Introduction

The realization that Schrödinger's equation would not suffice to provide a complete description of nature did not take a long time. When Schrödinger visited Bohr after formulating his now-famous equation, Bohr argued immediately that such a deterministic equation could not be sufficient to describe the quantum of action. Quantum theory prior to the discovery of Schrödinger's equation was dominated by the quantum of action, which was generally agreed to incorporate a statistical aspect that was indicative of non-causality or nondeterminism at a fundamental level. Hence, the idea that there would be some problem with a completely deterministic equation that is devoid of any statistical formalism arose overnight. The precise problems were made much more concise by Schrödinger [119] in which the prediction of entanglement under unitary evolution was found to be different than the product states expected under measurement.

One might expect that with the rather rapid identification of this issue with Schrödinger's equation, the problem could then be rapidly resolved. However, this has not occurred. Over ninety years has passed since the problem was identified, without solution. With the mathematical and physical developments that have occurred in the twentieth century, as well as the improvements in experimental abilities to probe nature, one would not have expected such a problem to remain unsolved for so long.

The answer we believe lies partly in the approach that many have been undertaking to resolve this problem. There are two general methodologies to consider, inductive and deductive reasoning. In a deductive investigation, one eliminates the possibilities one by one, subject to known constraints, until only a single possibility is left. In an inductive investigation, one works from what is known and expands outwards. In a deductive investigation, one creates hypotheses and attempts to eliminate these based on fundamental facts.

If one examines resolutions of most major physical problems in the past, there appears to be an underlying similarity in how they have been solved. The use of deductive reasoning most often appears when some new physical theory is discovered. Often such theories are considered revolutionary. As has been discussed already in Chapter 5, most scientific revolutions were advanced through the use of scientific deduction.

Aristotle introduced the notion of deductive and inductive reasoning.

Aristotle states [353, p. 108]

> *For every belief comes either through deduction (syllogism) or from induction.* [Prior Analytics II.23]

Popper [632, p. 9] states,

> *According to the view that will be put forward here, the method of critically testing theories, and selecting them according to the results*

of tests, always proceeds on the following lines. From a new idea, put up tentatively, and not yet justified in any way—an anticipation, a hypothesis, a theoretical system, or what you will—conclusions are drawn by means of logical deduction.

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Newton determined his laws from observations and deduction. The same has been attributed to Maxwell. Einstein utilized deductive reasoning to find errors in the prior approaches that led to his discovery of relativity. As well, Bohr utilized deductive reasoning in many of his investigations. On the other hand, the use of inductive reasoning most often is found when there is a discovery based on current physics.

An example of an inductive discovery is Dirac's quantization of the electromagnetic field. Lamb's finding of the Lamb shift and Bethe's subsequent computation. Feynman's path integrals and the predictions of particles such as quarks are based on symmetries within the current formalism of quantum mechanics. The vast majority of recent advances in medicine, electronics, materials, chemistry, aeronautics, etc. have been using inductive methodologies. One could argue that nearly 100% of all scientific progress and discoveries after 1926 have largely been inductive.

There are many who have utilized induction in failed attempts at resolving the measurement problem. As discussed in Chapter 4, Rosenfeld's paper on utilizing Schrödinger's equation to explain measurement is one such example. We suggest that if this problem could have been solved by an inductive application of Schrödinger's equation, it would have been solved in short order after 1926. Historically, the process that has been utilized to reveal new physics has overwhelmingly been deduction. The question one might ask is then why do so many people attempt to resolve this problem using induction?

One possibility is that the process of induction is taught and engrained in today's society in schools and universities rather than deduction. The idea of attending lectures, reading textbooks, and working through exercises where an inductive outcome is expected, is a procedure that is designed to develop the abilities of induction. A student graduates with a degree in a given subject when the student demonstrates the ability to solve a problem that one might be confronted within the future in an inductive manner. That is, the graduate with a degree is expected to be able to be given an abstract problem and formulate the problem in a manner so that the graduate can apply the methodologies that have been learned in school. There is certainly nothing wrong with this approach for nearly all problems—except those that cannot be solved by the current formalism. Welcome to the Measurement Problem.

The following differences should be noted regarding the application of induction and deduction. If the problem can be resolved using inductive techniques, both induction and deduction will give the same result and lead to the resolution of the problem. If the resolution of the problem requires the development or discovery of new principles for which the current inductive theory fails, then deduction will lead to the resolution of the problem, and induction may or may not. Note that in both cases, deduction resolves the problem. In cases where the problem falls within the inductive class of problems for which a given theory is designed to handle, induction succeeds generally faster than the application of deduction, but outside such a class, induction can fail. However, deduction applied to fundamental physics clearly differs from a straightforward application of deductive logic since physics is further constrained both by the results of empirical observation and by the existing body of physical principles that have been historically established. Due to the necessary consistency with these constraints, deduction within the foundations of physics is not an automatic process that can be easily mechanized, but rather an unruly enterprise requiring bold intuition and an ability to deal with paradox, uncertainty, and contradiction.

Historically, inductive reasoning is not a good approach to apply to fundamental physics in order to discover new physical laws and/or principles. Here are potential examples that illustrate why:

1. The Greeks' belief before 700 BC that Zeus is responsible for lightning striking the earth.

2. The conclusion that the Earth is round rather than flat. If you look around you it seems flat. Generalize that and you will conclude that the Earth is flat.

3. The conclusion that because a feather falls slower than a lead weight on the Earth, that the acceleration solely due to gravity must be proportional to mass. If one simply drops a feather versus a lead weight, there is air resistance and the feather falls slower than the lead weight. Implying induction, one generalizes that this is always the case, i.e., that gravitation accelerates objects differently based on the mass. It was believed prior to the discovery of Galileo in the 1500s that gravity would accelerate an object with higher mass faster than an object with lower mass. It is said that Galileo dropped two cannonballs of different masses from the top of the leaning tower of Pisa, and to the amazement of all, both cannonballs hit the ground at the same time. The fact that gravity accelerates objects independently of their mass was contrary to the inductive conclusion that was believed prior to 1500, and Galileo utilized a deductive process to reach this conclusion.

4. The inductive generalization, that because we do not see matter converting to energy, it is impossible for it to occur. This was the belief via induction before Einstein's relativity theory. This was only accepted after the special theory of relativity was developed by Einstein with the formulation of new principles discovered via deduction.

5. The assumption that the conversion between different periodic elements is physically impossible, before the understanding of nuclear processes. Again,

as this is not seen in standard chemical reactions, it is easy to incorrectly utilize induction to generalize this result to all physical processes. It was generally the belief in the 19th century that transmutation was impossible. However, this is false and it is possible via nuclear processes.

6. The assumption before the discovery of atoms, that all phenomena are due to a continuum, and individual atoms do not exist. Remarkably, this was the belief up until the turn of the twentieth century. It is interesting because different views were expressed at different times throughout history. Most philosophers took the status-quo continuum view and opposed new theoretical ideas such as Boltzmann's proposal based on the statistical mechanics of atoms. J. P. Perrin's 1908 experimental confirmation of Einstein's Brownian motion predictions along with the determination of Avogadro's constant confirmed atomic kinetic theory. At that point, most philosophers and other skeptics quickly switched sides.

7. The assumption before Einstein's explanation of the photoelectric effect, that such a threshold effect did not exist, and lowering the frequency but increasing the intensity will be able to cause photo-ionization of matter. This deductive prediction by Einstein and the experimental confirmation led the way for a particle interpretation versus a wave interpretation.

8. Because we have seen that we can predict fundamental constants with extreme precision using a combination of unitary evolution and measurement, then it must be that all physical processes obey unitary evolution.

9. Because we have not isolated any processes to date that are non-unitary, then all processes must be unitary

10. The conclusion that consciousness and free will eventually will be explained by currently known theory.

11. The reasoning that if many atomic configurations evolve via unitary evolution, that all configurations of matter are described by unitary evolution.

New physical principles may very well be discovered via the resolution of the measurement problem. Einstein believed that quantum mechanics is incomplete. In other words, Einstein believed that quantum mechanics needed to be completed. If Einstein worked at great length and could not figure out how to complete quantum mechanics, one ought to consider the use of deduction rather than the use of induction regarding this problem. Interestingly, Einstein used deductive methods for his earlier discoveries of relativity and light quanta, while his later efforts in interpreting quantum theory relied more and more on induction.

Essentially, induction is a process by which one defines a problem and then uses established principles to reach a conclusion. Insofar as the problem falls into the class of problems for which the particular theory that you were taught is correct, then induction will give the correct result. Induction is essentially a process whereby one takes an abstract problem and formulates a precise problem using mathematical or other methods for which a process exists for its solution.

Logically speaking, why not use a deductive approach? One will succeed in solving the problem if the problem can also be solved within an inductive formalism. And one will have the best chance of succeeding if the problem cannot be resolved within an inductive formalism.

Deduction is rather the reverse process. First one needs to make a set of assumptions that will be used in the investigation. Secondly, one needs to determine the logical possibilities that exist for the resolution of the problem, based on these fundamental assumptions. There generally will be a large number of possibilities. Then the possibilities need to be evaluated in terms of experimental and theoretical evidence in a manner to eliminate the possibilities until a single possibility remains. If no possibility remains, then the set of assumptions is wrong. One then needs to change the assumptions based on what has been learned and repeat the process.

Induction is an orthodox approach. One attends school and learns time-tested methodologies required to be applied in practice. In terms of physics, new results are obtained from laws already known. Essentially, the knowledge base is continually pushed outward and growth occurs. However, such a knowledge base has a fundamental limitation because it is based on a given set of axioms or fundamental laws. Suppose that a given phenomenon cannot be explained on the basis of the axioms and fundamental laws that are contained within the inductive approach. Instead suppose that the given phenomenon demands the development of new laws to explain it. Then such a problem is outside the scope of induction and is best approached using deduction.

Newton in Principia Mathematica proposed four rules regarding the pursuit of science [308, p. 205]. Rule 4 is relevant to the measurement problem:

> *Rule 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 hypothesis that may be imagined, till such time as other phenomena occur, by which they may either be made more accurate, or liable to exceptions.*

The phenomenon of measurement, by all means, does appear to be an exception to unitary evolution. Rule 4 of Newton states that induction should either be made more accurate or liable to exceptions. The process that is most applicable to Rule 4, when the current theory cannot be inferred by induction, is the process of deduction.