What is the Scientific Method?

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Preface

Although ‘The Scientific Method’ is a fairly ubiquitous phrase, through various considerations, we will begin to see that the poster flowchart that we recall adorning the wall of our fifth grade classroom does not do it justice. **What is the Scientific Method?** aims to take the reader through notable episodes of the history of particle physics while examining the ongoing philosophical discussion on the scientific method. Through the study of six prominent cases, we will examine six philosophical accounts of science:

- The Syntactic View of Theories, including
  - deduction,
  - induction, and
  - hypothetico-deductivism,
- the holistic view of theories,
- the semantic view of theories, and
- the critical views of scientific theories.

In conclusion and response, I will present the new, *encompassing view.*

Chapter 1

Deductivism

In this chapter, we will review the structure of deduction and present Aristotilian deductivism. Through the study of a letter from the Greek thinker Epicurus discussing the finitely divisible nature of matter, we will show why deduction should not be the essential logical view used in science.

1.1 Exigetical Account of Deductivism

1.1.1 Deduction

Deduction is a kind of argument that presumes an acceptance of certain statements and, using those statements, proves without chance of doubt that another statement follows directly. With a proper deductive argument, there can be no question whether the result follows from the premises because deduction only uses non-ampliative arguments, which means that the agreed premises already hold the information the deducer is bringing to light. For this reason, deduction is safe and powerful.

A common example is

$$\underbrace{All\ men\ are\ mortal}_{\text{major premise}},\ and\ \underbrace{Socarates\ is\ a\ man}_{\text{minor premise}},\ therefore,\ \underbrace{Socarates\ is\ mortal}_{\text{conclusion}}.$$

In this case, we accept that there is a condition of mortality on all elements of the set of all men, and we observe that Socrates is a member of this set, so must have the condition. If you accept the two premises, the conclusion is indisputable. Furthermore, no one can justly disagree that the conclusion follow from the premises, even if they don't accept them as true.

Deduction provides a level of rigor that is necessary for proofs in mathematics. For example, the proposition that two even integers sum to an even integer is something that most can agree with, but to prove it is to show that there is no 'special case' that can come up. Here, we assume the previously proven notion that the integers ($\mathbb{Z}$) form a ring under the operations of addition and multiplication, and the following definition of an even integer.

Definition 1. $a \in \mathbb{Z}$ is *even* if and only if there is some $b \in \mathbb{Z}$ such that $2b = a$.

Theorem 1. Any two even integers sum to an even integer.
PROOF. Choose any two even integers, a and b. By definition, there exist $\hat{a}, \hat{b} \in \mathbb{Z}$ such that $2\hat{a} = a$ and $2\hat{b} = b$. Now we can write,

$$a + b = 2\hat{a} + 2\hat{b} = 2(\hat{a} + \hat{b}).$$

We can see that there is some integer, namely $\hat{a}+\hat{b}$ (since the integers are closed under addition), such that $2(\hat{a} + \hat{b}) = a + b$, so by our accepted definition of even numbers, $a + b$ is even. Since a and b were arbitrary, we have just proved that any two even integers sum to an even integer. $\square$

Figure 1.1: Example Proof

The distinction in math, is the convention of axioms that anyone wishing to be in the mathematical community must accept. Math is created from the axioms that mathematicians believe are interesting and reasonable to develop, so is sometimes useful in the sciences.

This is the trade off for science: the premises are always open to dispute. Considering the deduction concerning Socrates, the major premise can only be known to be true with 100% certainty if we were to observe the death of every man who ever and will ever live. Obviously this is impossible. This is a metaphysical issue. Since deductive arguments are non-ampliative, if we want to know conclusions in say, physics, definitively, then our premises must be, in a way, 'bigger' than physics, and must be facts about reality itself, in the field of metaphysics. This leads to many interesting issues that we will discuss later.

1.1.2 Aristotelian Deductivism

As a deductivist, Aristotle championed deduction, believing that it must be the essential logical view in science. In the first line of *Posterior Analytics*, Aristotle says that "all instruction given or received by way of argument proceeds from pre-existent knowledge," a statement that exemplifies the exact procedure of a deduction (Gimbel 5). He addresses the notion of defining premises in his second section, asserting that we must "know them better than the conclusion," meaning that the premises must be solid in order to get solid results. Moreover, the premises hold the knowledge that the deduction is uncovering, so in order to believe the results, you must accept the premises (Gimbel 8).

Aristotle also made sure that the terms he used are well defined and accepted before he used them. This is necessary to him (and many will agree) in order to reduce confusion and proceed in a demonstration. Of these terms, he is particularly adamant about ‘nature’ (Gimbel 11-13). He claims (and uses as many of his major premises) that certain objects have an indisputable nature that is inherent to the object or the class of objects to which it belongs. Most notably, Aristotle distinguished between the essential and the accidental properties of an object. The *essential* qualities are what Aristotle uses as “basic truths” or “immediate propositions,” something that he believes is so evidently true that it does not need a proof (Gimbel 7). Aristotle also uses ‘self-evident’ metaphysical truths to justify many arguments he makes.

1.2 Case: Epicurus and Atomism

The study of particle physics, surprisingly, has early beginnings. I believe it is natural to wonder how something is made and how its construction affects its function. What is surprising is that Epicurus, a Greek thinker living in the late 300s to early 200s BCE, deduced a considerable amount of what many still believe is true in 2019.

A prominent issue in this field was the concept of particle divisibility: whether there are fundamental particles that cannot be divided, or if matter can be infinitely split. Some major groups had different ideas of the structure of matter. Some thinkers like Aristotle believed that earth, fire, water, and air were the fundamental components of all matter, but that matter was infinitely divisible. Atomists, on the other hand, believed that matter was made of atoms that could not be divided and interacted with each other in predictable and organized ways.

This case is a letter from Epicurus to Herodotus, presenting his deductive argument for why the Atomist view of matter is correct. He used a deductive argument from things he believed to be absolute truths.

Epicurus starts with the self-evident truth that nothing can every be destroyed into non-existence (for if it could, then "everything would have perished"), and nothing can arise out of nothing (for if it could "anything would have arisen out of anything"). He is using the metaphysical law that nothing can jump in or out of existence. He uses this premise to imply that the "sum of total things was always such as it is now, and such it will remain." In other words, he is declaring the necessary conservation of matter in the universe as a physical law.

Epicurus states as another metaphysical self-evident truth that everything in the universe is either a body or space. This is something that we can observe with our senses, he reasons: if there were no space, there would be nothing for bodies to move through. Also, our brains are not capable of conceiving anything not of those two categories to exist. Then, Epicurus says that since nothing can be "destroyed and pass into non-existence," there is some piece of matter that can not be infinitely divided. He extends this argument further and concludes that some objects are made up of only one of these elemental substances and others are compounds of them. Thus, the first bodies must have also been of the same construction (since no new matter can be created or destroyed).

Because there are so many different things that we see (metaphysical self-evident truth) and atoms will produce the same object even in large quantities, there must be many kinds of atoms and an infinite number of each. And because each atom is separated from the others by space unless they get tangled with each other (self-evident truth), they are in continuous motion, near or far, bouncing off each other. Since no mass can be created or destroyed, this has always been happening (Gimbel 331).

1.3 A Response from Aristotle

Of course, Aristotle, the father of just about every scientific study, also had a view on particle division. As stated earlier, he disagrees with the assertion that particles that can only be divided and in fact also disagrees in the Atomist view. Here, however, we are concerned with Epicurus's methodology, the way that he conducts his study.

Clearly, he provides an Aristotelian deductive argument: he attempts to justify every claim he makes with the *self-evident* metaphysical facts that he presents, or he uses statements he has previously proven. For example, he takes the conservation of matter to be an absolute truth and uses this as the basis of many of his other arguments. He believes that he does not use anything unproven or not completely self-evident. This is the exact methodology that Aristotle champions and uses in his own work, so we can expect that he would agree with Epicurus's method.

1.4 Evaluation

There is a problem with relying on only deduction for science: premises have to be accepted, and so could be wrong. The metaphysical 'self-evident' truths that both Aristotle and Epicurus use are not really self-evident. Both thinkers are sneaking in these assumptions that might seem obvious, but actually are not. Since the goal of deduction is to prove claims with 100% assurance, assuming a premise that is not proven flies directly in the face of this method. Aristotle's assumptions about the nature of objects is an example of this huge oversight.

There will never be anything we can know to be undoubtfully true that we can use to derive useful results. That being said, there are some times in science, particularly when a proposition is proven beyond reasonable doubt and is producing reproducible and useful results, that deduction can be used to derive other knowledge from that initial proposition.

Apart from theoretical issues with a deductive method for science, we can see how it holds up to the scrutiny of modern, presently accepted results. Most now accept that atoms themselves can be divided into protons, neutrons, and electrons. Also, protons and neutrons are themselves divisible. While Epicurus did not get everything right, I am very surprised and amazed that he reached a semi-accurate result.

It is evident that this situation resembles 'a stopped clock that is right twice a day' and while in mathematics deductions are necessary, scientific deductions are not as fruitful. Supposing the implications that were used were in fact valid (even though many were not), the presumptions might not be, so in the interest of examining and determining *new* truths about the world, deduction alone is not sufficient.

Chapter 2

Inductivism

In this chapter, we will review the structure of inductivism and present Newtonian Inductivism. Through the study of James Clerk Maxwell's discussion of molecular science, we will show how induction is used in science and how it is problematic as a scientific method.

2.1 Exigetical Account of Inductivism

2.1.1 Induction

In contrast to deduction, induction *is* ampliative. That is, it takes the narrow and broadens it. What this method contributes in respect to cultivation of new knowledge (as opposed to the deductive refinement of old knowledge) is contrasted with the probabilistic uncertainty that is introduced. Let us take the very simple example of a repeated observation of the sunrise. Our data is summarized in Figure 2.1.

There is probabilistic reason to believe that the sun will rise on Day 100. The

Day (trial) number	Observation
Day 1	Sun Rises
Day 2	Sun Rises
Day 3	Sun Rises
Day 4	Sun Rises
Day 5	Sun Rises
Day 6	Sun Rises
...	Sun Rises
Day 99	Sun Rises

Figure 2.1: Example Data

more diverse and large the sample is, the higher this probability is: you can intuitively say that the sun will rise because you have seen the sun rise every day of your life. This exemplifies *enumerative* induction, where we induce information about Day 100 based on Days 1 through 99.

While it is possible to calculate this probability numerically, it is easy to intuitively judge when the probability is higher than 50%. Of course, the sun could explode tonight and not come up the next morning. This is where induction is lacking: with induction's ampliative nature, one can only get very high probability, never complete certainty. We might be inclined to ask why we should believe the results from an inductive study, and the answer lies only in the aforementioned probability. An Individual might decide to align with the side of low probability, but to do so seems ridiculous to most.

2.1.2 Newtonian Inductivism

Inductivism is the belief that induction alone is the essential logical view in science. As an inductivist, Newton uses enumerative induction as a basis for four rules for a scientific method in his masterwork *The Mathematical Principles of Natural Philosophy*:

1. “We are to admit no more causes of natural things such as are both true and sufficient to explain their appearances” (Gimbel 53).

2. “Therefore to the same natural effects we must, as far as possible, assign the same causes” (Gimbel 53).

3. “The qualities of bodies, which admit neither intensification nor remission of degrees, and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever” (Gimbel 53).

4. “In experimental philosophy we are to look upon propositions inferred by general induction from phenomena as accurately or very nearly true, notwithstanding any contrary hypotheses that may be imagined, till such a time as other phenomena occur, by which that they may either be made more accurate, or liable to exceptions” (Gimbel 55).

We can interpret the first two rules as a response (rebuttal) to Aristotle: the first is what William of Ockham coined as ‘Ockham’s razor’, claiming that for an effect, fewer causes is more likely. For example, by rule one, when trying to explain why leaves are green, it is more likely that it has something to do with their function, than that someone comes along and paints them all.

Similarly, the second rule says that similar effects most probably have the same cause. The flame in a candle and the sun have similar effects, so probably, the same rules govern the behavior of both. Rules three and four can be seen as a response to Descartes, who believed we must build all knowledge deductively like Euclidean geometry.

Newton say in three that if a property is observed in all instances of a body, assert it of all bodies, which is Bacon's idea of inductive generalization. From our previous example, we would conclude that the sun will rise every day. In four, he proposes that a scientist must observe the world and when there is a pattern, use induction to generalize and hold this generalization to be true until a counterexample is observed. Again, from our previous example, the assertion that the sun will always rise can be held true until there is a day that the sun does not rise.

These rules are a refined construction using ideas of enumerative induction. To Newton, these ideas can be used more accessibly in science. According to him, all science can be done uncreatively, simply just applying these rules in repetition.

2.2 Case: James Clerk Maxwell on Molecules

James Clerk Maxwell was a very prominent physicist and mathematician who provided a beautiful unification of electricity and magnetism and advanced the fields of astro and particle physics. While many people did not believe in the existence of molecules and atoms because no one could observe them, Maxwell attempts to argue for their existence scientifically in his 1873 paper *Molocules* (Gimbel 78).

Maxwell hypothesizes that atoms exist and then shows how the implications of such a hypothesis are observed. He starts by defining an atom as a "body that cannot be cut in two" and a molecule as "the smallest possible portion of a particular substance" (Gimbel 357). He then explains by presenting the example of a water drop: we can all hold a drop of water and the more skilled we are, the more we can divide the water drop again and again where "the parts are similar to the whole in every respect except absolute size" (Gimbel 358). Eventually either our technology or senses aren't good enough to continue the process but that fact does not seem to be the end of the process, for the technology that we have now is better than 10 years before and so we can divide water further than before. This begs the question: what will stop the processes, and will it ever stop? Maxwell then recounts some past scientists and philosophers that believe in finite particle division and then comes out as being among that group. Maxwell clarifies that (if they exist) all atoms are molecules (of some elementary substance), but not all molecules are atoms (Gimbel 358).

The research starts with the presentation of observed and known thermodynamic properties of gases: gases placed inside containers press on the container walls and any body also in the container. This happens because repetitious impacts of gas particles on objects present like continuous pressure. This would imply that the pressure is proportional to the number of particles. The particle view explains this relation between pressure and gas density discovered by Robert Boyle.

Similarly, Charles discovered increasing the temperature of a gas increases the pressure of the gas linearly. The particle view explains this, since increasing the temperature increases the square speed of the particles linearly, which will in turn increase the pressure, since the molecules will strike the sides more times per second and with a stronger force. We have that

$$P(\text{total}) = \frac{N}{3V}[mv^2]_{\text{avg}}, \tag{2.1}$$

where P is pressure, N is number of molecules, V is the volume of the container, and $[mv^2]_{\text{avg}}$ is the average mass-velocity squared product of the molecules (Moore 80).

The particle view also explains the observation by Dr. Ludwig Boltzman, of what will occur when gases that have the same volume and pressure but different weights collide and mix. The larger and heavier atoms will go slower and the smaller and lighter atoms will move faster, resulting in the mixture having a uniform average energy of motion. From this Maxwell identifies the fact that a cubic centimeter (cc) of any gas at any given pressure or temperature contains the same number of molecules (Gimbel 359).

Maxwell then begins to discuss specific research that has been done. He starts with Dr. Joule's experimentation to determine that the speed of a hydrogen atom at 1 atmosphere of pressure and 0 degrees Celsius is 1859 meters per second. This implies, Maxwell argues, that the particles must be moving in many different directions and they must be constantly colliding. Otherwise, we would be ripped to shreds by the storm of particles moving at such high speeds (faster than any bullet at the time) (Gimbel 359).

From this implication, Maxwell begins to discuss the notion of diffusion of three types: matter, momentum, and energy. He uses an example of a bottle of ammonia (that has a very strong and distinctive scent) opened on one side of a room to show that it takes longer for the particles to reach the other side of the room than if you expected them to move linearly at 1895 meters per second. Maxwell mentions both that Priestly was the first to remark on this and the work done by Dalton that shows the independence of diffusion and chemical reactions between the gas molecules. He also highlights Graham's technique for identifying the effects of diffusion, which is difficult given the invisible nature of most gases, and prof. Stefan's technique for using a technique that involved measuring the temperature change of the gas around a heat source (Gimbel 360-1).

From Clausius's idea of a particle's *mean path*, Maxwell calculated the average distance a particle travels before being redirected, based on data from Loschmidt's diffusion experiments, and concluded that this path was about one tenth of a light wavelength. This explains even more why the fast moving particles don't hurt us.

2.3 A Response from Newton

What Maxwell does might at first seem as though he simply assumes that he is correct and presents some interesting results on thermodynamics, but what he is actually doing is developing an intricate inductive framework based on Newton's four rules. He starts by using rule two and shows a collection of similar trials that can all be explained with the same cause. Using rule one, to him, the simplest explanation is the molecular view of matter.

Then, throughout the rest of the explanation, he is continuously checking the results of other experiments to make sure that the theory and its implications (which involves deductive reasoning) is consistent with the results, which exemplifies rule number four. Obviously, he has not experimented or collected data on all gases in the universe, but with what he has observed, he uses enumerative induction to assert these claims about all gases.

Maxwell also uses inductive generalization to specify numerical solutions regarding characteristics about gases. He can only observe and measure a finite number of instances of gases but still makes a generalization for all instances of that gas.

Newton would have mixed feelings about how Maxwell did his study. There is a clear inductive framework that uses the rules and guides that Newton set out; however, Newton would disagree with Maxwell's use of a hypothesis and hypothetico-deductivist techniques. As a pure inductivist, Newton believes that the involvement of a hypothesis will skew the science and introduce unimaginable error.

2.4 Evaluation

Since Maxwell was never able to actually directly observe atoms, he never used pure induction the way that Newton had outlined. However, Maxwell's study shows how induction is not enough for science. As demonstrated, there are situations where there needs to be an aspect of a scientific method *in addition* to induction: there is no way to use induction in a situation where you can't observe what you are trying to study, especially if what you are trying to study is under the question of existence.

Maxwell's research was a very effective application of hypothetico-deductivist techniques. Along with Newton's rules of induction, Maxwell shows how induction used well can be a part of a productive way to do science but leaves something to be desired by some: the creative possibility of a hypothesis. In addition, the problems introduced by Hume, Goodman, and Hempel make the use of induction worrisome.

Chapter 3

Hypothetico-Deductivism

In this chapter, we will review the structure of hypothetico-deductivism given by R. B. Braithwait. Through the study of Ernest Rutherford's Gold Foil experiment, we will show how hypothetico-deductivism is used in science and how it is problematic.

3.1 Exigetical Account of Hypothetico-Deductivism

Deduction and induction both impose a logic of discovery, where there is a definite method of establishing and demonstrating a claim. It is with hypothetico-deduction that we first encounter the idea of the free context of discovery.

A free context of discovery holds no constraint on the method in which the claim to be demonstrated is found. While inductivists and deductivists believe that such an arbitrary hypothesis will lead to untrue results, hypothetico-deductivists use a method that involves a hypothesis and incorporates a logic of justification to compensate for the free context of discovery.

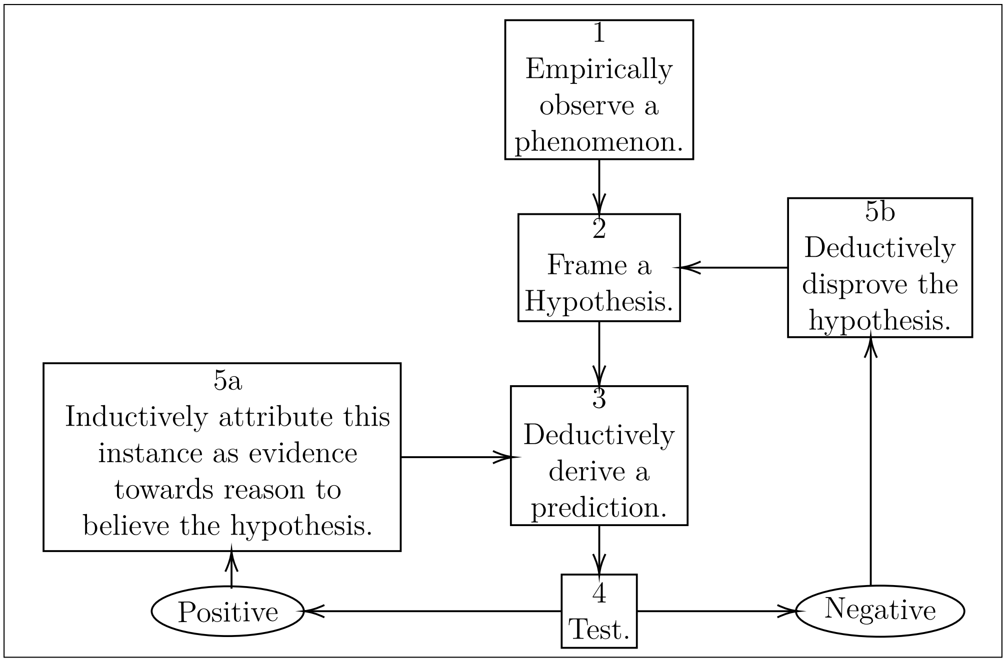

Figure 3.1: Hypothetico-Deductivist Method Flow Chart

The first step of the hypothetico-deductivist method is to make an observation of the world and determine the subject of study. The next is to formulate a hypothesis that could explain the phenomenon that was observed. Again, since hypothetico-deductivism imposes a free context of discovery, the hypothesis can be produced in any way that is desirable. The third step is to use deduction to derive a testable prediction. That is, assuming that the hypothesis is correct, what should be observed? The fourth step is to test the prediction. If the test is negative, deductively conclude that the hypothesis was false by Modus Tollens[1]. At this point you must discount the proposed hypothesis completely and try again (or give up!). If the test is positive, then the experiment inductively contributes *evidence* to the hypothesis, and the degree of belief in the hypothesis is increased. This method is outlined in Figure 3.1.

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[1] *Modus Tollens* is a property in formal logic for propositions P and Q: if $\neg Q$, and P implies Q, then $\neg P$.

Clearly, only the segments known with deduction can be certain: if a hypothesis is framed and implies a prediction, and the prediction is wrong, then it is certain that the hypothesis is wrong. The other side of the justification uses induction. Hypothetico-deductivists believe that this method will produce good results and that the inductive aspect of the method, with repitition, will give good enough reason to believe the hypothesis.

3.2 Case: Rutherford and the Discovery of the Nucleus

In this case, Rutherford writes on his observations and experiences working with deflections of α (alpha) and β (beta) particles passing through a thin plate of matter (about 0.00004 cm thick). In §1 of his paper, Rutherford starts by recounting some of the known relative information. In particular, he sets up what will be discussed in the rest of the paper by saying that "there seems to be no doubt that such swiftly moving particles pass through the atoms in their path, and that the deflexions observed are due to the strong electric field traversed within the atomic system." He also mentions the work done by Geiger and Marsden on the same subject: "some of the α particles must suffer deflexions of more than a right angle at a single encounter," about 1 in 20,000 (Rutherford 1). This observation is the motivation for his work.

At this point in history, it is accepted that atoms exist, and they are composed of an equal number of evenly distributed negatively and positively charged particles.

This is J.J. Thompson's famously coined 'Plum Pudding' model. Rutherford discusses this model's explanation of why a negatively charged particle deflects while passing through the atom: the repulsion and the attraction of the negative and positive particles in the atom, respectively. It was shown that the average deflection after m encounters is $\sqrt{m}\theta$, with θ being the average deflection from one encounter. This theory is based on the assumption that the scattering due to one encounter is small. Here, Rutherford proposes his research: it should be possible to get an idea of the structure of the atom since the alpha and beta particles come very close to it and its deflections are observable (Rutherford 2-3).

In §2, Rutherford outlines the theory behind the deflections, assuming that the atoms are not structured the way that J.J. Thompson had suggested, but instead, each has a center with a charge of $\pm Ne$, surrounded by a charge of $\mp Ne$ distributed over a sphere with radius R, where $e = 4.56 \times 10^{-10}$ E.S. and N is the number of charged particles. Rutherford assures us that the calculations are identical whether the atom is positive inside or outside, so we will suppose that the center sphere is positive and the outside is negative. From previously known results, Rutherford writes that the electric force X and potential V at a distance r from the center of an atom at a point inside the atom are given by (Rutherford 3)

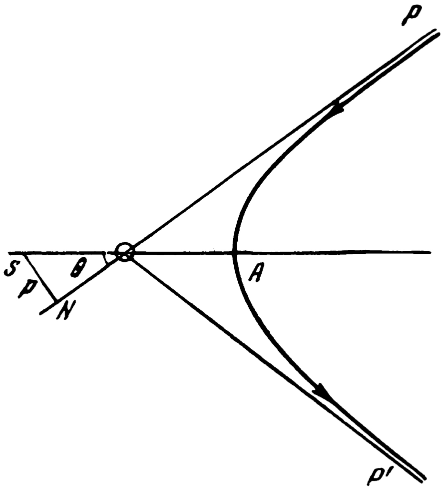

Figure 3.2: Deflection of a Particle

$$X = Ne \cdot \left(\frac{1}{r^2} - \frac{r}{R^3}\right) \text{ and} \tag{3.1}$$

$$V = Ne \cdot \left(\frac{1}{r} - \frac{3}{2R} + \frac{r^2}{2R^3}\right). \tag{3.2}$$

Also, a particle of mass m and charge E that is shot with a velocity u directly towards the center of an atom will be stopped at a distance b from the center of the atom, with (Rutherford 4)

$$\frac{mu^2}{2} = NeE \cdot \left(\frac{1}{b} - \frac{3}{2R} + \frac{b^2}{2R^3}\right). \tag{3.3}$$

Rutherford argues that b will be quite small compared to $R \approx 10^{-8}$ cm because the α particle will travel very close to the center charge before being turned back, so the uniformly distributed negative charge can be neglected: we only need to consider the center charge. He continues his derivation, using geometry and the conservation of energy to conclude that the particle's deviation angle ϕ is related to p, the particle's perpendicular distance from the center-on direction of initial motion, by (Rutherford 5)

$$\cot\left(\frac{\phi}{2}\right) = \frac{2p}{b}. \tag{3.4}$$

Figure 3.2 shows a diagram of an arbitrary deflection. For example, some values of p/b and ϕ are organized in the table below.

p/b	10.7	5.4	2	1	0.5	0.26	0.125
ϕ	5°	11°	28°	53°	90 °	127°	152°

In §7, Rutherford compares the theory with the experimental results. Rutherford reports that the number of α particles scattered through a large angle has been observed to be proportional to $(NeE)^2$, but if the charge is distributed in single units, it is proportional to Ne^2 instead of N^2e^2. He explains why the mass is not an important factor in the computation as well as why a single *pencil* of charges would not apply to the theory. Rutherford concludes that "considering the evidence as a whole, it seems simplest to suppose that the atom contains a central charge distributed through a very small volume, and that the large single deflexions are due to the central charge as a whole, and not to its constituents" (Rutherford 20). He also brings up that there is still a possibility that the negative *satellites* could have some effect on the deflection but that more experimentation needs to be done and more evidence collected.

From these conclusions, Rutherford postulates that the value of an atom's central charge is approximately proportional to its atomic weight (Rutherford 20). He also notes that Nagaoka had mathematically considered the *Saturn* model of the atom, where there is a positive center with orbiting electrons, and showed that the atom would be theoretically stable if the force were strong enough. Rutherford finishes his paper by saying that future work should be done to determine the sign of the charge on the parts of the atom by considering interactions with a β particle (Rutherford 21).

3.3 A Response from Braithwait

Braithwait would be very pleased with how Rutherford did his study: he followed the rigid outlined hypothetico-deductivist structure in his experimentation. Rutherford started by noting observations that he had made. He then framed a hypothesis (that that atom has an orbital structure) to try to explain what he had observed. §2 of his paper is solely focused on the derivation of the experiment from the solid foundation of theory that he is using. He is sure to mention that after the clean derivation of expected occurrences, they will "compare the deductions from the theory with the experimental data available" (Rutherford 3).

It is also important to note that Rutherford is writing with the voice of a hypothetico-deductivist as well! He often uses phrases like "it seems reasonable to suppose," as he frames a hypothesis, and "confirms the main conclusions of the theory," when talking about experimental evidence (Rutherford 2). Rutherford is exhibiting how hypothetico-deductivists believe that as they compile evidence, they are gaining reason to believe their hypothesis and eventually *confirm* it.

In §7, Rutherford reiterates that "comparing the theory outlined in this paper with the experimental result" is important in the procedure (Rutherford 19). He also repeatedly makes reference to all of the "evidence" that has been collected and must be collected to show the hypothesis is true. This is exactly how a hypothetico-deductivist would frame the work was done. Since the experiment was consistent with the predicted outcome from the theory, Rutherford argues for the truth of his hypothesis and readily provides another place to look for more confirming evidence and more areas of research that would be interesting. In doing so, he completes a full loop of the procedure we outlined earlier.

3.4 Evaluation

As a method for science, hypothetico-deductivism has its strengths and weaknessess. Of course, looking at the the procedure, we can admire its rigid structure. As said before, since there is a *logic* of justification that provides rigor, there is an accepted free context of discovery in hypothetico-deductivism that allows scientists to be creative.

However, hypothetico-deductivism is heavily reliant on induction. We can see with Hemple, Goodman, and Hume that induction has problems that need to be addressed before it can be used without worry. Another issue is related to the deduction of the experiment from the hypothesis. Of course, some background theory must be used in order to imply the expected outcome from the hypothesis, even if this theory is as basic as 'how we can use our eyes to observe the markings on a ruler?' If an experiment is negative, how can we be sure that it is the *hypothesis* that was incorrect? It is possible that another part of the theory had flaws. We will explore this idea further in the next chapter. For these reasons, hypothetico-deductivism is a good try that could possibly produce good science, as it did in this case, but its problems outnumber its strengths, which is highly unsatisfying.

Chapter 4

The Holisitic View of Theories

In this chapter, we will review the structure of the holistic view of theories given by Imre Lakatos. After examining Niels Bohr's atomic model, we will show how the holisitic view of theories, takes much into consideration that has been thus far lacking, but still does not provide for every realist searching for truth.

4.1 Exigetical Account of The Holistic View

First, we must quickly discuss two philosophers, Karl Popper and Thomas Kuhn. Popper developed falsificationism, which is very similar to hypothetico-deductivism, except there is no notion of ever 'confirming' a hypothesis. Instead, falsificationists holds that there is no way to ever verify a statement, but only have instances of corroboration. The value of a theory is measured by how falsifiable it is, or in other words, how many ways it could be wrong. The more general a theory is, the more cases it is possibly applicable to, so the more falsifiable and powerful it is. As

Lakatos says, “all theories are equally unprovable . . . but also equally improbable,” so falsificationism is a comfortable “retreat” for rational thought (Gimbel 200-1).

Kuhn, like Lakatos, was a holist, and developed the idea of a paradigm. As discussed at the end of the previous chapter, there is a problem with only discussing singular theories. We need to, instead, Kuhn argues, consider sets of scientific theories, or *paradigms*: if we are to experimentally test a theory, we must use deduction on an initial supposition to form an experiment, but the deduction requires other knowledge. If the test is negative, how are we supposed to know if it is the one main supposition or the reliant knowledge that is incorrect? Kuhn holds that there is no way to just test one singular theory, we may only operate within paradigms. A consequence of this, however, is that there is no way to compare them. This means that although we can change paradigms, there can be no concept of improvement. Kuhn proposes a complete “psychology of discovery,” rather than a logic (Gimbel 210).

Lakatos takes the best qualities from each and posits the idea of a “research programme” (Gimbel 198). A research programme is constructed of a *hard core* and a *protective belt*. As Lakatos says, “it is this protective belt of auxiliary hypotheses which has to bear the brunt of tests and get adjusted and readjusted, or even completely replaced, to defend the thus-hardened core” (Gimbel 207). This means that if an experiment is derived and is negative, only the hypotheses in the protective belt can be under question. The research programme is thus defined by its hard core, but by Popper’s classification, since there is no way the hard core is ever wrong, it is not actually science, which presents an issue if it is at the heart of a scientific theory.

From Popper, Lakatos modifies falsification as a way to show the value of a research program. He incorporates (originally) Popper's idea of "ad hoc hypotheses" (Gimbel 204). If researcher in a research programme must make many additions to the protective belt in order to save the hard core, the research program is called *degenerative*. In this case, the research programme is getting larger while also becoming applicable to comparatively fewer instances. If instead, the research programme becomes applicable to more cases without addition to the protective belt (it is more falsifiable), it is called progressive. In this way, we can judge the value of research programmes by comparing the number of theories to the number of cases for which they are applicable. The smaller this ratio, the 'better' the research programme is.

4.2 Case: The Bohr Model

As Dr. Brian Smith writes, in 1911, Niels Bohr had an idea, after working under J.J. Thompson at Cambridge, that since light was now considered not as continuously propagating waves, but rather as discrete energy packets, the model of the atom, which was based on Newtonian mechanics, needed to be changed in order to be consistent with the update. Thompson did not appreciate the suggestion, so Bohr moved to the university of Manchester, where he studied under Ernest Rutherford and learned about his proposed model (Smith 10). The classical model at the time had an issue with instability: Maxwell's laws imply that the electrons accelerating (circulating) around the nucleus should emit a single frequency radiation and spiral down to the nucleus. However, experimental data showed that the atoms only emit radiation when excited–when it is exposed to an electric discharge, for example–and when they do, they emit a spectrum of discrete frequencies. Bohr attempts to fix this inconsistency and explain both phenomena (Ghin 337).

Bohr made the assumption that the orbital shape of the electrons' orbits is circular with "discrete orbital frequencies . . . and therefore specific discrete energy levels." He uses only classical formulas to do his derivations (Ghin 337). Specifically, he drew only from classical mechanics and the Coulomb force law. As Ghin mentions, "in his original paper, Bohr claims that his theory is based on two main assumptions and two special ones" (Ghin 338). These are

1. "That the dynamical equilibrium of the systems in the stationary states can be discussed by help of the ordinary mechanics, while the passing of the system between two stationary states cannot be treated on that basis.
2. "That the latter process is followed by the emission of a *homogeneous* radiation, for which the relation between the frequency and the amount of energy emmitted is the one given by Planck's theory" (Bohr 7).
3. "That the different stationary states correspond to the emission of a different number of Planck's energy quanta.
4. "That the frequency of the radiation emitted during the passing of the system from a state in which no energy is yet radiated out to one of the stationary states, is equal to half the frequency of revolution of the electron in the latter state" (Bohr 8).

Bohr then proposed that electrons could only be in quantized radii, with the nth

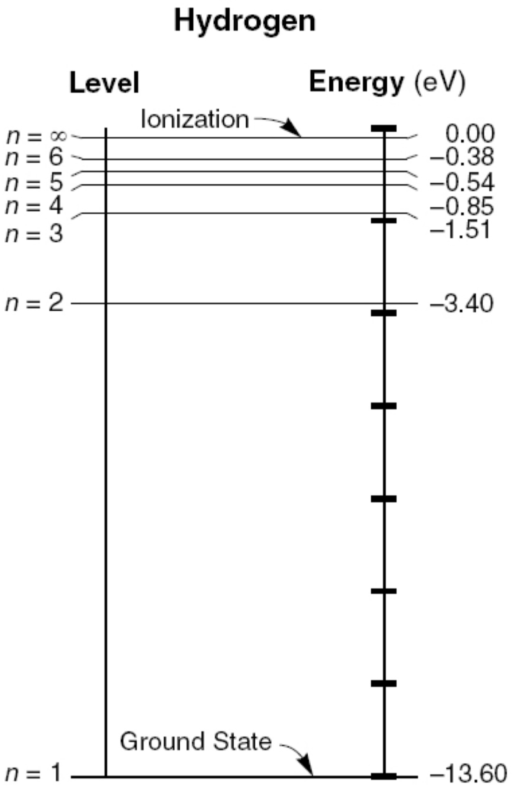

Figure 4.1: Energy Levels for the Hydrogen Atom

radius being

$$r_n = \frac{4\pi\epsilon_0\hbar^2}{m_e e^2} n^2, \tag{4.1}$$

where m_e is the mass of an electron, $\hbar = \frac{h}{2\pi}$ (with h, Planck's constant), and e is the charge on an electron (Smith 10). The different radii, he argues, correspond to different energy values (levels) the electrons can take on, given by (see Figure 4.1)

$$E_n = \frac{2\pi m e^4}{n^2 h^2}. \tag{4.2}$$

Using this hypothesis, Bohr explains the spectral lines of light emission of excited gasses by using Planck's relation between energy E and wavelength ν,

$$E = h\nu, \tag{4.3}$$

and his hypothesis of quantized energy levels. Bohr suggests that when electrons transition from a higher energy level E_{high} to a lower one E_{low} (which happens after a gas is excited) the electron gives off energy $E = E_{\text{high}} - E_{\text{low}}$ in the form of light with a wavelength ν. Bohr offers that the wavelengths we see correspond to differences between energy levels. With this model, Bohr identified the ground state of Hydrogen to be 13.6 eV (eV is electron Volts), which was also experimentally found previously as the Rydberg Constant, $R = 13.6$ eV (Smith 12).

4.3 A Response from Lakatos

Lakatos would like many parts of how Bohr did his work: he exemplifies all of the parts of a research programme. To begin with, Bohr makes it very clear that he is operating in a larger system. As Ghin discusses, the model that Bohr constructs is very transparently dependent on certain other assumptions. This is exactly how Lakatos sees scientific theories being intertwined and related.

Ghin also points out how Bohr himself distinguishes between kinds of assumptions that he makes. The assumption of and dependency on classical mechanics and the Coulomb force law show the respect given to the hard core of the research programme. The other assumptions can be seen as part of the protective belt, that were used but not regarded with such rigidity.

Bohr shows how the theory can be used in more cases than were known before as now the atomic spectrum has been explained. This means by Lakatos' standard, and in this respect, Bohr is contributing progressively to the research programme. However, we can notice that "Bohr's… postulate… [that] the energy of an emitted photon from an atom is given by the difference in energy level, contradicts the concepts of classical physics in which an oscillating charge emits radiation at its frequency of oscillation" (Smith 12). This means that Bohr is also contradicting a hard core fact of the research programme, and so is beginning to break away from the programme to start a new one. Ghin suggests that this is the case when saying that it is possible to "separate Coulomb's formula from the rest of Maxwell's theory of electromagnetism," which would allow for Bohr's theory not to rest on now outdated theories.

In either case, Lakatos would recognize Bohr playing as a follower of the rules of a research programme and commend him on his work.

4.4 Evaluation

As a method, Lakatos' holistic view does not have the ability to satisfy all of the realists. The structure is pragmatically strong; however, this pragmatism is what I take issue with. We can see that the definition of progressive that Lakatos offers is completely dependent on Occam's razor: he would like to assert that the simplest programmes are closest to the truth.

Realists want science to find truth of the universe, but this method requires that those who wish to use it *agree* with the definition of a progressive research programme, so any realist who wants to use this method, must accept Ockham's razor as a dogmatic and objective fact of the universe. The realist must accept that the nature of Lakatos' method is to find the programme that best fits Lakatos' definition. Even though his definition is ubiquitously used (as in Ockham's razor), it still must be accepted.

For anyone who does not accept Ockham's razor (and this is not inherently *illogical* since one cannot argue for or against a dogmatic belief), this method is not well grounded: since the definition of progressive must be accepted, it cannot be objective, and therefore cannot assert that programs that fit its definition are actually closer to an objective truth than degenerate ones. For the Ockham's razor-denier, to understand what it means to be closer to the truth using a definition not grounded in dogmatic belief is absolutely nonsensical.

Even if you are a realist that dogmatically accepts Ockham's razor (and thus also Lakatos' definition of progressive), since there is a possibility that the programme will one day become degenerate, there is no way to have confidence in the absolute truth of any research programme. The holistic view gives the best information, until a more progressive programme arises, but since the process could continue indefinitely, the truth might never found. This built in way to allow for growth, leaves the freedom to individuals to decide how to align themselves with the science they are studying, but also completely undermines the search for absolute and objective truth. In this way, the realist could never be satisfied with the Lakatos' holistic method.

The syntactic view would like to assert that scientific theories should contain true statements. Since we have not so far found a way to actually demonstrate that a scientific statement is objectively true, we can begin to examine a different approach where we do not look for truth.

Chapter 5

The Semantic View of Theories

In this chapter, we will review the structure of the semantic view of theories given by Ronald Giere. By examining the discovery of quarks and the development of the Standard Model, we will show how the semantic view of theories provides a logically coherent method for the instrumentalist but that the broad scope and applicability lacks a motivation.

5.1 Exigetical Account of the Semantic View

Thus far, we have only considered that scientific theories are sets of statements. The holistic view takes the realist approach and holds that these statements can be tested holistically and can be true or false. The semantic view challenges this and takes the instrumentalist stance, proposing that scientific theories are actually sets of models. Instead of finding the truth of the universe, the semantists are looking for an explanation of physical systems.

From here, we must become increasingly rigorous with what we define to be a model. We will discuss this definition and then how the abstract idea of a model can be used in the structure of a scientific method.

Much like a logician, Giere defines a *model* to be an "abstract entit[y]" that completely satisfies a set of formal equations or deterministic relationships (Gimbel 265). Models do not exist in the real world: they are not the rigged miniature volcanoes that fifth graders make for a science fair or the large scale three-dimensional sculpture of an ant at an insect exhibit. An example is the simple harmonic oscillator (SHO). There is no concrete instance of a simple harmonic oscillator in the real world, for friction is never avoidable, and there are certain mathematical approximations used to greatly simplify the "socially constructed" formulas that are related to the SHO (Gimbel 265).

The model is abstractly constructed "as something that exactly satisfies the equations" that relate to it (Gimbel 266). That is, assuming some equations or relationships, the interpretation of those relationships as an abstract construction (the model) must exactly satisfy the relationships. The "equations are *true* of the corresponding model," but this is obvious because of the dependent way in which the model is defined (Gimbel 265). Models cannot, however, be true or false. They aren't statements and so cannot assert any claim.

Although it is possible for models to not be related to the concrete world, it is possible (and perhaps useful) to correlate a model with a situation in the real world. A *theoretical hypothesis* connects the model to the real situation by asserting that there is a resemblance of a certain degree in certain aspects, a similarity. Since the hypothesis is a statement that is making an assertion, the hypothesis can be true or false (Gimbel 267). A scientific theory is then made of "two elements: (1) a population of models, and (2) various hypothesis linking those models with systems in the real world" (Gimbel 268).

To use this method, construct a model with associated equations and then make a hypothesis about the model's relation to a real situation. One could then use the model to make a prediction and then test the real system. For a possible interpretation, one could say that the more often the experimental results are close to the model-derived prediction, the better the model is.

5.2 Case: The Standard Model & the Discovery of the Top Quark

As defined by CERN, "The Standard Model explains how the basic building blocks of matter interact, governed by four fundamental forces." There are 12 of these fundamental (indivisible) particles. They are separated into two groups (quarks and leptons) with six particles each. In each group, the particles are paired into *generations.*

The decay hierarchy of the particles is explained with the concept of generations: "The lightest and most stable particles make up the first generation, whereas the heavier and less-stable particles belong to the second and third generations. All stable matter in the universe is made from particles that belong to the first generation; any heavier particles quickly decay to more stable ones.” The *up* quark is paired with the *down* quark in the first generation. *Charm* and *strange* are in the second generation, and *top* and *bottom* are in the third. We also know that “quarks also come in three different *colours* and only mix in such ways as to form colourless objects.” The pairs of leptons behave in a similar way: “the *electron* and the *electron neutrino*, the *muon* and the *muon neutrino*, and the *tau* and the *tau neutrino.* The electron, the muon, and the tau all have an electric charge and a sizeable mass, whereas the neutrinos are electrically neutral and have very little mass” (CERN).

The four forces are the strong force, the weak force, the electromagnetic force, and the gravitational force, and they work at different strengths over different ranges: “Gravity is the weakest but it has an infinite range. The electromagnetic force also has infinite range but it is many times stronger than gravity. The weak and strong forces are effective only over a very short range and dominate only at the level of subatomic particles. Despite its name, the weak force is much stronger than gravity but it is indeed the weakest of the other three. The strong force, as the name suggests, is the strongest of all four fundamental interactions” (CERN).

The forces are due to an exchange of *bosons*, which are force-carrier particles. Each of the fundamental forces has an associated boson: “the strong force is carried by the *gluon*, the electromagnetic force is carried by the *photon*, and the *W and Z bosons* are responsible for the weak force. Although not yet found, the *graviton* should be the corresponding force-carrying particle of gravity.” The standard model, however, is lacking in this regard because it does not account for one out of the four fundamental forces. The theory of general relativity rules over large scale interaction and is not easily compatible with the standard model. Luckily, on a very small scale, gravitation is negligible. Many questions are still being asked and answered about the standard model. In 2012 CERN's large *hadron* (a particle that is influenced by the strong nuclear force (Riordan 3)) collider observed a new particle, the *Higgs Boson*, the last that was predicted by the standard model (CERN).

The atom is comprised of a nucleus and an electron cloud. The electrons are fundamental particles, and the nucleus is comprised of protons (made up of two ups and a down) and neutrons (made up of two downs and an up), and is held together with the strong nuclear force by means of gluons and quantum chromadynamics theory (Riordan 13, Kibble 6).

In the early 1960s particle physicists found the size of protons and neutrons and considered them to be indivisible. Soon, different variations of particles were discovered that were being affected by the strong nuclear force. Gell-Mann and Ne'eman introduced the SU(3) symmetry in 1961 to account for this by grouping particles together by spin. Their construction was very similar to the periodic table as it predicted new particles and sorted the ones already discovered. This was very effective and gained much notoriety in the physics community (Riordan 3). In an effort to more deeply understand the SU(3) construction, Gell-Mann and Ne'eman proposed the idea of quarks with fractional charges as mathematical constructs; most physicists took the concept to be useful mathematically, but not physically relevant (Riordan 4).

Years of searching later, there still had not been an observation of a quark. It was not until electron scattering experiments, by collaborators from the Massachusetts

Institute of Technology and the Stanford Linear Accelerator Center, conducted between 1967 and 1973, that the first evidence for quarks as physical entities was found (Riordan 2). By 1973, the internal construction of protons and neutrons was known. Eventually, in 1974 and then in 1977, more particles were found, whose existence wouldn't be possible without a third, fourth, fifth, and sixth quark. All but the sixth, *top*, had been observed (Riordan 18).

In 1985 the Fermilab collider was first activated and began using its CDF (Collision Detector at Fermilab) to collide particles with very high energies. A group at CERN confirmed that the mass of the top will be greater than 77 GeV($/c^2$) (Liss 55). It soon became clear that due to the size of the particle, an immense amount of energy would be needed to be concentrated into a very small space (Liss 54). In 1992 the DØ group also began working in Fermilab, competing with the CDF group to find evidence for the top quark, and both groups began to develop large instruments. The DØ device relied on a very accurate calorimeter that measured the collision energy (Liss 56).

Of the the trillions of collisions, the CDF team had isolated 12 important events, 5.7 of which were statistically determined to involved the creation of a top, within uncertainty of 1 in 400 (Liss 57). On April 22, 1994, the team decided to report finding "evidence for the existence of a top quark." A seminar was held between teams and only a few weeks later, the DØ team also found corroborating data. A new algorithm was written for maximizing the efficiency of the vertex detector and began processing more collisions. By the time final presentations were given on March 2, 1995, both teams were able to show that the probability that the signals detected were background noise was less than 1 in 500,000. Since then, there have been more than 100 experimental instances of a top quark, but there is still much to be discovered. The huge mass (compared to the other quarks) of 175.6 GeV($/c^2$) “suggests that it may be fundamentally different from the other quarks, and therein lies the hope that it may lead us past the Standard Model” (Liss 58).

5.3 A Response from Giere

Giere would admire the efforts and techniques of all of the scientists and thinkers that contributed to this project over time and around the world. The Standard Model is a great example of the kind of model that Giere suggests. The model is a conceptual and abstractly visual construction and is associated with many equations and relationships. It is not perfectly correlated to the real world (because of the absence of account for gravity), but it gives close predictable results.

Giere would especially admire Gell-Mann and Ne’eman for proposing quarks as a useful mathematical construction. This is exactly the mindset that an instrumentalist would have about how to solve a scientific problem. There is also the opportunity for improvement as more and more work gets gone. Just as the model was improved upon by many people as it was changed to what it is today, it can still get better.

However, some aspects of the process of the search for the top quark deviated from Giere’s plan. In fact, some arguments were similar to Lakatos’ method discussed in the previous chapter. For example, Liss talks of “evidence for the top quark” (58) and how the (hard core of the) Standard Model requires certain properties of the top quark, and that these properties (such as mass and charge) were taken into account when searching for the particle (55). Still, the way Liss describes the possibility and hopeful probability of moving past the Standard Model is indicative of a Girieian mindset.

5.4 Evaluation

There is no logical flaw in this method, which makes it a useful tool for the instrumentalist or pragmatist. Using models is a way of explaining systems without being bothered to search for truth. The extreme pragmatic nature of the semantic view allows for individualized or community-defined progress since the only merit placed on a model is its continued use. As soon as a model does not explain or predict as well as the community or individual using it would wish it to, the model can be replaced or added to.

The use of models is so ubiquitous and helpful that many people already do so without thinking about it. In particle physics, it is notably useful because the objects being studied are too small to observe naturally, and the pieces of the model are not conceptually like anything we see in the macroscopic world. With the help of a theoretical model, however, one can find a way to visualize, learn about, and research the infinitesimal.

On the other hand, it is easy to see how the idea of a model can be applied to any idea or subject. For some, this widespread applicability (which on one hand makes the method broad enough to be logically sound) leaves the results vacuous: since there is an open interpretation of the degree to which a model correlates to a system, there is no clear definition of what constitutes *proper* science. We will discuss this further in Chapter 7. Many people would like to consider a study to be science only if it occupies a higher caliber of thought, reason, and justification. For this, we must discuss the the role that our ever-changing society plays in the scientific method.

Chapter 6

The Critical View of Theories

In this chapter, we will examine the structure of the critical view of theories given by Bruno Latour. After studying string theory and discussing of the legitimacy of pursuing a complete solution, we will show how the critical view of theories provides a consideration that has not been accounted for.

6.1 Exigetical Account of the Critical View

It is commonly known how the mid to late 20th century ushered in the postmodern era, a time filled with an increase in skepticism and rejection of modern universal ideas about topics such as truth, reality, and society. Much of this critique works against concepts from the Enlightenment. With this wave of re-evaluation, the same kind of questioning begins to affect the philosophy of science.

As more fundamental ideas began coming into question, a divergence in philosophy appeared. *Analytic* and *continental* philosophers assume contrasting axiomatic (fundamental) principles about objective truths: the analytics dogmatically believe that there are objective truths of the universe, while the contentalists (somewhat contradictorily) believe that there are no objective truths. From these initial assumptions, analytic philosophers take the stance that philosophical (thus philosophical scientific) problems are linguistic muddles, that, if analyzed cleanly, can be sorted and left to other fields of study to solve or discarded as mere tricks of speech. Contrastingly, continental philosophers take the stance that all philosophical problems are about social power. The disagreements between these two groups over the topic of science became known as the *Science Wars*. The principal tension of the dispute is over whether *scientific facts* are in reality facts or are just social constructions (Gimbel PC).

In 2002, Bruno Latour, a historian, philosopher, and sociologist of science, provides his concise but insightful take on the science wars. He says that the analytic philosophers take an oversimplified view of science. Real science, he says, is done with instruments and has *data* that is interpreted by a community. Of course, then, the community will be influenced by politics, money, and power. As Latour puts it, if you are an astrophysicist, "when you are asking for money, you say 'The instruments permit quasars to speak'." Scientists will argue politically when it suits them (Gimbel 311).

A scientist plays two parts: the part of the diligent worker, but also that of the politician. Scientists are "wolves pretending to be sheep under attack by wolves," that is, 'under attack' by the contentalists who try to question the validity of their work (Gimbel 308). Latour reduces the Science Wars to "two intelligent academics posing stupid questions to each other" (Gimbel 309). The problems can be fixed: Latour suggests that if you want to understand real science, you must find a way to remove all of the power structures surrounding it (Gimbel 314). This criticism of socital exemplifies the postmodernist effort.

6.2 Case: Lee Smolin and String Theory

String theory was first proposed in 1970 and has grown rapidly since then. The goal of String theory is to "explain the multitude of different particles as being different vibration states on quantized strings." Also, the theory is about "many-dimensional objects called branes" (Johansson 200). On a large scale, many hope (and have been hoping for a long time) that string theory would be the "Theory of Everything," giving the answers to all remaining open problems in physics (Johansson 199).

The original version required the existence of 26 dimensions and was conceived to describe the strong force, but the later-developed *super-symetric* string theory only requires 10. The six dimensions that are not directly observable are thought to be "curled up or 'compactified'." The theory contains the idea of a spin two state that could be interpreted as a graviton (the gravitational force carrying particle that is missing in the standard model, as discussed in the previous chapter) (Johansson 200).

String theory would like to solve three main problems with particle physics:

1. The strong and weak nuclear and the electromagnetic fundamental forces are described with quantum field theory while the fundamental force of gravity is described by Einstein's theory of general relativity. Both have been established

rigorously but are incompatible. This is an issue when the effects of one cannot be ignored (as is the case with studies of the early universe). String theory would connect these two theories (Johansson 200-1).

2. Many physicists are bothered by the number of fundamental particles in the standard model and question whether they are *all* fundamental. String theory would explain that these particles are just different modes of the same object.

3. The values of constants used in the standard model have been “inserted by hand,” which has become less and less satisfying recently. String theory could explain where these numbers come from (Johansson 201).

Many people, however, including the famous theoretical physicist Lee Smolin, are heavily opposed to string theory because of its inability to predict any observable phenomena (Johansson 199). He also argues that it is an issue that string theorists have come to monopolize almost all of the important positions at major universities, forcing students into string theory. He claims “that other approaches to deal with the problems of quantum gravity [are] not given enough funding and . . . this is not fair” (Johansson 207). In this way, he argues that the progress that could be made using other theories is being stifled.

Smolin says that “we have to talk about the sociology of theoretical physics.” He says that we must look at the power inside the structure of theoretical physics. Clearly, older and more established physicists have power over younger up and coming by way of the promise of a career, but there is something more going on. Smolin says that aside from *why* we should or should not support string theory, we should investigate "why string theory, in spite of a dearth of experimental predictions, has monopolized the resources available to advance fundamental physics, thus choking off the investigation of equally promising alternative approaches." He notes that there has always been a "dominant field" in theoretical physics, and string theory is just the current example, preceded by nuclear physics and then elementary particle physics (Smolin 246).

To explain this, Smolin points to a few common characteristics seen in the string community. The first is the arrogance of many string theorists. Smolin quotes JoAnne Hewett, a particle physicist at the Stanford Linear Accelerator Center, as saying that many string theorists "truly believe that all non-stringy theorists are inferior scientists." She also adds that"string theorists have been hired into faculty positions at a disproportionately high level not necessarily commensurate with ability in all cases, and the younger string theorists are usually not well educated in particle physics" (Smolin 247). Another is the exclusivity and boundary construction related to the arrogance: Smolin recounts that "only at string theory conferences have people come up to me and asked, 'What are you doing here?'"(Smolin 249).

Smolin also points out the cult-like reliance younger scientists have on the older scientists in the field. He says that "string theorists are the only scientists I've ever met who typically want to know what the senior people in the field, such as Edward Witten, think before expressing their own views" (Smolin 252). In addition, Smolin summarizes that the string community suffers from a "lack of appreciation for the extent to which a research program might ought to involve risk," as well as the "tendency to interpret evidence optimistically" (Smolin 261). He makes the direct comparison between these qualities and the qualities exemplified by a group who suffers from groupthink, and while the comparison is not one-to-one, it is close enough to cause worry (Smolin 263).

It is important to note, however, that the first group that studied string theory was not funded well but was still able to interest a large group of people (Johansson 207). Smolin responds by saying that "the beautiful simplicity of [string theory] is what excited us originally and what has kept many people so excited; a single kind of entity, satisfying a single simple law" (Smolin 175).

6.3 A Response from Latour

Smolin's argument that string theory is retarding progress in particle physics comes from a philosophical basis, claiming that it is not *fair* that string theory has risen to its current place. The lack of a testable result is an expected complaint for experimental physicists to make. That being the case, many string theorists are not phased by this deficiency; while they would like a "novel testable prediction [to come] out true," they still continue to work, hoping there will be a derivable test in the future (Johansson 206).

Along these lines, we can examine string theory itself as a postmodernist endeavour: the string theorists have developed into a community that is content to live in the theoretical (O'Leary). Just as other postmodernists question human nature or objective truth, these scientists question evidence, the one thing that most people associate with science.

Latour himself might be conflicted over this dispute. On one hand, the idea of questioning evidence is a postmodern idea, so as a postmodernist it might appeal to his sense of skepticism. On the other hand, Smolin's sociological argument would most likely win Latour over. Latour says that "only by modifying the concept of science can we prevent the political use that [scientists] make of it" (Gimbel 313). The community that Smolin described is the kind that Latour would like to do away with in order to purify science to become a force without the involvement of a social-political power.

6.4 Evaluation

We have been discussing potential scientific methods, but actually what we have been doing is considering what elements are necessary to present in order to convince someone of something scientific. However, it is possible that what will convince one person is different from what will convince another. Clearly, if science were *only* a political matter swayed by a dominating power structure, then there would be no content within the structure to be used in the politics or argument. This is impossible, so we must discuss the underlying content of arguments that will convince people to support a claim.

It seems that Latour is optimistic in thinking that it is possible to weed the politics out of science. It is clear from Smolin that there has been a history of political powers at play in physics, and with nothing to put the powers in check, what would disarm them? Politics is an inevitability that we cannot avoid. In the next and final chapter, we will discuss how we can play this game instead of fighting it.

Chapter 7

The Encompassing View

I will discuss the manner in which scientific theories can be individualized on Giere's model and the perfect example that the field of particle physics makes of this method's operation. We will move our focus from the workings of the community to the underlying workings of the individual that give rise to the macroscopic societal phenomena we observe.

I preface what follows with the assumption that we are all individuals and all have sets of *mental baggage* comprising our most fundamental, personal, and *dogmatic beliefs*. These statements are the axioms from which we are able to derive *judgment* and *opinion*, so they are not open to external debate: they cannot be forcibly changed by any means of external deductive logic. In other words, these sets of statements define rationality, so much like the incommensurable Khunian paradigms, are incomparable.

Nothing prevents people from attempting to change others' sets or arguing the superiority of one over the other, but it is impossible to do so deductively (and so decisively). However, it is very possible that in order to be accepted, get a job, or achieve any other goal, people lie about what mental baggage they have. The sets *can* change over time, but since they contain dogmatic beliefs, the means to change one must be on the order of a religious conversion: the motivation must be subconscious, for one cannot, by definition, *choose* to believe something dogmatically. Nevertheless, it is possible for people to discover *that* they believe something. In other words, they have had a realization of a belief they held subconsciously. Furthermore, I am not assuming anything that precludes these axiom sets from being dissonant or self-contradictory. May I also be clear that there is no plague on humanity requiring that people know their complete axiom sets or even that they have them.

I use the following definitions. An *objective truth* (if such a thing were to exist) is a statement that is true regardless of the statements in your mental baggage. That is, it is a statement that everyone could consider to be true. A *subjective truth* is a statement that lies in at least one person's mental baggage. *Realists* are interested in finding the truths of the universe so have in their mental baggage a statement asserting the existence of such objective truths.

Recall that the power of deduction goes to waste as a stand-alone method for a realist; for anyone else, the possibility of deducing truth is unimportant. There is no way to deduce truths of the universe from artificial assumptions, even if the assumptions seem obvious: if you assume a statement to be true, then it must be in your personal baggage (it is subjective, not objective). Of course, as a tool, deduction can be used, but the publishing of initial suppositions is necessary to give meaning or weight to the conclusions.

We also note that the issues with hypothetico-deduction and falsification that were introduced by holists such as Lakatos are in fact logical problems that need to be considered. The Law of Modus Tollens shows why statements cannot be shown to be false in isolation: any method of observation of any phenomenon can be called into question. So, we must consider ourselves logical holists.

In the syntactic view, we considered several *small and tidy* methods and assumed implicitly that we should be able to find one that would appeal to everyone. Our review of the semantic view and the critical view deductively showed that this could not possibly be a plausible goal. Here we will consider a more universal method allowing for the individualism we are assuming. As was explained in Section 5.4, the framework of Giere's model (here I am only referring to Giere's logician definition of a model as the abstract entity that satisfies a set of equations or deterministic relationships) is simple and by itself does not make any assertions. The underdetermined applicability of this kind of model makes it accessible to everyone. We can use this as the foundation for the encompassing view.

Since this definition of model is so general, it is up to the individual to put meaning behind it. Only if a person is working completely alone, with never an intent to interact with anyone else, is it impossible way to require any specific structure of the work produced. For this reason, we will consider communities. As there is no field specification in the definition of a model, *useful*, *interesting*, or *proper* science can be whatever the people determines. The community will have various members with various sets of mental baggage, so the opinions of what is important to be studied will also be varied. This immediately allows for the possibility of disputes and a political structure.

However, the presence of politics in science does not do away with rationality. People will operate under the rationality of their own baggage, so communities comprised of individuals with complementing mental baggage can form. Within these communities, there will be a coherent rationality that is derived from common mental baggage statements. After all, nothing else *can* define rationality. Overall, the more powerful (be that monetarily or rhetorically) will prevail. As mentioned earlier, it is possible that the more powerful will *indoctrinate* (to borrow a concept from Khun) those who are less powerful (be they younger or in a minority of mental baggages) and attempt to instill provisional truths that the majority has accepted. This can be done simply through education. For example, if the provisional truths are reliant on axioms that the weaker ones don't have, but the weaker ones desire to join the majority, they may have to pretend to accept them.

As discussed earlier, since there is no way to actually determine objective truth of the universe, it is perhaps useful to discuss *provisional* or *operational* truths: statements that are taken as temporarily true. Keep in mind that no one is able to control what assumptions people walk around with in their mental baggage, so the way people accept provisional truths (if they do) and the degree to which they allow for the prioritization or ranking of these truths is completely individual. It is possible, for example, that some people become increasingly convinced of a provisional truth, so the statement becomes asymptotically close to being in their mental baggage, but by definition, this is not how the contents of mental baggage can be changed.

We can now explore how individuals can operate with this method. The realist, who wants science to move towards objective truth, can view the model as a proposed accurate picture of reality while the pragmatist can view the model as a useful tool to help explain the world. A Lakatosian can take some models to be hard core, while others are able to be tweaked. For the purpose of convincing others to take on certain provisional truths, we can look at some different techniques that can be used. Of course, a singular technique cannot be expected to convince everyone because the person you are trying to convince might have a completely disjoint set of mental baggage. As previously discussed, this is the fundamental idea motivating the encompassing view.

For one technique, we can rescue induction from the death grips of Hume, Goodman, and Hempel. A person can have in mental baggage that repeated events (such as corroboration of results to predictions from a model), constitute an acceptance of the provisional truth that *the same will happen in the future*. In this way, the model's connection to the real system could be added as an operational truth.

We might also want to discuss progress. Since we have accepted an individualized society of thinkers, we can only then return to the power of the community to truly decide what is considered progress, for the value of a result is subjective. A Lakatosian can consider a theory to be progressing with the previously discussed definition, while another can hold a completely different definition of progress in their mental bagage. In this way, the job of the scientist is blurry: while a cancer researcher or theoretical physicist might not be met with much deterrent external forces, someone studying climate change might be. It might be difficult to comprehend, but again, since there is no way to completely demonstrate the existence of an objective truth, it is the job of scientists to present the argument that will keep the paychecks coming and satisfy whatever moral obligations they might have.

In the specific field of particle physics, we have seen though Smolin how the diversity of subfields has led to a system where smaller groups operate under different assumptions and have categorized progress internally. More and more, personal and individual beliefs are reflected in scientific work, which has led to a diverse population of scientists who continuously argue with each other. It is clear that much science has bled into society, and the continued search for more people to become involved in science fields shows the need for political validation: as more people are encouraged to join a science, the more possibility there is to win over a young scientist who thinks as you do.

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I have upheld the highest principles of honesty and integrity in all of my academic work and have not witnessed a violation of the Honor Code.

Although ‘The Scientific Method’ is a fairly ubiquitous phrase, through various considerations, we will begin to see that the poster flowchart that we recall adorning the wall of our fifth grade classroom does not do it justice. **What is the Scientific Method?** aims to take the reader through notable episodes of the history of particle physics while examining the ongoing philosophical discussion on the scientific method.