objectively tested by means of observation and experiment as positivists consider observation as the only means of true knowledge.Thus according to this view laws are the most general statements which constitute a scientific theory. The following characteristics of laws can be delineated.[1]

a) Laws must have the syntactical form of universal conditionals.

b) Laws must not be restricted in their application to any finite region of space and time.

c) None of the terms occurring in scientific laws can refer to particular items.

d) Scientific laws do not express any form of necessity, either logical or causal.

The question that now arises is "How can we construct a true scientific theory?". In other words, "How can we evaluate the attempts that are aimed at the formulation of a true theory?". At this stage the question concerning the relation- between theory and observation becomes important. But the problem is that no finite number of observations can decide the truth or falsity of a law. In solving this problem of induction two schools of thought namely 'confirmationism' and 'falsificatioism' branched off from the orthodox positivist philosophy of science.

According to confirmationists one can use empirical evidence to provide a varying degree of positive support for the truth of scientific theories where as falsificationalists argue that there is no logic of confirmation. They hold that observations can only be used to show that a putative theory is false. That means any prediction that is deduced from a theory if turns out to be incorrect, implies that the theory under consideration itself is incorrect. The confirmationist construal of theories is generally based upon the calculus of probability. As the falsificationists rule out the inductive justification for the confirmation of a theory, they consider that only deductive relationship can be established between theory and observation. Hence for falsificationists the processes of theory evaluation is hypothetico-deductive.

The strong opponents of positivist philosophy of science are realists. They share with the positivists the.view that science is an empirically-based, rational and objective enterprise and its aim is to provide true explanation and prediction. But they differ from positivists in insisting on the primacy of explanation in the pursuit of science. For them explanation of an event does not mean just showing it as an instance of well established regularities. They rule out the positivists' adherence to sensory experience and their consideration that the purpose of science is not to get 'behind' or 'beyond' the sensory experience. They insist that a true explanation must make reference to the underlying structures and mechanisms which are involved in the causal process. They, unlike positivists recognise the element of causal necessity in reality. The description of these structures and mechanisms is the task of theories. Thus the central aim of a theory is to describe the underlying structures and mechanisms and the way they operate to generate various phenomena which we wish to understand or explain.Keeping these interpretations of scientific theories in view we proceed to the role of models in theory-formulation and theory-extension and the philosophical problems that emerge from the use of models in theory-formulation and theory extension.

Despite the differences regarding the role of models in scientific practice it is a well established fact that scientific research uses models in many places in different ways. Though we confine our discussion to a few examples for the sake of convenience it is very important to recognise the multiple role of models. The following few delineations[2] of theory construction give the main motives underlying the use of models.

1. If no theory is known for a certain domain of facts and we have another set of facts for which we have a well established theory and these two sets of facts have certain important characteristics in common then we use the well established as a model to theorise the field under investigation from very basic points.

2. We have a set of facts of a particular domain and for those a theory is established. But it is

mathematically very difficult to get solutions due to inadequate techniques at present. Then we interpret the fundamental notions of the theory in a model in such a way that simplified assumptions can express this assignment. Under these simplified assumptions the equations became solvable. For example, in the study of heat conduction the theory of harmonic oscillators is used.

3. If the two theories are without contact with each other we can try to use one as a model for the other or to introduce a common model interpreting both and thus relating the theories to each other.

4. If a theory is well confirmed but incomplete, we can assign a model in the hope of achieving completeness through the study of model.

5. Having a theory about a set of facts does not mean that we have explained these facts. Of course, positivist conception of theory does not consider this point as important. But in any actual scientific practice it is important. Any way in such cases models can yield explanations.

6. In constructing a theory about an object which is too big or too small or too far away or too dangerous to be observed or experimented upon, model systems are constructed on which we can experiment. This kind of application of models, where scale models are used is not directly connected to theorising or theory development. But this kind of use of models is also very important in scientific practice.

7. If the theoretical level is far away from the observational level, concepts cannot be immediately interpreted in terms of observations. Then models are introduced to construct the bridge between the theoretical and the observational level. Then the theoretical predicates and observational predicates can be interpreted as predicates of the model. In this way the model furnishes relationships between the two interpretations. This intermediary

model can be used to construct the abstract theory.

It is quite possible to find some more functions of models in scientific practice related to theory-construction and theory-extension etc. Though the aims of using models in theorising are different, Leo Apostel in his article 'Formal study of Models' says:

Theory formation, simplification, reduction, extension, adequation, explanation, concretisation, globalisation, action or experimentation constitute a kind of system.[3]

The multidimensional use of models in scientific practice, which aims at theorising can be expressed in his own words more clearly:

It appears indeed that models have been introduced in function of relations between theories and theories, between experiments and theories, between experiments and experiments, between intellectual structures and the subjects using these structures and in all these cases this has occurred in order dynamically to produce new results.[4]

Now, let us look at how a model works in theorising. At this stage the words of Stephen Pepper are very much relevant to understand how we try to explain any new observation. He says:

The method in principle seems to be this: A man desiring to understand the world looks about for a clue to its comprehension. He pitches upon some area of commonsense fact and tries if he can not understand other areas in terms of this one. The original area becomes then his basic analogy or root metaphor. He describes as best he can the characteristics of this area, or if you will, discriminates its structure. A list of its structural characteristics becomes his basic concepts of explanation and description.[5]

This assertion of Pepper regarding the whole context of our epistemic activities is repeated by M.H.Abram when he says:

Any area of investigation, so long as it lacks prior concepts to give it structure an express terminology with which it can be managed, appears to the inquiring mind inchoate - either a blank, or an elusive and tantalizing confusion. Our usual recourse is , more or less deliberately, to cast about for objects which offer parallels to dimly sensed aspects of the new situation, to use the better known to elucidate the less known, to discuss the intangible in terms of tangible. This analogical procedure seems characteristic of much intellectual enterprise. There is a deal of wisdom in the popular locution for "what is its nature?" namely "what's it like?". We tend to describe the nature of something in similes and metaphors, and the vehicles of these recurrent figures, when analyzed, often turn out to be the attributes of an implicit analogue through which we are viewing the object we describe ".[6]

The aim of science is to make us understand a new phenomenon. We try to understand the

new phenomenon in terms of familiar ones. Maxwell, who strongly argued for the use of models in effectual study of science in the earlier days, says:

> The first process therefore in the effectual study of the science must be one of the simplifications and reduction of the results of previous investigation to form in which the mind can grasp them.[7]

Ernest Nagel[8] also says that though a genuinely satisfactory scientific explanation must reduce the unfamiliar to the already familiar, it is dubious at its face value. However, according to him, when it is properly understood it has some merit in it. That is, though Nagel gives only a tentative approval for the view that we explain unfamiliar phenomenon in terms of familiar concepts, it is an obvious fact in scientific practice. We describe an unfamiliar phenomenon in familiar language which is taken from a familiar system namely model. That means model provides an 'interpretation'.

E.H.Hutten in his paper 'The role of models in physics' identifies the following general conditions [9] in using models.

1. Whenever we invent a new way of speaking we must start before language just as we must terminate after language i.e, with an experiment. This condition implies that the aim of using model is to build up new terminology >

2. An exact copy can not be a model. There should be some dissimilarity between model and the thing modelled (Mary Hesse also says that analogy includes similarity and difference).

3. As we are using model to explain an unfamiliar phenomenon we must be familiar with the model, that means we must know how to use it and describe it.

Now, let us proceed to consider in detail the role of model in theorising.Here the views of Hutten are very pertinent.[10] When we use a model it allows us to set up a mathematical equation. From this we can derive other mathematical expressions. That means a mathematical formalism

symbolises the unfamiliar situation or the theory under investigation. To put it in more formal language, model gives the 'syntactic' rules for using the predicates, either theoretical or observational, in which we explain the unfamiliar phenomenon. But any theory can not be equated with the pure syntactic structure. We should also have the references to the mathematical variables of the syntactic structure. In other words, we should know how to interpret the syntactic structure. At this stage model introduces a descriptive key concept and provides 'semantic rules'. Once the syntactic and semantic rules combined together, we can now have a new terminology with the help of which we can describe the unfamiliar phenomenon. Here the point that should be marked is, as the utility of the model lies in the fact that the model is not the theory under investigation, theory and the model are different in a significant way. As there is a difference between theory and the model, the model always can give only a partial interpretation. In other words, though model and theory share the same syntactical rules,(as an equation is always capable of many interpretations) the model can not give all the semantic rules. Thus a model is only used to introduce technical concepts and to construct more advanced theory which does not directly relate to experiment.That means the model bridges the gap between experiment and theory.

Mary Hesse" in her paper 'Models in Physics' delineates the characteristics of the models which enable us to understand the role of models in theorising and her view supplements the above account. Arguing that even the mathematical formalisms can be models-a view which was not accepted by some of the philosophers like Max Black and E.H.Hutten-she tries to give a partial definition of models. She says that models including mathematical formalisms, mechanical and other imaginable or picturable models have two characteristics, namely, 'Formal rules' and 'Pointers'. The description of these two characteristics can throw light on the role of models. According to Hesse a model must have a necessary internal structure which may consist simply of axioms and rules of inference of a mathematical formalism. These are only formal rules. These formal rules can be equated with the 'syntactical rules' of the above account. It is obvious that a model can not be simply a system of formal rules as it has some suggestions implicity for the

extension and generalisation of a theory. If we have a formal system consisting certain axioms and rules of inference which are internally consistent, it is quite possible to reach another formal system by making some additions to and generalisations of the original system. The modifications or generalisations are pointed by the model. In case of mathematical models they are suggested by mathematics, and in case of mechanical models the additions to the formal system are suggested by the empirical behaviour of the undertaken mechanical process when certain features of the process, which were previously neglected, are taken into consideration. The following example makes it clear.

In case of elastic sphere model of gas the original ideal gas equation is $PV = RT$. When gases are considered as composed of elastic spheres and their radii are taken into account, which were previously neglected, the calculus or the formal system of the molecular theory of gases changes to $(P + y5^\wedge (V - b) = RT$. This equation which is called Vander Waal's equation is a more accurate description of the behaviour of gases than the original law.

The pointers of the model are generally contained in a haze of mathematical and physical surroundings of the model. These pointers can be useful for the further extension and some times are misleading, when we take into consideration wrong pointers like the colour of the billiard balls. The colour of the billiard balls will not be helpful for the extension of the theory where as elasticity is a useful concept because it can be cited in the theory of collision. This concept points to an addition to the formal system of the molecular theory of gases and thereby brings the theory nearer to the experiment. There can be any number of pointers for a model. Hesse underling the creativity in scientific practice, says that there are no rules to pick out these pointers.

It is also important to take into account the view which compares the role of model with the role of a metaphor. This view, which was first mentioned by E.H.Hutten in his paper 'The role of Models in Physics' was latter extensively discussed by Max Black in his articles 'Metaphor' and 'Models and Archetypes'. Hutten says:

> We are forced to employ models when, for one reason or another, we can not give a direct and complete description in the language we normally use. Ordinarily, when words fail us we have recourse to analogy and metaphor. The model functions as a more general kind of metaphor.[12]

But he says that metaphor only suggests the rules of usage whereas model specifically indicates some of these rules. In other words metaphor suggests the meaning of an expression without precision whereas model specifies the meaning of an expression. Max Black, though has his own conception of precision of scientific language, argues that model works like a metaphor. He says that model also like metaphor bring together two separate domains into cognitive relation by a distinctive operation of transfer of the implications.

The main objection against the use of model is that a model may be a 'potential intellectual trap' and an 'invaluable intellectual tool'. Earnest Nagel[13] argues that the danger involved in formulation of a theory in terms of a model is that some inessential feature of a model may be wrongly assigned to the theory. He also argues that the model may be confused with the theory itself. As far as the first objection is concerned it is accepted that there may be 'pointers' which are misleading. The above objection is mainly rooted in the concept of scientific practice as an extremely rule governed practice and in neglecting the role of creativity in scientific practice. Scientific practice is undoubtedly a trial and error process that does not involve a cut and dry method. The second objection can be easily ruled out as the success of a model is based on the differences between the model and theory. That is to say, the confusion between a model and a theory, though a distinct possibility, can be detected sooner or later in the course of our scientific practice itself.

Having shown the role of model in the theoretical context of scientific practice, I now discuss the second of three questions which were delineated in the first chapter. Answers to the question, "Are models intrinsic to theorising or are only heuristic devices?" given by different schools of philosophy of science are very important as they emanate from various construals of explanation and theory. If an answer to the above question is successfully established it becomes the

justification for their construal of science. Some philosophers, mainly positivists, woulfi gany that models are intrinsic to theorising. Some philosopher like N.R.Campbell, Marshall Specteraacd'5H the Realists strongly oppose the above view and they try to show that models are indispensable to theorising by giving a new description of the concept of 'theory' itself. Though the question seems to be related only to the role of models , the debate is only an aspect of continuing controversy between the positivist and the realist interpretations of scientific theories. Let us try to locate the problem regarding the role of model in this long time controversy.

Many of the philosophical problems have their roots in the differences between empirical laws and scientific theories. Take the example of Boyle's law and the Kinetic theory of gases to distinguish an empirical law from a scientific theory. In Boyle's law we find descriptive terms which refer to observable or measurable objects and in Kinetic theory we find terms like 'molecule' which refer to unobservable objects. Basing on such a distinction descriptive vocabulary of science is divided into the observational and the theoretical vocabulary. From this it follows that a theory is a set of statements which contains at least one theoretical term among its descriptive terms. Explaining the nature of these theoretical terms became an important problem in philosophy of science. In an attempt to solve this problem philosophers of science tried to understand the role of theories in science. The basic questions regarding theories which are indirectly but strongly connected to the role of models are:

1. What is the structure of a scientific theory and how does the scientist use the theory ?

2. How should we understand the theoretical terms that refer to unobservables ?

3. Do these theories necessarily presuppose the existence of the theoretical entities and if so, how do the scientists know that these entities exist ?"

Carnap gave the standard positivist conception of the structure of a theory. According to him a theory is a partially interpreted formal system and its axioms contain both observational and

theoretical terms. From these axioms, with the help of inference rules, the consequences of the theory namely laws will be deduced. He says that even though the primitive theoretical terms are not interpreted the scientists know how to derive non-theoretical consequences. Such a structure of theory enables the scientist to explain data and to predict the occurrence of future events. Hempel says that certain axioms which relate the observational and theoretical terms play an important role in the interpretation of the theory. These axioms which are called 'interpretative sentences' or "correspondence rules" enable the axioms which contain theoretical terms to have empirical consequences.

The view regarding the structure of the theories that was proposed by Carnap was accepted by almost all positivists and some others as well. But many philosophers objected to the positivist conception of theories and even the possibility of drawing distinction between theoretical and observational terms. Philosophers like Maxwell Grover and Peter Achinstien successfully showed that the distinction that is drawn by positivist between theoretical terms and observational terms can not be justified. They say that this distinction is only based on our present state of knowledge and the instruments available to us. Hence, according to them the controversy regarding the ontological status of theoretical entities itself is a pseudo-controversy.

At this stage another group of philosophers of science which includes people like N.R.Campbell, E.H.Hutten, Marshall Spector approached the problem from a different point of view, which caught the attention of all schools of philosophers of science. They argue that the positivist construal of theory-structure is not adequate as it lacks the most important aspect namely 'analogy'. They say that positivists failed to give the proper account of the role of models in understanding and developing scientific theories. According to them a model of a theory is a complete interpretation of the theory and this interpretation makes the statements of the theory true.

Now let us look at the arguments regarding the intrinsicality of models to theorising.

The problem regarding the nature of the role of the models can be traced to the second half of the nineteenth century. The question:

Is it necessary for a theory to be understood in terms of some analogy or model?[14]

came into limelight when scientists were forced to give up the mechanical models of the ether as they failed in explaining the phenomenon of light and electromagnetism. The first person who attacked severely the use of models was the French physicist Pierre Duhem. In 1914 Duhem in his book 'La The'orie Physique' criticized the English tendency of using models in explaining a new phenomenon. According to him only the continental science had the elegance of the abstraction and systamaticity, which he considered as the hallmark of scientific knowledge. The following words of Duhem make very clear his position regarding the use of models:

> Here is a book (by Oliver Lodge) intended to expound the modern theories of electricity and to expound a new theory. In it are nothing but strings which move around pulleys, which roll around drums which go through pearl beads...toothed wheels which are geared to one another and engage hooks. We thought we were entering the tranquil and neatly ordered abode of reason, but we find ourselves in a factory.[15]

His main objection to models is that models are incoherent, superficial and distract the explanation from the logical order. He says that models are not built for satisfying the reason but for the pleasure of imagination. For him , the essence of a theory consists in it's economic and systematic order, but not in analogy.

Though Duhem is against using models in theorising he admits that the mechanical models may be useful psychological aids in understanding and extending theories. But this concession is in no way amounts to accepting the position of 'modellists', who argue that models are intrinsic to theories, because psychological aids might include anything like astrological beliefs and dreams. It is said that German scientist Kekule formulated the structure of the Benzene, after having a dream of a snake biting its tail. But now it is not necessary to mention the dream of Kekule in explaining the structure of Benzene, though it helped psychologically in formulating Benzene circle. Modellists are not obviously referring to this kind of aids when they are arguing that models are essential to

the logic of scientific theories.

A systematic form of the argument in favour of the essential dependence of theories on models was first developed by N.R.Campbell. Campbell in his work 'Physics, the elements' attacks the view that models are not essential to theories-a view upheld by his contemporaries like Heinrich Herz, Ernst Mach, Pierre Duhem etc. He starts his arguments by describing what he considers to be the structure of a theory which later came to be called hypothetico-deductive form. According to Campbell" a theory is a connected set of propositions which can be divided into two groups, namely, 'hypothesis' and 'dictionary'. The propositions which constitute the hypothesis are incapable of proof or disproof. Though these propositions are significant, when taken apart from the dictionary they are meaningless and arbitrary. These propositions provide the ideas, through 'definition by postulate' which are characteristics of the hypothesis. There will be some ideas or terms which are related to the terms of the hypothesis by means of dictionary. It is possible to know the truth or falsity of the propositions involving these terms. These propositions are only laws. Dictionary relates these laws which are deduced, with the propositions of hypothesis stating that if the first set of the propositions is true then the second set is true and vice versa.

Campbell illustrates the above account of the structure of a theory with the help of Kinetic theory of gases. He says that the above mentioned structure namely Hypothetico deductive structure is not adequate for an explanatory theory. Any structure of theory should allow hypothetical terms or theoretical terms. The theoretical terms can't be given any explicit empirical interpretation by this structure as the theoretical terms are not present in the dictionary. He shows that Kinetic theory of gases which is accepted as a scientific theory has two characteristics. One is the structure which consists of a hypothesis and a dictionary and the other, which renders the theory cognitively valuable namely "analogy". The propositions of the hypothesis must display analogy to some known laws. He criticises philosophers of science for being least inclined to understand the intimate connections between analogy and hypothesis, in other words, analogy and theory (Theory is

nothing but a 'proved' hypothesis). He holds that analogies are an utterly essential part of theories and any theory without analogy would be useless. The view that analogies are only "aids" to the development of theory can be true if physical sciences are purely logical sciences and aimed at the construction of a set of propositions which are logically connected. He says that finding the analogy which helps in establishing a theory is really a check on theory construction. Taking a dig at his opponents he says that any body can invent a logically satisfactory theory to explain a law, and the difficulty lies in finding a theory which will explain the laws logically and at the same time displays the requisite analogy.He strongly opposes the view that analogies i.e, models are only heuristic devices in establishing a theory saying:

> To regard analogy as an aid to the invention of theories is as absurd as to regard melody as an aid to the composition of sonatas. If the satisfaction of laws of harmony and the formal principles of development were all that were required for music, we could all be great composers; it is the absence of the melodic sense which prevents us all from attaining musical eminence by the simple process of purchasing a text book.[7]

Campbell says that view regarding models as mere heuristic devices is rooted in the false opinion regarding the nature of theories. Some fail to see 'hypothesis' as a distinct set of propositions and consider it merely as a law of which full proof is not yet forthcoming. The view Campbell opposes, finds its echo in Negel who in his The structure of science, perhaps the last classic in the positivist tradition in philosophy of science says:

> …. the distinction between experimental laws and theories is not a sharp one and that no precisely formulated criterion is available for identifying the statements to be classified under these rubrics.[18]

Opposing such a view Campbell says theory is not a law as it can not be proved by a direct experiment like a law. In case of a law the method by which it was suggested is not important; for, its truth or falsity can be established experimentally. But to accept a theory, any additional experimental verifications are not necessary. Boyle's Law and Gay-Lussac's law were already established before formulating Kinetic theory of gases. A theory is accepted not because it gives some valuable experimental knowledge, but on account of the analogy by which the theory is suggested. Apart from this, a theory, unlike a law, contains hypothetical terms, which are not

completely determined by experimental procedures or results. He says that people who are only interested in final products like laws, can only simply ignore the way they are attained and consider 'analogies' as dispensable. He also says that though a theory can be logically equivalent to a set of laws, what it means is different from what it asserts. It is this distinction which is the most important in understanding how a theory explains. A theory is valuable only if it evokes new ideas which laws cannot do. In support of his view Campbell argues that model is essential to theory because without the model the theory is not intellectually satisfying as an explanation of the empirical data. The model allows or enables theory not only to modify and extend itself but also to predict laws, a very important property of theories which they can possess only if they display some kind of material analogy

R.B.Braithwaite," who opposes Campbell's view argues that models may be psychological aids in attaining 'semantic ascent'. But they are not essential to theories. He starts his argument by pointing out the isomorphism between the structure of a model and a theory. According to him a theory and a model for that theory can both be expressed by the same calculus. That is model is another interpretation of the theory's calculus, which need not JC be sound. As answer to the question, "why use models at all?" in scientific thinking , he says that if there are no unobservable non logical concepts namely theoretical concepts in the initial hypotheses there is no point in using models. But in almost all the cases the initial hypothesis of a theory contain these theoretical terms. Understanding these theoretical terms is obviously a fundamental problem in philosophy of science. Philosophers like Campbell think that these theoretical terms, there by the explanatory hypothesis of the theory, can be understood by representing the theory by a model whose structure corresponds to the calculus of the theory but in which all the concepts are familiar. With the help of correlates of the theoretical terms in the model which are familiar, the theoretical terms may be understood. He characterizes the modellist view of scientific explanations as:

> a stage-by-stage doctrine: Theory T, has to be understood by constructing a model for it, all of whose concepts are observable: Theory T_2 can be understood by constructing a model for it with the concepts of theory T, and so on".[20]

Braithwaite tries to show that the view of the modellists that the modelled theory will be stronger theory than the bare theory is not sound. Modellists argue that a model is predictive in a way in which the bare theory is not. Model gives new generalisations at observational level apart from giving the understanding of the theoretical terms, which the theory itself cannot provide. Braithwaite delineates from the account of Campbell four possible predictive novelties that can come out of the model. The possible ways to draw these predictive novelties are 1. with out changing the initial hypothesis, 2. adding an extra hypothesis relating a new observable property to the theoretical concepts, 3. adding an extra hypothesis relating together theoretical concepts of the theory, and 4. adding extra hypothesis containing new theoretical concepts. These four possibilities of which at least one is necessary for extending or developing a theory can be actualised, according to modellists only by the use of models. This is precisely the claim that Braithwaite questions. In other words, Braithwaite questions whether and if at all how much the employment of a model assists in providing any of above predictive novelties. He says that in the case of first type of predictive novelty any proposition that can be obtained from the model can be obtained from the theory also as there is no exact addition in the axioms of the calculus , which is same for both model and the theory. Hence the contribution of model is nothing in theory development. Same is the case with the second type of predictive novelty also. In this case a new proposition of the model, relating a new observable property to the theoretical concept is added to the calculus. Braithwaite says that the difficulty in this case lies in discovering such an observable property. In other words, passage from observational language to theoretical language is not possible. Braithwaite, though rules out the assistance of models in first and second type of predictive novelties, says that the claim that model can provide genuine assistance in theory development is likely to be plausible in other two cases. The reason for this is that in the case of third type there is an addition of a proposition to the axioms of the calculus which gives the relation between the theoretical terms. And in the case of fourth type there is an addition to the number of theoretical terms. It may be true that the model may point towards its extension unlike a bare calculus, since model tries to interpret theoretical

terms in terms of familiar concepts and there can be propositions generated by using model which relate these familiar concepts. That means model can provide suggestions of how the theory can be extended. Braithwaite, though accepts that model can provide suggestion for theory extensions, rules out the view that pointing towards extension provides an argument for inferring from the known features of the model to unknown features of the theory. He says that though the model suggests extensions of the theory,the question whether the theory will bear extensions of its initial hypothesis can only be settled by experimental test. In such testing model has no role to play. Hence, the claim that modelled theory can have more predictive power than a bare theory, that is ,the claim that model is intrinsic to theory can't be justified. It is obvious that Braithwaite by acknowledging that models suggest, if not bring about theory development is more liberal vis-a-vis a hard core anti modellists who rejects any relevance of model for theory development.

To the question of the modellists "what is it to understand a theory?" or "How can theoretical concepts be understood without considering a model in which there are familiar terms corresponding theoretical terms?", Braithwaite gives an answer which can be labelled as 'contextualism'. The same view is also upheld by Quine, Carnap, Einstein, Frank and Hempel. According to contextualism the meaning of a theoretical term is completely derived from the empirical consequences which are drawn from the theory. Here the meaning of a theoretical term is considered as contextual but is not identified with explicit empirical meaning. An understanding of the meaning of a theoretical term means understanding the role it plays in the calculus of the theory in relation to other terms.

In answering the further question of modellists, namely, "If contextualist account of meaning of theoretical terms is adequate, why do scientists use models?", Braithwaite says that a complete understanding of theoretical terms requires 'semantic ascent'-an ascent from thinking of things from thinking of symbolism. In explaining a theory we have to consider the uninterpreted calculus. Many people find it difficult to understand uninterpreted calculus. Hence they follow the easy method -

thinking of the deductive system in terms of model whose concepts are familiar and then formalising the model as the calculus. In this process of passing from the uninterpreted calculus to model and then to the theory which is expressed by the same calculus, the model should be disinterpreted forgetting the non-logical terms or theoretical terms and this disinterpreted calculus will be reinterpreted as a scientific theory. The advantage in this stage-by-stage and round about way is that at any point there is no need to consider the uninterpreted calculus. The advantage in this process of interpreting the calculus is only psychological. Of course, 'semantic ascent' cannot be avoided. According to the Contextualists semantic ascent in principle, if not in practice does not require the use of model. Hence, Braithwaite concludes that the modellists' claim that their account of a theory which incorporates model as an essential part cannot be justified.

Marshall spector[21] in his article 'models and theories' criticises Braithwaite's account of the role of models. He says that Braithwaite's account is inadequate as it does not make room for certain factors which do legitimately arise from the use of models. He says that Braithwaite's explication of a model as just & another interpretation of the theory's calculus includes other things which are not considered as models by scientists. He provides a major amendment to Braithwaite's explication of models. He says that if only identity of formal structure is sufficient between a theory and its model, as Braithwaite says, there may not be any relevant connection between the subject matter of the model and that of the theory. Spector maintains that there must be a substantive analogy between the observable properties of the domain of the theory and the corresponding properties in the domain of the model. This is what Hesse and Campbell mean when they say that there must be some material analogy between the theory and the model.

It is also important to take note of the more extreme view of anti-modellists. They hold that no interpretation of all the theoretical terms is required. Hence, for them, a model which is mainly used for proving interpretation to the uninterpreted calculus of a theory becomes a mere heuristic device. They view theory as a black box. When data are fed into it, predictions would emerge

without any question regarding the meaning of the theoretical terms, which they consider as mere parts of deductive machinery. The liberal version of anti modellsim which is called contextualism may accept that models provide. suggestions for extensions of the theory. But according to the above mentioned extreme form of anti modellism models are only 'props for feeble minds'.

Let us try to evaluate the above accounts of role of models in theorising which are based upon their respective conceptions of theory and explanation. Against the anti-modellist view, it may be noted, that both of its versions presuppose a hard and fast line between observational terms and theoretical terms. If there is one significant point that is made by the post positivist philosophy of science it is the point concerning the theory la denness of the observations. The theory la • denness of the observations has been convincingly argued out by Popper, Hanson, Kuhn, Feyerabend and many other eminent philosophers of science. Kuhn and Feyerabend take radical stance by denying even a relative autonomy of observations. The idea of theory la deness of observations sets at
distinction
naught the hard and fast between observational and theoretical terms.

Further, the anti-modellists have highly questionable conception of a scientific theory. According to it a scientific theory is essentially a deductive structure with an interpretation. But such a view of theory is totally a-historical. After all scientific theories are put forward in order to answer a specific question or a set of questions. Disentangling a scientific theory from the question to which it is addressed and its ultimate ontological presuppositions as well as the consequences would lead to a conception of theory which in no way squares with actual scientific practice. It is true that by and large scientific theories, at least in some areas, have a deductive structure. It may also be true that the deductive idea is the guiding motto of all scientific theorising. But from this it doesn't follow that deductive character constitutes the essence of scientific theories.

Though contextualist version of anti-modellism appears to be more liberal than the other version in so far as it construes meaning of theoretical terms as a function of the contextual totality is extremely narrow in its construal of 'context'. No doubt, the context of the theoretical concepts is

grasped in and through the context. But the 'context' cannot be exhausted in terms of the location of a theoretical term as determined by the syntactical rules of the deductive structure called theory. Such a notion of context is too bloodless to be of use. Understanding the way theoretical terms are taught and learnt is a process which is very complex. The complexity has been lost sight of by both the older positivists according to whom to learn a theoretical terms is to know the necessary and sufficient conditions of its application and the contextualists according to whom the syntactical rules do the job of identifying the context. Identifying a context of a theoretical term is to know more than its location in a deductive system - a point underlined by the need for an act of ostension. In fact it is even more than that. The complexity of the process is very well brought out by Kuhn. He says:

> If I were to exhibit to you the deflected needle of a galvanometer, telling you that the cause of the deflection was called 'electric charge', You would need more than good memory to apply the term correctly in a thunderstorm or to the cause of the heating of your electric blanket. Where natural-kind terms are at issue, a number of acts of ostension are required. . . . (further) establishing the referent of a natural kind term requires exposure not only to varied members of that kind but also to members of others to individuals, that is, to which the term might through a multiplicity of such exposures the student can acquire …. the *feature space* and the knowledge of *salience* required to link language to the world.[22]

It is precisely this that a model facilitates. It is through the models that we read the map that we have constructed in the form of theories. In other words, models are constitutive of scientific theorising and not extraneous to them precisely because it is the models which hook the theoretical terms onto reality. This directly takes us to the next question "How are models related to reality?", which we discuss in the next chapter. However it must be noted that many times scientific theories speak not directly about nature but only about models. There are many important scientific theories which speak about models only, rather than about nature. It is relevant to note what Kuhn says in this connection:

> Bohr's atom model was intended to be taken only more or less literally: electrons and nuclei were not thought to be exactly like small billiard or ping-pong balls; only some of the laws of mechanics and electromagnetic theory were thought to apply to them; finding out which ones did apply and where the similarities to billiard balls lay was a central task in the development of the quantum theory. Further more, even when that process of exploring potential similarities had gone as far as it could (it has never been completed), the model remained essential to the theory. Without its aid, one can't even

today write down the Schrodinger equation for a complex atom or molecule, for it is to the model, not directly to nature that the various terms in that equation refer.[23]

Thus, whether theories speak about models or about nature through models, models are indispensable components of theories both from the point of view of their function (ie., prediction) and content (ie., meaning). It is the recognition of their intrinsic relation with theories, that has brought the concept of model to the forefront of philosophical reflections on science. In fact this very recognition has shed a great deal of light over the question regarding the relation between reality and our scientific representation of it - a question which concerns the nature of scientific creativity. It is to this issue of seminal epistemological significance that we turn in the next and final chapter.

NOTES

1. Keat, Russell and Urry, John : *Social Theory as Science,?.* 14.

2. Apos^tel, Leo:'Towards the Formal Study of Models in the Nonformal Sciences', *The Concept and Role of Models in Mathematics and Natural and Social sciences,* edited by B.H.Kazemier and D.Vuysje,pp.l-2.

3. Ibid; P.3.

4. Ibid; P.3.

5. Pepper, Stephen.C -.*WorldHypotheses,* pp.91-92.

6. Abrams, *M.H:Tlie Mirror and the Lamp,*pp.31 -32.

7. Maxwell, James Clerk: *The Scientific Papers of James Maxwell,pp.* 155-156.

8. Nagel, Ernest; *Structure of Science: Problems in the Logic ofScietific Explanation,* P. 107.

9. cf. Hutten, E.H:The Role of Models in *Physics',British Journal of Philosophy of science, Volume I,*pp.286-287.

10. cf. Ibid;pp.288-289.

11. Hesse, Mary.B:'Models in Physics',*British Journal of Philosophy of science, Volume* V,pp.212-214.

12. Hutten, E.H: opcit,P.289.

13. Nagel, Ernest: opcit, P. 115.

14. Hesse, *Mary.B:Mode!s and Analogies in Science,?.* 1.

15. Quoted in Hesse,Mary *Models and Analogies in science,?.*

16. cf.Cambell,N.R:'What is a theory',*Readings in Philosophy of science,* edited by Baruch.A.Brody,pp.258-263.

17. Ibid;pp.259-260.

18. Nagel, Erenst: qpcit, P. 106.

19. cf. Braithwaite,R.B;'Models in Empirical sciences *'Readings in Philosophy of scince,* edited by Baruch.A.Brody,pp.270-275.

20. Ibid;P.271.

21. cf. Spector, Marshall:'Models and Theories',*Readings in Philosophy of science,* edited by Baruch.A.Brody, pp.279-286.

22. Kuhn,Thomas.S:'Metaphor in science',*Metaphor and Thought,ypA* 12-413.

23. Ibid; pp.414-415.

CHAPTER 3

MODELS AND REALITY

The explication of the role of models done in the second chapter establishes the indispensability of models for theorising. Following Campbell's and Hesse's arguments we concluded that models play crucial role in providing predictivity to theories. Apart from this, it was shown that models provide interpretation or meaning to the theoretical terms that occur in theories. Now the question that logically follows from the above conclusions concerns the relation between models and reality. The question, which we try to answer in this chapter, "How are models and reality related?" that is, "Do models represent reality, and if, so how?" is a special case of the central problem of epistemology, namely, the problem of truth.

Some philosophers of science while accepting models as essential ingredient of theories in the sense they provide predictivity to theories and meaning to the theoretical terms, deny the ontological status of the objects, corresponding to a model. Campbell, who strongly opposed the view that models are mere heuristic devices in theorising, does not commit himself to the existence of the putative entities corresponding to the model. The view according to which it is not correct to interpret models as representing or corresponding to a reality or a set of real entities is called Anti-Realism. Against such an anti-realist view scientists like Maxwell and Lord Kelvin strongly argue for the necessity of the existential use of models.It also seems to be the general feature of the scientific practice of great scientists like Rutherford and Bohr. When they were presenting their explanations in their respective fields, it seems they conceived themselves to be describing the phenomenon as it is but not presenting 'a mathematical formula in fancy dress'.[1]

Though Maxwell at first regards Faraday's lines of force as purely geometric conceptions he later says that the lines of force:

must not be regarded as mere mathematical abstractions. They are the directions in which

the medium is exerting a tension like that of a rope, or rather, like that of our own muscle.[2]

Maxwell says that the price paid for the ontological unbelief of the mechanical medium consisting of lines of force is the explanatory power of the theory. A contemporary of Maxwell, Lord .Kelvin in his account for the existence of ether says:

> we must not listen to any suggestion that we are to look upon the luminiferous ether as an ideal way of putting the thing. A real matter between us and the remotest stars I believe there is and that light consists of real motions of that matter. . . . .We know the luminiferous ether better than we know any other kind of matter in some particulars. We know it for its elasticity; we know it in respect to the constancy of the velocity of propagation of light for different periods.... luminiferous ether must be a substance of most extreme simplicity. We might imagine it to be a material whose ultimate property is to be incompressible; to have a definite rigidity for vibrations in times less than a certain limit, and yet to have the absolutely yielding character that we recognise in wax like bodies when the force is continued for a sufficient time.[3]

Thus the realistic interpretation of models has a very respectable history.

However Braithwaite can be said to be the first man who presented the most precise explication of the status of models from the anti-realist point of view.[4] He says that identifying the objects of the model with the objects of the theory is a logical error. In other words, the question of the reality of the objects of the model does not arise at all. For him, thinking of a scientific theory in terms of a model is just 'as-if thinking but not 'as-being' thinking. Marshall Spector in his paper 'models and theories' says that the question regarding the reality of the objects of the model, legitimately arises. He says that Braithwaite's explication of models as just another interpretation of theory calculus is inadequate. If the identity of the formal structure is the only thing then required there will not be any connection between the subject matter of the model and that of the theory. But in actual scientific practice scientists do not consider as model these kinds of systems which have only identity of formal structure. A geometrical interpretation of the calculus of a theory cannot be a model. The following example[s] of elastic sphere model of gases makes Marshall spector's position more clear.

In the calculus of the kinetic theory of gases, some terms are interpreted as designating observable or measurable properties of the gas like volume, pressure and temperature and some other

terms are interpreted as designating unobservable entities, namely, molecules. Here the important point is that some terms of the original calculus when interpret to represent the theory or the model have the same designation. For example, the expression for the total rate of momentum transfer per unit area to the walls of the container. This is nothing but force per unit area which is the pressure on the walls of the container. This shows that the interpretation of the calculus in the theory and in the model not only has a formal identity but also a substantive identity. This kind of identification which we have seen in the case of pressure is equally true in the case of volume also. On the basis of the above mentioned identities we can say at least that, gases behave as if they were composed of small elastic spheres. We may feel that some more conformation is needed through experiments before we claim that gases are composed of elastic spheres. The 'molecular beam' experiment furnishes the conformation test. By a suitable experimental arrangement we open a slit on the wall of the container of gas. The result of this will be the same as in the case of a stream of small particles having a certain mean kinetic energy coming from the slit in accordance with the dynamics of such particles. Thus this experiment completes the analogy between the properties of the theory and of the model and thereby warrants us to identify the objects of the theory with the objects of the model.

The above example clearly shows that for any system to be used as a model, mere formal identity with the original system is not sufficient as Braithwaite argues. There must be a substantive similarity between the designata of the defined terms of the calculus when it is used to represent the observable properties of the theory and corresponding properties of the model. Here the point that should be underlined is that, if there is more than similarity (that means an identity of the properties) the model is no longer merely a model but qualifies as' candidate for reality'.[6]

However, there are reasons for the Anti-Realists like Nagel and Braithwaite to deny that models are candidates for reality. They consider identifying or confusing model with the theory is dangerous, because the implications of the model when assigned to the theory may turn out to be false. This objection arises from overlooking the possibility of exclusion of negative analogy between the model

and the theory, if the implications of the model are not relevant to the theory, they can be excluded. Apart from this, the above objection can be made against any theory in the sense that not only from models but also from a theory wrong implications can be drawn. Another objection of the anti-realists, against making existential claims regarding the models is, that models are deliberate simplifications and distortions of the actual situations. Hence they cannot be identified with the theories. It is true that models are used sometimes as intended simplifications in scientific practice. But this is not always so. There are models whose texture can be as complex as theories. Infact even theories involve selection of particular features of phenomena and thus are simplifications.

The main objection that is rooted in a very crude concept of representation - that is a simple copy theory, is that though models are accepted as essential ingredients of theories there is no evidence for endowing them with 'reality'. That is to say, the objection is that, since in no straight forward sense models can be copies of reality. Models cannot be considered as representations of reality and hence realism is wrong. Wartofsky in his paper 'The model muddle: proposals for an immodest realism' rules out the crude or naive concept of representation and proposes a sophisticated representationalist account of theories and models to maintain realism. Watrofsky refuses to take the simple-minded notion of picturing as a paradigm of representation. He says that the view basing on the copy theory-that scientific theories and models do not look like what they are theories and models of-is nonsense. On the contrary, he argues that even the 'pictures', 'copies' and 'mirror images' are the most complex cases of representation and not basic ones. We consider them as basic because they are very familiar forms of representations to us. Hence models are pictures of what they model when allowed the above complex sense of picturing. Models are pictures which refer to something. Though anything can be model of anything including itself, we do not use a particular thing as a model of itself. In other words, modelling relation cannot be reflexive. Hence the reference of the model is something outside it which is real. To use Kemeny's expression they are 'intended factual true descriptions'.

Watrofsky also proposes[7] to abandon the distinctions between analogies, models, theories etc., not because these distinctions cannot be made but because that they exhibit essential commonality. He gives a typology of models in terms of ad hoc models, computational models, as-if models etc.,. He says that this typology of models is based on the degree of existential commitment which each type suggests. He argues that:

> these distinctions among degrees of belief or existential commitment need to be supported by an analogy of the ways in which models of all these types represent: therefore, not simply an analysis of their structural properties, but of the relation between such properties and the purported reference of the models.[8]

In support of his representationalist account Watrofsky provides a brief analysis[9] of language as essentially descriptive and thus representational and words as essentially referenial. Watrofsky takes a position opposite that of philosophers for whom the idea of mirroring nature is a delusion. His attempt is an attempt to rehabilitate 'truth' which has been somewhat undermined by post-positivist trends. He says:

> we begin modelling, therefore, with our first mimetic acts and with our first use of language. And we continue modelling by way of what on various grounds, have been distinguished as analogies, models, metaphors, hypotheses and theories. The immodesty of the activity lies in this. If I am right, then more of our activity is truth seeking than we know or acknowledge, generally. For models purport reference and reference purport truth and falsity. There may be more analytic sense than poetry in the characterization of man as a truth-seeking animal.[10]

Thus Watrofsky establishes that models, theories analogies etc., are species of the genus called representation and they are intended descriptions. The above accounts of Marshall Spector and Watrofsky show us that models (and therefore theories as well) do represent reality. Now it needs to be further clarified in what sense models represent reality. This is necessary to find out which form of realism concerning models is acceptable. The two important schools of realism are convergent realism and constructive realism. According to convergent realism our successive theories increasingly correspond to an extra-scientific reality. That means our more recent theories are more close to truth. The recent theories preserve the theoretical relations and the apparent referents of the

previous theories and there by the earlier theories become the limiting cases of the recent theories. Thus science progresses towards truth by reducing the gap between Truth and our theories. But this gap can never be filled completely. Convergent realism considers Truth as the absolute standard in evaluating the relative worth of the theories in succession. Now the question is "If the measure of scientific progress is approximation to truth or verisimilitude, what is the measure of verisimilitude itself?" Convergent realists say that the 'success' that is exhibited by the mature sciences can be the measure of verisimilitude. They try to relate 'success' and 'verisimilitude' with the help of the notion of reference." A theory can be said to be successful if all or some of its central terms are referenial. Thus, convergent realism depends for its legitimacy on the stability of the referenstiality of some important terms of scientific theories.

But the notion of success of theories based on the functional relation between the success of theories and the referenial achievement cannot be justified. In the history of science we can find many referenial theories which are unsuccessful and many non-referenial which are successful. The idea of stable referent so central to convergent realism was sought to be explicated by philosophers like Putnam, in terms of causal theory of reference. Convergent realists applied causal theory of reference which is successful in case of proper names to the natural kind terms including theoretical terms.

The application of causal theory of reference in explaining the process of fixing referents in the case of natural kind terms in the context of science is called into question by Kuhn. He says:

> Though os tens ion is basic in establishing referents both for proper names and for natural kind terms, the two differ not only in complexity but also in nature.[12]

The tracing of life-lines required for fixing referents as is envisaged by the causal theory of reference is impossible in the case of natural kind terms since:

> the individuals which constitute natural families do have life-lines, but the natural family itself does not.[13]

Kuhn discusses in detail how establishing the referent of a natural kind term requires exposure not only to varied members of that kind but also the members of other kinds to which the term might otherwise have been mistakenly applied. In other words, a number of acts of ostension of various kinds are required to fix reference for natural kind terms like theoretical terms. Given its complexities and requirements, Kuhn very rightly points out that learning a theoretical term or fixing referent for it is very much parallel to the act of understanding a metaphor. According to Kuhn a metaphor is:

an essentially higher level version of the process by which ostension enters into the establishment of referents for natural kind terms.[14]

A metaphor involves both open ended set of comparisons and clear cut juxtaposions which are precisely involved in the fixing of reference for natural kind terms.

The main thrust of Kuhn's words quoted above is that scientific theories have a metaphorical character as is evidenced by the fact that the fixing of reference for theoretical terms shares some features with the act involved in using or understanding a metaphor. We have, at the end of the second chapter, seen how Kuhn convincingly shows that models are intrinsic to theories. Combining these two points, as it were, Kuhn says:

I would hazard the guess that the same interactive, similarity creating process which Black has isolated in the functioning of metaphor is vital also in the function of models in science.[15]

If theories/ models are to be construed on metaphorical lines and since a metaphor does not just describe the situation unlike a literal description, but also constructs the situation at least partly, the form of realism we have to make room for cannot be convergent one but constructive one. In other words, models, no doubt, represent reality, but they represent it by partly creating it in the way metaphors do. Thus, the above account of model-reality relation has not nullified the very idea of representation. It has given a subtler and broader account of representation rejecting the traditional idea of representation in science as progressive approximation of our knowledge to truth

or increasing correspondence between science and extra-scientific reality - an idea which has been undermined severely by Incommensurability thesis proposed by Kuhn and Feyerabend.

The constructive role of metaphor vis-a-vis reality which it represents can provide us the clue for understanding the nature of scientific creativity. The idea that models are merely pedagogic or heuristic as well as the consequent neglect of models as object of study in philosophy of science is not unrelated to the failure of philosophers of science to take seriously the phenomenon of scientific creativity. For scientific creativity lies mostly, if not always, in the creation of models. The question then is "How is the creation of models creative?" -It is Rom Harre who explains convincingly how the creation of models, both concrete and abstract, calls for an imaginative undertaking similar to creative acts in art. Raising the question:

> How could Darwin and Wallace describe the process of evolution in such detail if they had never, and given the time span of the process never could, observe it?"

Harre says:

> clearly they shared an imaginative conception of the organic history of the earth and the natural forces and processes that shaped it ......It is this conception which stands between their limited experience of organic biology and the utterly out of reach organic history of the earth.[17]

Harre calls this imaginative conception which lies between ignorance and reality as Icon of that reality. The Icon is the representative and surrogate of that reality. Harre makes a very important point in connection with the nature of evidence that is advanced in favour of an Icon, when he says:

> a great scientist cites supporting evidence, not as premises or even as evidence in the legal sense, but as anecdotes, illustrative of the power of the theory to make certain widely selected phenomenon intelligible.[18]

Creativity then must lie in the production of the conception of the unexperienced i.e, ... the production of Icons. Models are nothing but the embodiments of the Icons.

Harre distinguishes between two types of scientific imagination that creates Icons - reproductive imagination and transcendental imagination. The former produces Icons that resemble

the entities familiar to us in experience. Kekule's conception of the structure of Benzene such that the carbon atoms of Benzene form a stable ring, Harvey's conception of Blood circulation in terms of the hydraulic circuit, Van Helmont's conception of disease as an invasion of the body by an army of invisible organisms-all are examples of Icons of reproductive imagination. However, as Harre says:

> The scientific imagination does not confine itself to the same realm of creation as is continuous with the realm of perception. It attempts to conceive of the structure of the world beyond all possible experience."

The creation of such Icons, Harre traces to transcendental imagination. The Icon of field which science has created to explain the phenomenon of magnetism, electricity and gravity is an Icon produced by transcendental imagination. For:

> A field is a distribution of potentials, and though we speak of the energy of the field at a point that energy is not manifested in any kind of action. Thus a field is a fortiori imperceptible.[20]

Such Icons do not have any likeness with the objects of our actual experience. In fact, unlike the latter they have no qualities at all. But they share only one kind of attributes with the objects of the actual experience, namely, structure:

> It is this attribute which makes for the possibility of intelligibility of that world (the world of transcendental imagination) and of course for its mathematical description.[21]

Thus, since models embody Icons and since Icons exhibit different levels of abstractness depending on whether they are reproductive or transcendental or sharing both reproductive and transcendental character in varying degrees, models too can exhibit different degrees of concreteness or abstractness. The scale models are purely reproductive and mathematical models are purely transcendental; in between lie various other types of models. However what is important to note is that construction of models involves creative imagination. Precisely for this reason models represent reality in and through the process of creation. The reality we seek to represent through our models is partly at least created by the models themselves. Such a construal of representation departs from not only the conventional idea of representation as mirroring but also

seeks to replace our construal of reality by a better one. It replaces the idea of reality as a world 'lying out there' ready to be mirrored in our knowledge, by a conception of reality that makes the world a product of a creative encounter of man with a world which he fashions in terms of the cognitive artifacts such as models.

NOTES

1. Black, Max: *Models and Metaphor:,* P. 229.

2. Maxwell, James Clerk: *The Scientific Papers of James Clerk Maxweli.pp.* 155-156.

3. Thomsonson, Sir William : *Baltimore Lectures^* pp.8-12.

4. cf.Braithwaite R.B.: "Models in the Empirical Sciences*",Readings in Philosophy of science,*edited by Baruch.A.Broody.,pp.268-275.

5. cf.Spector Marshall: 'Models and *Theories'Readings in Philosophy of science* ,edited by Buruch. A.Broody.,pp.283-286.

6. cf.This expression issued by Rom Harre in his book 'An Introduction to the Logic of the Sciences'.

7. Wartofsky Marx.W-.*Models.-Representation and the Scientific understanding,* pp.2-3.

8. Ibid; P.3.

9. Ibid; pp.9-10.

10. Ibid; P. 10.

11. Of course, not all convergent realists invoke the notion of reference to mediate between success and truth or verisimilitude. Convergent realists like Karl Popper relate success and verisimilitude directly, whereas recent convergent realists like Putnam invoke the notion of reference. The argument of the latter runs as follows: The theories in mature science are successful. If a theory is successful,its terms genuinely refer. Therefore all or most of the central terms in theories in the mature sciences do refer.

Realism is sought to be thus established on the basis of supposedly established fact of growing stability of the referential fortunes of some of the key terms of some scientific theories.

12. Kuhn.Thomas.S: 'Metaphor in Science':; *Metaphor and Thought* :edited by Andrew Ortoney, P.412.

13. Ibid; P.411.

14. Ibid; P.413-414.

15. Ibid; P.415.

16. Harre, Rom:'The creativity in science', *Tfte Concept of Creativity in Science and Art* ,P.25.

17. Ibid; P.26.

18. Ibid; P. 19.

19. Ibid; P.30.

20. Ibid; P.30.

21. Ibid; P.30.

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