Dreams Of A Final Theory by S Weinberg

Preface

p.x On the other hand, the historians one reads for pleasure, from Tacitus and Gibbon to J. H. Elliott and S. E. Morison, mingle narrative and background while at the same time making a case for any conclusions that they wish to set before the reader. In writing this book I have tried to follow their lead, and to resist the temptations of tidiness.
As Enrico Fermi once said, one should never underestimate the pleasure we feel from hearing something we already know.

Chapter I: Prologue

p.6 Think of the space of scientific principles as being filled with arrows, pointing toward each principle and away from the others by which it is explained. These arrows of explanation have already revealed a remarkable pattern: they do not form separate disconnected clumps, representing independent sciences, and they do not wander aimlessly–rather they are all connected, and if followed backward they all seem to flow from a common starting point, to which all explanations may be traced, is what I mean by a final theory.
p.8 They were taught to calculate the deflection of a cathode ray or the fall of an oil droplet, not because that is the sort of thing everyone needs to calculate but because in doing these calculations they could experience for themselves what the principles of physics really mean. Our knowledge of the principles that determine these and other motions is at the core of physical science and a precious part of our civilization. From this point of view, the "physics" of Aristotle was no better than the earlier and less sophisticated speculations of Thales and Democritus.
p.9 When we say that one truth explains another, as for instance that the physical principles (the rules of quantum mechanics) governing electrons in electric fields explain the laws of chemistry, we do not necessarily mean that we can actually deduce the truths we claim have been explained.
p.10 Nothing like Hellenistic science was seen anywhere in the world until the rise of modern science in Europe in the seventeenth century.
p.11 It is with Isaac Newton that the modern dream of a final theory really begins. Quantitative scientific reasoning had never really disappeared, and by Newton's time it had already been revitalized, most notably by Galileo.
p.16 Paul Dirac, one of the founders of the new quantum mechanics, announced triumphantly in 1929 that "the underlying physical laws necessary for the mathematical theory of a larger part of physics and the whole of chemistry are thus completely known, and the difficulty is only that the application of these laws leads to equations much too complicated to be soluble."
p.17 When proper care is given to the definition of masses and electric charges and other constants the infinities all cancel, but *only* in theories of certain special kinds. We may thus find ourselves led mathematically to part or all of the final theory, as the only way of avoiding these infinities.
p.18 The discovery of a final theory in physics will not necessarily even help very much in making progress in understanding these phenomena (though it may with some)

Chapter II: On A Piece Of Chalk

p.19 By tracing these arrows of explanation back toward their source we have discovered a striking convergent pattern–perhaps the deepest thing we have yet learned about the universe.
p.27 Explanation, unlike deduction, carries a unique sense of *direction.* We have an overwhelming sense that the photon theory of light is more fundamental than any statement about heat radiation and is therefore the explanation of the properties of heat radiation.
A scientific explanation can also be something less than a deduction, for we may say that a fact is explained by some principle even though we cannot deduce it from that principle.
p.29 The fact that we scientists do not know how to state in a way that philosophers would approve what it is that we are doing in searching for scientific explanations does not mean that we are not doing

something worthwhile. We could use help from professional philosophers in understanding what it is that we are doing, but with or without their help we shall keep at it.
p.38 We would not expect to be able to deduce it from the laws of motion and gravitation alone. The separation of law and history is a delicate business, one we are continually learning how to do as we go along.
p.39 There is one other problem that must be confronted, one associated with the buzzword "emergence." As we look at nature at levels of greater and greater complexity, we see phenomena emerging that have no counterpart at the simpler levels, least of all at the level of the elementary particles.
p.41 Thermodynamics is more like a mode of reasoning that a body of universal physical law; wherever it applies it always allows us to justify the use of the same principles, but the explanation of why thermodynamics does apply to any particular system takes the form of a deduction using the methods of statistical mechanics from the details of what the system contains, and this inevitably leads us down to the level of the elementary particles. In terms of the image of arrows of explanation that I invoked earlier, we can think of thermodynamics as a certain pattern of arrows that occurs again and again in very different physical contexts, but, wherever this pattern of explanation occurs, the arrows can be traced back by the methods of statistical mechanics to deeper laws and ultimately to the principles of elementary particle physics.
p.42 The reasoning that leads to these rules is the same whether it is applied to humans or birds or extraterrestrials, but the reasoning always rests on certain assumptions about the organisms involved, and, if we ask *why* these assumptions should be found to be correct, we must seek the answer partly in terms of historical accidents and partly in terms of universals like the properties of DNA (or whatever takes its place on other planets) that must in turn find their explanation in physics and chemistry, and hence in the standard model of elementary particles.
p.43 This is not only because we are unable to use our first principles actually to calculate complicated phenomena; it is also a reflection of the sort of question we want to ask about these phenomena.
p.45 But (I repeat, and not for the last time) I am concerned here not so much with what scientists do, because this inevitably reflects both human limitations and human interests, as I am with the logical order built into nature itself. It is in this sense that branches of physics like thermodynamics and other sciences like chemistry and biology may be said to rest on deeper laws, and in particular on the laws of elementary particle physics.
p.46 In speaking here of a logical order of nature I have been tacitly taking what a historian of philosophy would call a "realist" position–realist not in the everyday modern sense of being hardheaded and without illusions, but in a much older sense, of believing in the reality of abstract ideas.
When we say that a thing is real we are simply expressing a sort of respect. We mean that the thing must be taken seriously because it can affect us in ways that are not entirely in our control and because we cannot learn about it without making an effort that goes beyond our own imagination.
p.49 One of the great services provided by the discovery of the pattern of scientific explanation is to show us that there are no such autonomous sciences.
p.50 For all of us, there is simply no alternative to making a judgment as well as we can that some of these ideas (perhaps most of them) are not worth pursuing. And our greatest aid in making this judgment is our understanding or the pattern of scientific explanation.

Chapter III: Two Cheers For Reductionism

p.51 If you go around asking why things are the way they are, and if, when you are given an explanation in terms of some scientific principle, you ask why that principle is true, and if like an ill-mannered child you persist in asking why? why? why? then sooner or later someone is going to call you a reductionist.
Reductionism has become a standard Bad Thing in the politics of science; Canada's Science Council recently attacked the Canadian Agricultural Services Coordinating Committee for being dominated by reductionists.
p.52 For me, reductionism is not a guideline for research programs, but an attitude toward nature itself. It is nothing more or less than the perception that scientific principles (and, in some cases, historical accidents) and that all these principles can be traced to one simple connected set of laws.
p.53 The reductionist worldview *is* chilling and impersonal. It has to be accepted as it is, not because we

like it, but because that is the way the world works.
p.55 One of the members of the board argued that we should not give the impression that we think that elementary particle physics is more fundamental than other fields, because it just tended to enrage our friends in other areas of physics.
The reason we give the impression that we think that elementary particle physics is more fundamental than other branches of physics is because it is. I do not know how to defend the amounts being spent on particle physics without being frank about this. But by elementary particle physics being more fundamental I do not mean that it is more mathematically profound or that it is more needed for progress in other fields or anything else but only that it is closer to the point of convergence of all our arrows of explanation.
p.57 It is not that the *discovery* of DNA was fundamental to all of the *science* of life, but rather that DNA itself is fundamental to all life itself. Living things are the way they are because through natural selection they have evolved to be that way, and evolution is possible because the properties of DNA and related molecules allow organisms to pass on their genetic blueprint to their offspring.
p.59 The difference between these two problems is that, when condensed matter physicists finally explain high-temperature superconductivity–whatever brilliant new ideas have to be invented along the way–in the end the explanation will take the form of a mathematical demonstration that deduces the existence of this phenomenon from *known* properties of electrons, photons, and atomic nuclei; in contrast, when particle physicists finally understand the origin of mass in the standard model the explanation will be based on aspects of the standard model about which we are today quite uncertain, and which we cannot learn (though we may guess) without new data from facilities like the Super Collider. Elementary particle physics thus represents a frontier of our knowledge in a way that condensed matter physics does not.
p.60 As I wrote in reply to Alvin, this sort of reasoning could be used to justify spending billions of dollars in classifying the butterflies of Texas, on the grounds that this would illuminate the classification of the butterflies of Oklahoma, and indeed of butterflies in general. This silly example was meant only to illustrate that it does not add much to the importance of an uninteresting scientific project to say that it is important to other uninteresting scientific projects.
p.61 Certainly questions about creativity and life are interesting because we are alive and would like to be creative. But there are other questions that are interesting because they carry us closer to the point of convergence of our explanations. Discovering the source of the Nile did nothing to illuminate the problems of Egyptian agriculture, but who can say that it was not interesting?
Also, it misses the point of this sort of question to speak of explaining the whole "in terms of the parts"; the study of quarks and electrons is fundamental not because all ordinary matter is composed of quarks and electrons but because we think that by studying quarks and electrons we will learn something about the *principles* that govern everything.
p.62 I suspect that all working scientists (and perhaps most people in general) are in practice just as reductionist as I am, although some like Ernst Mayr and Philip Anderson do not like to express themselves in these terms.
p.64 The same is true throughout all the sciences. We would not pay much attention to proposed autonomous law of macroeconomics that could not possibly be explained in terms of the behavior of individuals or to a hypothesis about superconductivity that could not possibly be explained in terms of the properties of electrons and photons and nuclei.

Chapter V:Tales Of Theory And Experiment

p.104 The reception of general relativity depended neither on experimental data alone nor on the intrinsic qualities of the theory alone but on a tangled web of theory and experiment. I have emphasized the theoretical side of this story as a counterweight to a naive overemphasis on experiment. Scientists and historians of science have long ago given up the old view of Francis Bacon, that scientific hypotheses should be developed by patient and unprejudiced observation of nature.
p.113 It was almost a calculation that Oppenheimer could have done in 1930, but it took the urgency of an experiment that needed to be explained and the encouragement of the ideas that were in the air at Shelter Island to get anyone to push the calculation through to completion.

Chapter VI: Beautiful Theories

p.150 There is another respect in which it seems to me that theoretical physics is a bad model for the arts. Our theories are very esoteric–necessarily so, because we are forced to develop these theories using a language, the language of mathematics, that has not become part of the general equipment of the educated public.

p.162 As it turned out, the theory of critical exponents has a simplicity and inevitability that makes it one of the most beautiful in all of physics. In contrast, the problem of calculating the precise temperatures of phase transitions is a messy one, whose solution involves complicated details of the iron or other substance that undergoes the phase transition, and for this reason it is studied either because of its practical importance or in want of anything better to do.

Chapter VII: Against Philosophy

p.167 In our hunt for the final theory, physicists are more like hounds than hawks; we have become good at sniffing around on the ground for traces of the beauty we expect in the laws of nature, but we do not seem to be able to see the path to the truth from the heights of philosophy.

But this has been learned through the experience of scientific research and rarely from the teachings of philosophers.

Wittgenstein remarked that "nothing seems to me less likely than that a scientist or mathematician who reads me should be seriously influenced in the way he works."

p.168 Some of it was good reading and even witty, like the writings of Wittgenstein and Paul Feyerabend. But only rarely did it seem to me to have anything to do with the work of science as I knew it According to Feyerabend, the notion of scientific explanation developed by some philosophers of science is so narrow that it is impossible to speak of one theory being explained by another, a view that would leave my generation of particle physicists with nothing to do.

I am not alone in this; I know of *no one* who has participated actively in the advance of physics in the postwar period whose research has been significantly helped by the work of philosophers.

p.169 The "mechanical philosophy" of Descartes had a powerful influence on Newton, not because it was right (Descartes did not seem to have the modern idea of testing theories quantitatively) but because it provided an example of the sort of mechanical theory that could make sense out of nature.

p.170 To be sure, this was partly due to the influence of philosophers like Voltaire and Kant. But here again the service of philosophy was a negative one; it helped only to free science from the constraints of philosophy itself.

p.173 Kant taught that space and time are not part of external reality but are rather preexisting structures in our minds that allow us to relate objects and events. To a Kantian the most shocking thing about Einstein's theories was that they demoted space and time to the status of ordinary aspects of the physical universe, aspects that could be affected by motion (in special relativity) or gravitation (in general relativity).

p.174 It is not in metaphysics that modern physics meets its greatest troubles, but in epistemology, the study of the nature and sources of knowledge.

p.175 The figure most often associated with the introduction of positivism into physics is Ernst Mach, physicist and philosopher of fin-de-siècle Vienna, for whom positivism served largely as an antidote to the metaphysics of Immanuel Kant. Einstein's 1905 paper on special relativity shows the obvious influence of Mach; it is full of observers measuring distances and times with rulers, clocks, and rays of light.

p.176 Despite its value to Einstein and Heisenberg, positivism has done as much harm as good. But, unlike the mechanical worldview, positivism has preserved its heroic aura, so that it survives to do damage in the future. George Gale even blames positivism for much of the current estrangement between physicists and philosophers.

Positivism was at the heart of the opposition to the atomic theory at the turn of the twentieth century.

p.177 As late as 1910, after atomism had been accepted by nearly everyone else, Mach wrote in a running debate with Planck that, "if belief in the reality of atoms is so crucial, then I renounce the physical way of thinking. I will not be a professional physicist, and I hand back my scientific reputation."

The resistance to atomism had a particularly unfortunate effect in retarding the acceptance of statistical mechanics, the reductionist theory that interprets heat in terms of the statistical distribution of the en-

ergies of the parts of any system. The development of this theory in the work of Maxwell, Boltzmann, Gibbs, and others was one of the triumphs of nineteenth century science, and in rejecting it the positivists were making the worst sort of mistake a scientist can make: not recognizing success when it happens.
p.180 But if one understands how theory-laden are all experimental data, it becomes apparent that all the successes of the atomic theory in chemistry and statistical mechanics already in the nineteenth century had constituted an observation of atoms.
p.181 Much of this angst over quantum electrodynamics was tinged with a positivist sense of guilt: some theorists feared that in speaking of the values of the electric and magnetic fields at a point in space occupied by an electron they were committing the sin of introducing elements into physics that in principle cannot be observed. This was true, but worrying about it only retarded the discovery of the real solution to the problem of infinities, that the infinities cancel when one is careful about the definition of the mass and charge of the electron.
p.184 The quark theory was only one step in a continuing process of reformulation of physical theory in terms that are more and more fundamental and a t the same time farther and farther from everyday experience. How can we hope to make a theory based on observables when no aspect of our experience–perhaps not even space and time–appears at the most fundamental level of our theories? It seems to me unlikely that the positivist attitude will be of much help in the future.
p.188 It is simply a logical fallacy to go from the observation that science is a social process to the conclusion that the final product, our scientific theories, is what it is because of the social and historical forces acting in this process. A party of mountain climbers may argue over the best path to the peak, and these arguments may be conditioned by the history and social structure of the expedition, but in the end either they find a good path to the peak or they do not, and when they get there they know it. (No one would give a book about mountain climbing the title *Constructing Everest.*)
Where then does this radical attack on the objectivity of scientific knowledge come from? One source I think is the old bugbear of positivism, this time applied to the study of science itself.
p.189 Would it be surprising if, when anthropologists and sociologists turned their attention to studying the work of scientists, they tried to recapture that delicious sense of superiority by denying the objective reality of the scientists' discoveries?
p.190 This hostility seems to me to be tragically misdirected. Even the most frightening Western applications of science such as nuclear weapons represent just one more example of mankind's timeless efforts to destroy itself with whatever weapons it can devise. Balancing this against the benign applications of science and its role in liberating the human spirit, I think that modern science, along with democracy and contrapuntal music, is something that the West has given the world in which we should take special pride.

Chapter VIII: Twentieth Century Blues

p.205 The puzzle of explaining this enormous difference in fundamental energies is therefore known in elementary particle physics today as the *hierarchy problem.*
p.207 And if we do not take this seriously, why should we demand that the standard model be renormalizable? The problem of infinities is still with us, but it is a problem for the final theory, not for a low-energy approximation like the standard model.
The reason, we think, can be traced to the fact that all the terms in the field equations, apart from the very simple renormalizable terms, necessarily appear in these equations divided by powers of something like the Planck energy.
This is such a tiny number that naturally no such effect has been detected. In other words, the condition of renormalizability that guided our thinking from the quantum electrodynamics of the 1940s to the standard model of the 1960s and 1970s was for practical purposes the right condition, though it was imposed for reasons that no longer seem relevant.

Chapter X: Facing Finality

p.233 Yet more radical is the suggestion that at bottom we shall find that there is no law at all.
Nielsen likewise needs some sort of metalaw to explain how the appearance of nature changes as we change the scale of distances and energies at which we make our measurements, and for this purpose assumes

the validity of what are called renormalization group equations, whose origin in a world without law is certainly problematic.

Chapter XI: What About God?

p.242 If there were anything we could discover in nature that *would* give us some special insight into the handiwork of God, it would have to be the final laws of nature.
p.244 Of course, like any other word, the word "God" can be given any meaning we like. If you want to say that "God is energy," then you can find God in a lump of coal. But if words are to have any value to us, we ought to respect the way that they have been used historically, and we ought especially to preserve distinctions that prevent the meanings of words from merging with the meanings of other words.
In this spirit, it seems to me that if the word "God" is to be of any use, it should be taken to mean an interested God, a creator and lawgiver who as established not only the laws of nature and the universe but also standards of good and evil, some personality that is concerned with our actions, something in short that it is appropriate for us to worship. This is the God that has mattered to men and women throughout history.
p.245 But what possible difference does it make to anyone if we use the word "God" in place of "order" or "harmony," except perhaps to avoid the accusation of having no God? Of course, anyone is free to use the word "God" in that way, but it seems to me that it makes the concept of God not so much wrong as unimportant.
p.246 The demystification of life has had a far greater effect on religious sensibilities than has any discovery of physical science. It is not surprising that it is reductionism in biology and the theory of evolution rather than the discoveries of physics and astronomy that continue to evoke the most intransigent opposition.
p.247 Of course, one could never hope to prove that no supernatural agency ever tips the scales in favor of some mutations and against others. But much the same could be said of any scientific theory. There is nothing in the successful application of Newton's or Einstein's laws of motion to the solar system that prevents us from supposing that every once in a while some comet gets a small shove from a divine agency.
p.248 In another respect I think that Johnson is right. He argues that there is an incompatibility between the naturalistic theory of evolution and religion as generally understood, and he takes to task the scientists and educators who deny it. He goes on to complain that "naturalistic evolution is consistent with the existence of 'God' only if by that term we mean no more than a first cause which retires from further activity after establishing the laws of nature and setting the natural mechanism in motion."
The inconsistency between the modern theory of evolution and belief in an interested God does not seem to me one of logic–one can imagine that God established the laws of nature and set the mechanism of evolution in motion with the intention that through natural selection you and I would someday appear–but there is a real inconsistency in temperament. After all, religion did not arise in the minds of men and women who speculated about infinitely prescient first causes but in the hearts of those who longed for the continual intervention of an interested God.
p.249 I replied that just as it would be wrong for those who are emotionally committed to atheism to give evolution more emphasis than would be otherwise appropriate in teaching biology, so it would be inconsistent with the First Amendment to give evolution less emphasis as a means of protecting religious belief. It is simply not the business of the public schools to concern themselves one way or the other with the religious implications of scientific theories.
For instance, in a review of Johnson's book, Stephen Gould remarks that science and religion do not come into conflict, because "science treats factual reality, while religion treats human morality." On most things I tend to agree with Gould, but here I think he goes too far; the meaning of religion is defined by what religious people actually believe, and the great majority of the world's people would be surprised to learn that religion has nothing to do with factual reality.
p.250 This seems to me to represent an important retreat of religion from positions it once occupied. Once nature seemed inexplicable without a nymph in every brook and a dryad in every tree.
Although I understand pretty well how brightly colored feathers devolved out of a competition for mates, it is almost irresistible to imagine that all this beauty was somehow laid on for our benefit. But the God of birds and trees would have to be also the God of birth defects and cancer.
Remembrance of the Holocaust leaves me unsympathetic to attempts to justify the ways of God to man.

p.251 If there is a God that has special plans for humans, then He has taken very great pains to hide His concern for us. To me it would seem impolite if not impious to bother such a God with our prayers.
Wheeler's conclusion seem to me to provide a good example of the dangers of taking too seriously the doctrine of positivism, that science should concern itself only with things that can be observed.
p.255 In my 1977 book, *The First Three Minutes*, I was rash enough to remark that "the more the universe seem comprehensible, the more it seems pointless." I did not mean that science teaches us he universe is pointless, but rather that the universe itself suggests no point.

Notes
p.302 More recently, responding to the heavy-handed sociological reinterpretation of scientific progress, the University of London geneticist J. S. Jones remarked that "the sociology of science bears the same relation to research as pornography does to sex: it is cheaper, easier and–as it is constrained only by the imagination–can be a lot more fun" [in a review of *The Mendelian Revolution: The Emergence of Hereditarian Concepts in Modern Science and Society*, by Peter J. Bowler, *Nature* 342 (1989): 352].
p.311 Holger Nielsen has proposed a "random dynamics": H. B. Nielsen, "Field Theories Without Fundamental Gauge Symmetries," in *The Constants of Physics*, ed. W. McCrea and M. J. Rees (London: Royal Society, 1983), p.51; reprinted in *Philosophical Transactions of the Royal Society of London* A310 (1983): 261.