On Beyond Darwin

By Chance or By Design

J.N. Patterson Hume

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Original Preface

Over the years I have collected quotations from papers and books which for various reasons were meaningful to me, just as people collect scraps of material in a ragbag. I thought it was time to open my ragbag and sort things out—to systematize all these odds and ends. I found that they fell into a number of categories or should I say—I put them into categories. I imagined that I could run a narrative through the quotations so that a coherent pattern would emerge. In this way, I would at least organize my own thoughts and perhaps help others to do the same.

So I began, with the help of a computer text editor and cooperation from my secretary Gwen Jacobs who used the whole project as the incentive to learn about text entry and editing on a computer. Inge Weber has handled revisions.

And now it's time to present my efforts.

A number of my friends and colleagues have read a draft of this book, and I have benefitted greatly from their constructive criticisms. Since I wrote the book to be read by as wide an audience as possible, the sample of people I chose to preview the draft was broad. It included W.O. Fennell (a systematic theologian), William Swinton (a Darwin expert), G.D. Scott and B.P. Stoicheff (physicists), Robert Finch (a French scholar), Charles Rackoff (a theoretical computer scientist), Stephen Hume (my son who also happens to be a computer scientist), R.C. Holt (a computer systems expert with whom I have coauthored books on computer programming), J.H. MacLachlan and R.B. de Sousa (philosophers of science), Phyllis Gotlieb (a science fiction writer), C.C. Gotlieb (a physicist turned computer scientist), Leslie Jones (a publisher's representative), and many more.

At the risk of giving the plot away and spoiling the suspense, I am starting with a summary of the basic ideas that I present in the book. This may be helpful as a general map of the territory that I have explored. Much of what is included in the book is well-accepted scientific knowledge but my own speculations and those of others are an integral part of the story. I have summarized these unorthodox views clearly after any chapter that contains them.

I could say more here, but I would rather let the book speak for itself.

J.N. Patterson Hume

University of Toronto, 1983

Preface

Time has passed since my father's original publishing of this work. I was one of the original readers, and the ideas presented in this book have made me a little more skeptical of the explanations of the Universe that have been proposed over the generation since then.

I find that the book stands the test of time, and it is still relevant to the critical thinking that is required to grasp the nature of things, Physics.

The last typesetting of this book was done on a custom word processing computer, and now I find I can republish it using more modern desktop and web publishing tools. There is a companion website for the book at:

http://onbeyonddarwin.com/

Be ready to deal with your natural defenses as these ideas will shake some of your assumptions. At a minimum, this book will challenge you to think. Throughout the book, there are many quotes from other physicists and scholars, that lend insight as to what they too held in doubt.

Please send your thoughts to comments@onbeyonddarwin.com or join the web based discussions.

Stephen Hume

2006

Contents

Original Preface iii
Preface v
Summary 1
Getting Started 7
On Beyond Darwin 17
The Origin of Laws 29
What Needs Explanation 39
The Information Content of Laws . . . 45
The Impossibility of Isolation 53
Electromagnetic Interaction. 67
The Energy Crisis 79
Cosmic Noise 93
The Stochastic Atom 111
The Two-Slit Mystery 125
Trapped Inside 145
Shedding Light on Inverse-Square Laws 161
The Nature of Things. 173
References 181

Summary

Various answers have been given to the question of whether the present state of the universe is the result of chance or design. Newton believed that there is a design and that the design is discoverable by man. The evidence for design was the existence of general laws. For Newton, the idea of a design was consistent with his religion. This same kind of metaphysical view was held by Einstein who believed that a spirit is evident in the laws of the universe. Einstein's own work was directed at finding the single law or theory, that would explain everything, although he did not succeed in finding it.

Much of physical science has been influenced by the widely held premise—that there are general laws which govern or describe what goes on in the universe. Our physics, if you will, has been influenced by metaphysics. Even when, in the twentieth century, it was found necessary to invoke chance in connection with atomic physics, the randomness was quickly incorporated into a general law—the uncertainty principle. In the nineteenth century, randomness entered with far less notice in the second law of thermodynamics. Although we think that when an event happens by chance it does not at the same time happen by design, somehow scientists have included the chance element as part of the design.

For many people, the existence of general laws implies a design in the universe—even with some elements of chance—and the existence of a design implies a Designer or Creator. Put the opposite way, the belief that many scientists have held—that there is a Designer—has influenced the present shape of science. Experimental facts are usually considered to be explained when they fit a general law—no further investigation is necessary, except perhaps, to subsume the general law under a more general law.

In the nineteenth century, the work of Charles Darwin on the origin of species denied the activity of a Creator in the special creation of each species. Darwin's theory of evolution, by chance variation and natural selection, ran counter to contemporary religious convictions. (Creationists still believe that if science does not accord with religion it is bound to be wrong.) But Darwin was trying to show that evolution happened according to general laws, although the laws did contain a large element of chance in them. He too believed that the universe was governed—or described—by laws that could be discovered by scientists, although he did not hold this view because of religious convictions.

Some people have used the presence of chance in the laws of evolution or in the laws of physics to argue that there is no design in the universe, only chance events. The presence of the chance element in the laws has been used by them to deny the existence of a Designer.

I believe that the scientific study of the biological and physical universe should neither be able to affirm nor deny the existence of a Designer, Creator, or Spirit—call it what you will. It is my strong belief that the question of whether the present state of the universe is the result of chance or design, or even a mixture of chance and design, is an unanswerable question. It will never be decidable by scientific means. I believe that science is neutral on the religious question. This is, if you will, my metaphysical position.

But, as it is presently framed, science does not seem to me to be neutral—it was developed by scientists who were not neutral and their metaphysical attitudes are still there in the science.

Newton in many ways set the pattern of scientific thought. He believed that the behavior of specific things was explained by the existence of general laws. But, how do you explain the existence of general laws? Most scientists say that the order we observe in the universe arises because there are general laws. But, I believe that general laws imply design. To resolve my dilemma I have had to turn Newton around and say that the existence of general laws ought to be explained by the behavior of specific things.

But, you may object, there would be no order in the universe if there were no general laws, and I agree that there is evident order. My thesis is that the order can be explained by the fact that everything in the universe is made up of a few fundamental objects or particles. The most important of these fundamental particles are electrons, protons, and neutrons. If we know the properties of these three, all else can be deduced. There are only a few basic species of things.

Darwin showed that the properties of a particular species of living things are related to the local environment of that species. In the case of fundamental particles, the local environment of a particle is provided by all the other fundamental particles in the universe.

It is one thing to suggest a new point of view in science and another to show first, that the new point of view can be consistently held, and second, that there is any benefit to changing to that new point of view. This is why I have attempted in this book to go through the whole body of physical theory to see how all the general laws might be explained in terms of the properties of specific things like electrons, protons, and neutrons. It is a very large project and, in the main, I have relied on explanations that have already been put forward by other scientists but have often not received any kind of general acceptance. In some few cases, I have had to make some speculations of my own. These speculations seem reasonable to me in the context of the larger argument but perhaps would not otherwise be considered seriously. They must be taken as examples of the kind of explanation I seek, and the case I make must be looked at as a whole.

But, what is the benefit of all this effort? It opens doors that have remained shut—when a general law is accepted as an explanation, questioning often ceases. By opening the doors I have been led to ideas of considerable novelty—ideas that are perhaps worth consideration. But, as it happens, there is another benefit that I did not anticipate. In my examination, I have come to a description of the way things are that is, to me, considerably simpler than the present orthodox view, based on general laws. As an information scientist and as a person who taught Physics for many years, I welcome a corpus of physical scientific knowledge that is easier to comprehend. It is all too simple for the average person to drown in the information explosion or give up in trying to learn very much about physical science. We as scientists must do everything we can to keep it simple.

But, you say, what if the universe is not simple? If it were simple, I would have to try to explain why it was simple. In fact, in this book one of my main problems, beside the apparent existence of general laws, is the existence of simplicities. These too are often taken as evidence of a Designer—a Designer who, moreover, is rational. Simplicities, to me, require an explanation.

All scientists know that scientific truth is tentative but, nevertheless, radical changes in that truth are rarely accepted. Evolution of knowledge is much more comfortable. But, sometimes a more drastic revision recommends itself.

It is the object of science to replace, or save, experiences, by the reproduction and anticipation of facts in thought. Memory is handier than experience.

Ernst Mach

When you build a system it is either a ragbag or a bed of Procrustes.

Robert Finch

CHAPTER 1

Getting Started

I taught university-level Physics for over twenty years. During that period a new discipline, Computer Science, grew up and I was part of the pioneering development in this new field. Although my university work was then taken up completely with Computer Science, I still could not get Physics off my mind.

My Ph.D. degree in Physics at the University of Toronto involved making numerical calculations to try to understand the behavior of complex atoms. It was the need to do numerical calculations that first led me into the fascinating world of computers. Although electronic computers had been designed and built in the late forties, by the time I got my doctor's degree in 1949 I really had not heard anything about them.

Then, in 1952, the University of Toronto acquired one of the first two electronic computers ever marketed commercially. It was a Ferranti Mark I computer, a copy of the one at the University of Manchester. In a short space of time I was up to my ears in writing programs, designing operating systems, and developing a new programming language so that more scientists could take advantage of this marvellous new tool for research.

In the process, I got distracted from my own Physics research calculations and was caught up in the birth pains of a new science. Because Computer Science did not become a discipline, recognized by the University of Toronto, until 1964, I remained in the Department of Physics and taught courses in Physics exclusively.

My research interests lay in Computer Science, but as a Physicist, my main role was that of a teacher. In that role I had the good fortune to collaborate with Professor Donald G. Ivey in some very exciting projects in Physics education. This activity ran in parallel with my computer work.

Just as computers were a technological development I knew nothing about until I had finished my formal education, another electronic advance, television, burst upon me quite unexpectedly. In Canada, television was just in its infancy in 1958 when Dr. Ivey and I were invited to prepare and present a series of twelve half-hour programs on Physics for a general audience. I suppose you would call it educational TV. It was to be broadcast, as an early-evening series, on the Canadian Broadcasting Corporation (CBC) station in Toronto. The programs were recorded on film by a process called kinescope. This meant that a movie camera—black and white, of course—was aimed at a tiny TV screen and the program recorded. The film was not to be edited, so the performance was effectively *live on film*. It was a fantastic experience. To be allowed complete control over the content and presentation for twelve half hours of—local—prime time television was quite a challenge! We loved it; and, as it turned out, the audience loved us.

In the summer of 1959, Don Ivey and I went *live* over the entire CBC network and most of its affiliated stations, at 10:30 at night, in a second twelve-week series called *Two for Physics*. Again, the two of us had complete charge of content and presentation. What an opportunity for us! Presenting our subject to an audience larger than any professor could hope to meet in a lifetime of teaching. What a responsibility—to the scientific community and to the University of Toronto!

We tried to present science, and by that I mean physical science, as a human activity that every reasonably well-educated person should know something about. Physics is complicated, and it is not easy to reduce all the technical terminology and mathematical formalism to terms that are accessible to anyone with an open mind. But, our goal was to do our damnedest. Somehow our public, which remember was a minority audience, understood what we were trying to do. They often wrote to us saying "We don't understand everything you say, but don't stop trying."

We really tried to explain Physics in ordinary words and that meant that we had to rethink it for ourselves. No longer could we hide behind terms like *kinetic energy* or *impedance* and expect successful communication. Formulas were used only occasionally. We presented Physics without all the paraphernalia that goes with it in an ordinary university course.

Our television work was rebroadcast over the Public Broadcasting System in the United States and, on a Boston channel, caught the eye of Stephen White who was working with the Physical Science Study Committee (PSSC) in its *films for high schools* program. This led to our making four movies for PSSC. The first of these, *Frames of Reference*, was given the Edison award as the best science education film for 1962. Another, *Random Events*, got a silver medal from the Scientific Institute in Rome.

The experience with PSSC, and particularly with masterminds like Professors Jerrold R. Zacharias and Francis L. Friedman, gave us a whole new insight into Physics education. They were rethinking what was to be taught in high schools. Tradition be damned; everything must be rethought; nothing taken for granted. It had really never occurred to me that I could rethink Physics—perhaps the presentation of physics, but not the subject itself. It was an overwhelming sense of responsibility that it gave us, and an unbelievable feeling of freedom. I had never really questioned fundamentals in Physics. Now I can't stop. I sympathize with Descartes, the founder of analytic geometry, who believed in the maxim of doubting everything that had up to his time passed as established truth! I became an inveterate doubter.

As I continued to teach Physics, more and more of the established *textbook* material seemed suspect. Ernst Mach in his unconventional textbook on *Heat*, published near the end of the nineteenth century, catches my mood as he writes:

> Many a reader must have had the experience that, relating generally accepted viewpoints with a certain enthusiasm, he suddenly realizes that the matter no longer comes from the heart. Quiet considerations afterwards usually lead to the discovery of logical discrepancies that once admitted become unbearable.

After we had finished with our television and film work which lasted six years, Dr. Ivey and I launched into a very ambitious project—to write a university-level textbook in Physics. The text—actually in two volumes—was to be based on the PSSC philosophy of questioning, rethinking, and reworking fundamental physics, this time for serious university students in the physical sciences and engineering.

Many of the logical discrepancies I found in Physics have been worked through in our text. We had, as in our television programs, the idea of presenting Physics in all its complexity, not simplifying it just so that it could be easily digested. We presented it in as organized and systematic a way as we could so that a maximum understanding would be possible. The book was published, received excellent reviews, but was not a runaway best seller.

Our job as university professors is to pass along accumulated knowledge so that it can be used by the next generation of scientists as they approach research or apply the information in industrial situations. Well-understood half-truths will not do, unless you believe that a truth half-understood is no better. But, there is the chance that some bright young students will go well beyond half-understanding and that is why we wrote as we did.

Truth is a dangerous word. First of all I am limiting the word truth to the realm of science. I am referring to scientific truth rather than philosophical truth which is a much more general idea encompassing a much broader view of reality. By scientific truth, I mean "the best available interpretation of facts that we have at the moment." This permits the possibility that we will have a better interpretation of presently available facts, or that we will, in the future, have more facts which may precipitate a reinterpretation. All scientists recognize the tentative character of their scientific knowledge.

This meaning of scientific truth is relative to the current situation, not absolute scientific truth. There might even be two competing interpretations of available facts with no more merit in one than the other. Then to me both interpretations are "true".

We, as scientists, live in a constantly changing world and our science —or knowledge of the world—is constantly evolving. As Mach puts it, we know we are not finished and we live with the idea:

> The highest philosophy of the scientific investigation is precisely this toleration of an incomplete conception of the world and a preference for it rather than an apparently perfect, but inadequate conception [1].

Some scientists believe that there is an absolute scientific truth and that our present scientific truth is coming closer and closer to this absolute. But, I really believe that the notion of an ultimately knowable absolute scientific truth is not appropriate. The idea that we are coming closer, by degrees, toward a *true* truth is no doubt encouraged by the fact that many of our scientific interpretations—or theories—are evolved from earlier ones. But, there are many counter examples to this idea of a gradual approach to scientific truth. Some abrupt changes in theory have been more revolutionary than evolutionary. Some of them might have been more revolutionary than they needed to be. For example, the quantum theory of the atom was a complete break with scientific tradition. The traditional is sometimes referred to as *classical*, the revolutionary view of quantum theory as *modern*.

But theories, call them classical or modern, are interpretations of certain observed facts about the world. These interpretations depend on what facts just happen to be known at any particular time and on the personality of and influences on the scientist. As Thomas Kuhn, the modern philosopher and historian of science, puts it in his book on scientific revolutions:

> An apparently arbitrary element, compounded of personal and historical accident, is always a formative ingredient of the beliefs espoused by a given scientific community at a given time. [2]

As science develops, it seems to evolve or *revolve* on the chance discoveries of fact and the chance nature and influences of the people interpreting the facts. But from these chance events emerges a kind of pattern, an orderliness that some people call the scientific method. Although what this method is I cannot describe concisely.

Most scientists are engaged in what Kuhn calls "normal science," adding to and evolving what is already there. The results of their experiments or theoretical analyses are published in learned journals so that other scientists need not waste time duplicating the same work. And so the body of knowledge grows. Most of this publication is virtually inaccessible to the public. It is written for an entirely different audience. Much of it is inaccessible to scientists outside the narrow field of specialization, and people live in scientific compartments separated from—if not alienated from—other scientists even in the same discipline, such as Physics. This specialization has become a way of life, since each separate area is extremely complex and often requires a lifetime of concentration to make significant advances.

But there are breakthroughs, often from outside the scientific establishment. Commenting on Einstein's revolutionary paper published in 1905 on what is known now as special relativity, C.P. Snow notes that its style was not what is normally wanted in scientific journals. Einstein, he said, had a strange poetic freedom and very little mathematics. It would probably not be accepted in today's journals. But who is to say?

If one has an idea which departs in a major way from the current scientific model, or paradigm, of the world, it is often vigorously resisted by scientists practising normal science, the establishment. And so it should be. We cannot afford to have the orderly development of knowledge sent this way and that like a ship without a rudder every time some *crackpot* has an idea. Most ideas, like most mutations in biological evolution, are not viable. But, some ideas are viable, Einstein's for example.

By this time, you can probably tell that I have an idea. It evolved over a period of twenty years. Pieces of it I unsuccessfully have tried to publish in journals—a fact that proves nothing one way or another. My only recourse is to put the case as clearly as I can in a book, a book that is accessible to as many people as possible. This is somewhat of a scientific no-no. As Kuhn points out:

> No longer will his [a creative scientist's] researches usually be embodied in books addressed like Franklin's *Experiments... on Electricity* or Darwin's *Origin of Species*, to anyone who might be interested in the subject matter of the field. Instead, they will usually appear as brief articles addressed only to professional colleagues, the men whose knowledge of a shared paradigm can be assumed and who prove to be the only ones able to read the papers addressed to them.
>
> Today in the sciences, books are usually either texts or retrospective reflections upon one aspect or another of the scientific life. The scientist who writes one is more likely to find his professional reputation impaired than enhanced. [3]

The state of my reputation will have to take its chances! I have this idea and would at least like someone to give it a hearing. I am encouraged by that old saying "The one who insists on never uttering an error must remain silent." I cannot remain silent any longer.

But what is the idea? Can I not state it in so many words? Obviously, I must come at it several different ways but let me make a first attempt. The subtitle of this book is called *By Chance or By Design* and it refers to the universe. Is the present state of the universe the result of chance or design?

I believe that physical science, as it is practised by the establishment, is based on the premise that there is a design in the universe and that the design is discernible by man. I will argue that this widely held premise has its roots in theological thinking and, if closely examined, cannot be supported by actual evidence. It is my thesis that whether or not there is a design is what we in Computer Science call an undecidable question. From our position inside the thing that we are studying, I believe that it is—and always will be—impossible to decide whether it is by chance or design—or even by a mixture of chance and design—that we are here.

What is more important, the assumption that there is discernible design in the universe stops scientists from investigating beyond a certain point. They accept the laws that they have discovered—or contrived—as sufficient explanation of the way things are, and are inclined not to examine them as critically as they ought. In the end, this may hold them back in their attempt to accumulate knowledge about the universe.

For me, general laws imply design and I will try to show that there are no discernible general laws. I will describe how, in the process of looking at laws differently, I was led to a serious reappraisal of many of the well-established ideas in physical science.

Let me quote Charles Darwin in a letter to his friend Joseph Hooker:

> I have been now ever since my return [from the voyage on the Beagle] engaged in a very presumptuous work, and I know no one individual who would not say a very foolish one… At last gleams of light have come, and I am almost convinced (quite contrary to the opinion I started with) that species are not (it is like confessing a murder) immutable. [4]

Darwin said species are not immutable. By this statement, he was refuting the idea that each species had been designed to fit neatly into its own special place in the overall scheme of creation. But, Darwin still believed that behind evolution there lay laws that govern that evolution. In particular he believed that laws, such as the law of gravity, govern the behavior of the physical world. My thesis is that the evidence of design in the physical world that we have through the existence of laws is an illusion; that there is no evidence of a plan of creation or unity of design in any scientific knowledge that we have.

I return to Darwin, this time from *The Origin of Species* which was first published in 1859:

> Although I am fully convinced of the truth of the views given in this volume under the form of an abstract, I by no means expect to convince experienced naturalists whose minds are stocked with a multitude of facts all viewed, during a long course of years, from a point of view directly opposite to mine. It is so easy to hide our ignorance under such expressions as the "plan of creation," "unity of design," etc., and to think that we give an explanation when we only restate a fact. Anyone whose disposition leads him to attach more weight to unexplained difficulties than to the explanation of a certain number of facts will certainly reject my theory. A few naturalists, endowed with much flexibility of mind, and who have already begun to doubt on the immutability of species, may be influenced by the volume; but I look with confidence to the future, to young and rising naturalists, who will be able to view both sides of the question with impartiality. [5]

Scientists see order in the world; without order there could be no science. This order stems, most say, from the existence of laws that govern the behavior of all matter. Some will say instead that the laws describe the behavior, not govern it; but the result is about the same. General or universal laws that describe—or govern—the behavior of a large class of different objects seem to indicate design. But, I claim all these general laws, when closely examined, can be shown not to be general laws.

In this chapter I have introduced myself as a somewhat unconventional scientist, not without credentials. I have indicated some of the influences on my thinking because I believe that it is important to be aware of the environment of scientific thought. One of my principal points later on is that we have too often ignored the environment, in say a physical interaction between two objects, as if it did not matter. Surely, one of the major points of Darwin's theory of evolution is that the environment matters. Darwin, in several important ways, is a starting point for me and in the next chapter I will show how my ideas about the inanimate world are a logical extension of his ideas about the animate world.

CHAPTER 2

On Beyond Darwin

Hans Reichenbach in his book *The Rise of Scientific Philosophy* says:

> The evolution of life is but the last chapter in a longer story, the story of the evolution of the universe. [1]

Charles Darwin in his 1859 book *The Origin of Species* set out his basic ideas of the evolution of life—the "story of the evolution of the universe" has been the subject of much investigation since that time.

Evolution is change and development over a period of time. For Darwin the nature of the change was fundamentally a gradual one, neither abrupt nor cataclysmic.

Evolution need not be something that happens over a long period of time. A book by Nobel Prize winner Steven Weinberg called *The First Three Minutes* says this:

> In the beginning there was an explosion. Not an explosion like those familiar on earth, starting from a definite center and spreading out to engulf more and more of the circumambient air, but an explosion which occurred simultaneously everywhere, filling all space from the beginning, with every particle of matter rushing apart from every other particle... These particles—electrons, positrons, neutrons, photons—were continually being created out of pure energy and then after short lives being annihilated again. Their number therefore was not preordained, but fixed instead by a balance between processes of creation and annihilation. [2]

The book describes what happened, according to the best current information, in the first three minutes *after* the creation of the universe. The subject of creation or initiation of the universe is not discussed—that topic is quite beyond scientific investigation.

As Werner Heisenberg, the author of the uncertainty principle in physics, puts it:

> Causality can only explain later events by earlier events, but it can never explain the beginning. [3]

Or, as Reichenbach says:

> To ask how matter was generated from nothing, or to ask for a first cause, in the sense of a cause of the first event, or of the universe as a whole, is not a meaningful question.
>
> Explanation in terms of causes means pointing out a previous event that is connected with the later event in terms of general laws. [4]

In Weinberg's account of the early evolution of the universe, he says that particles of matter and photons—particles of radiation— "were continually being created out of pure energy." Just what "pure energy" is I do not know but naturally there is no explanation of where it comes from. It is an unanswerable question. Whenever a question seems unanswerable by rational or scientific means, it has been a habit of people in the past to explain the situation by stating that it was the act of the Creator of the universe. The existence of a Creator explains creation. Before Darwin, most people, including scientists, accepted the idea that each species of living beings had been created—by the Creator—in a special act of creation, presumably sometime after the creation of the universe. Darwin said:

> Authors of the highest eminence seem to be fully satisfied with the view that each species has been independently created. To my mind it accords better with what we know of the laws impressed on matter by the Creator, that the production and extinction of the past and present inhabitants of the world should have been due to secondary causes, like those determining the birth and death of the individual. When I view all beings not as special creations, but as the lineal descendants of some few beings which lived long

> before the first bed of the Silurian system was deposited, they seem to me to become ennobled. [5]

Darwin's theory removed the active participation of the Creator from the development of the different species but continued to attribute the origin of "the laws impressed upon matter" to the Creator. Darwin's aim—perhaps influenced by his wife, who was religious—was, in fact, to show that biological events followed a law—the law of evolution—just as astronomical events did. In his preface to a modern edition of *The Origin of Species*, John Burrow says:

> Darwin had asked in his 1842 sketch, comparing the state of biology to physics, "What would the Astronomer say to the doctrine that the planets moved [not] according to the laws of gravitation, but from the Creator having willed each separate planet to move in its particular orbit." After 1859 biologists no longer needed to say things of that kind and nor did anyone else. [6]

Darwin himself in *The Origin of Species* writes:

> ... whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved. [7]

The use of the word "fixed" in connection with "law of gravity" shows that Darwin took the law as given. There is no indication that he believed that the law might have evolved over time. It has been the aim of scientists ever since Newton's time to try to discover the laws, presumed to be fixed and constant everywhere, by which the universe operates. These laws, being themselves unexplained, were presumed to be the work of the Creator. Man's relationship to the Creator was judged as special within the creation in that he could know what was in the "mind" of the Creator.

Prince Albert, consort of Queen Victoria, indicated his view of the special position that man, as scientist, holds:

> His Reason being created after the image of God, he has to use it to discover the laws by which the Almighty governs His creation and, by making these laws his standard

> of action, to conquer nature to his use; himself a Divine instrument. [8]

Darwin's work had merely repositioned the Creator's main activity to an initiating one, of laying down the laws and starting creation, rather than a continuing one. As Gertrude Himmelfarb points out in her book on Darwin:

> *Macmillan's Magazine* argued that the basic religious beliefs—the nobility of conscience, our power of communion with God, and our hopes of immortality—were in no way impugned by Darwinism, since no matter how far back Darwin succeeded in tracing the evolution of man, the laws governing that evolution must still ultimately be ascribed to a Creator. [9]

One reaction to Darwin's work shortly after its publication came from Frederick Temple, who emphasized that God's power is found in the laws rather than in miraculous interference with them:

> The fixed laws of science can supply natural religion with numberless illustrations of the wisdom, the beneficence, the order, the beauty that characterize the workmanship of God ... [10]

Temple uses the term "natural religion." Sometimes this is referred to as "natural theology," a knowledge of God—the Creator—through nature. Himmelfarb says:

> "Natural theology"—the search for "evidences" of Christianity and God in the facts of nature—was not a device invented by shrewd theologians to make science subservient to religion. It was, rather, an attempt to explore nature in the only way that seemed to make nature, as well as God, intelligible—in terms of design. Paley set down the first principle of the creed: "There cannot be design without a designer, contrivance without contriver." And although he himself preferred to look for illustrations of design where he could find no evidence of natural or

> mechanical laws, others found design precisely in the operation of such laws…
>
> Earlier, in the seventeenth century, it had been mathematics that had been invoked to demonstrate the rationality and thus the divine providence of the universe: Newton's scientific work was inspired by the same religious mission that led him to devote so many years to the allegorical examination of the prophecies of Daniel. In the eighteenth and early nineteenth centuries it was natural science that was ransacked for "Christian evidences." [11]

This activity of looking to nature for confirmation of God's existence was more accessible to the general population through the life sciences than through the physical sciences. As Burrow says:

> To pursue in any detail the pleasing evidence of harmony and divine purpose in the Newtonian heavens required some rather abstruse mathematics; to trace the same evidences in each leaf, stamen and antenna was well within the scope of any country clergyman with a collecting basket. To follow the workings of nature was to explore the mind of its Creator and to receive renewed assurances of his benevolence. [12]

Burrow indicates that this great popularity of finding God in nature in Victorian times had a kind of fifth column effect:

> Bug-hunting was the Trojan horse of Victorian agnosticism. [13]

It was after all through this kind of activity—bug hunting—that Darwin's theory *evolved*. Darwin's theory was based on the chance events of variation and natural selection, not on any predetermined design for any particular species, even man. Darwin resisted any attempt to introduce a purpose or telos into the evolutionary chain of events. Himmelfarb reports:

> When Asa Gray interpreted him [Darwin] as saying that the system of nature had "received at its first formation the impress of the will of its Author, foreseeing the varied yet necessary laws of its action throughout the whole of its

> existence, ordaining when and how each particular part of the stupendous plan should be realized in effect," Darwin protested that this was not at all what he meant. To find such evidences of design not only in the end product of natural selection but also in each stage of it was to deny his theory altogether. For if each variation was predetermined so as to conduce to the proper end, there was no need for natural selection at all, the whole point of his theory being that, out of undesigned and random variations, selection created an evolutionary pattern. [14]

Darwin anticipated his critics in the *Origin* itself:

> That many and grave objections may be advanced against the theory of descent with modification through natural selection, I do not deny. I have endeavoured to give to them their full force. Nothing at first can appear more difficult to believe than that the more complex organs and instincts should have been perfected, not by means superior to, though analogous with, human reason, but by the accumulation of innumerable slight variations, each good for the individual possessor... and, lastly, that there is a struggle for existence leading to the preservation of each profitable deviation of structure or instinct. [15]

He emphasizes that the temptation to see design in complex organs is almost overwhelming but must be resisted:

> It is scarcely possible to avoid comparing the eye to a telescope. We know that this instrument has been perfected by the long-continued efforts of the highest human intellects; and we naturally infer that the eye has been formed by a somewhat analogous process. But may not this inference be presumptuous? Have we any right to assume that the Creator works by intellectual powers like those of man?... Let this process [variation and natural selection] go on for millions on millions of years; and during each year on millions of individuals of many kinds; and may we not believe that a living optical instrument might thus be formed as

> superior to one of glass, as the works of the Creator are to those of man? [16]

Still, the Creator and his methods—those of evolution now—are very apparent. Even though initial design and purpose of the creation are not to be believed, predetermined principles or laws governing the evolution and operation of the universe are acceptable ideas.

Darwin had made a great step forward over his scientific forebears in evolution. Thomas Kuhn notes:

> All the well-known pre-Darwinian evolutionary theories—those of Lamarck, Chambers, Spencer and the German Natur Philosophen had taken evolution to be a goal-directed process. The "idea" of man and of the contemporary flora and fauna was thought to have been present from the first creation of life, perhaps in the mind of God. [17]

Darwin knew that the scientific community would not abandon the idea of a goal in creation lightly, and he was right. Himmelfarb summarizes the situation:

> What all his critics assumed to be a major difficulty in his theory, he blandly took as confirmation of that theory. While they objected that perfection implied design, that complex and intricate organs could not have evolved by the slow process of selection acting upon chance variations, he insisted that such organs could never have been created in a perfect state. [18]

Not all members of the community were displeased to see chance triumph over design as Himmelfarb continues to say:

> Some Calvinists gloried in it precisely because it exalted chance, not design. It was this that confirmed their faith in special providence, in the arbitrary election of the chosen, and in the spontaneous, unpredictable, and often tragic nature of the universe. [19]

It has often been the case that freedom from strict adherence to law has been welcomed by religious thinkers as a loophole through which God might intervene, as Providence, in the operation of the universe without contravening His own design principles. Of course, such an intervention would mean that the chance events were not really *chance* events and design principles based on chance would indeed have been contravened.

The position of natural theology, as it stands now, rests on finding evidence for God in the existence of the laws that govern—or describe—the universe, including the law of evolution. As was mentioned by Burrow, the reason people preferred to look at the life sciences rather than the physical sciences for evidences of design was that Physics involved some rather "abstruse mathematics" and for many people even a simple physical formula is abstruse.

Most peoples' faith in the confirmation of religion by science is usually somewhat secondhand. They look to the distinguished men of science for statements of faith, and these statements are not hard to find. Albert Einstein is one of the most distinguished:

> Everyone who is seriously involved in the pursuit of science becomes convinced that a spirit is manifest in the laws of the universe—a spirit vastly superior to that of man, and one in the face of which we with our modest powers must feel humble. [20]

Einstein is just one in a long succession of scientists before and after Darwin who accepted the existence of universal laws as evidence of a Divine plan. Newton started it all with his universal law of gravitation and his laws of motion—and many since have seen similar evidences of the hand of the Creator. Maupertuis in 1747 invented a principle called the principle of least action which he believed was evidence of the wisdom of the Creator. Leibniz invented the idea that this was the best of all possible worlds, an idea that Voltaire mocked in *Candide*.

As an apologia on the title page of the *Origin* Darwin quoted Bacon's *Advancement of Learning*:

> To conclude, therefore, let no man out of a weak conceit of sobriety, or an ill-applied moderation, think or maintain,

> that a man can search too far or be too well studied in the book of God's word, or in the book of God's works; divinity or philosophy; but rather let men endeavour an endless progress or proficience in both. [21]

This is a clear statement that science was an investigation in the "book of God's works." Darwin weakened but did not destroy natural theology.

Natural theology is alive and well today. A surgeon friend of mine recently offered a talk, as a layman, at a church service which I attended. He spoke with great conviction about the fact that his belief in God rested securely on the magnificence of the law and order of the universe. Dr. Werner Von Braun, the rocket specialist, stated in a letter in 1972:

> One cannot be exposed to the law and order of the universe without concluding that there must be design and purpose behind it all.

But, many modern theologians are not pinning their religious beliefs on natural theology. Paul Tillich in his *Systematic Theology I* states:

> If the element of fore-seeing [in Providence] is emphasized, God becomes the omniscient spectator who knows what will happen but who does not interfere with the freedom of his creatures. If the element of fore-ordering is emphasized, God becomes a planner who has ordered everything that will happen "before the foundations of the world"; all natural and historical processes are nothing more than the execution of this supratemporal divine plan… Both interpretations of Providence must be rejected… Providence is not interference; it is creation. Providence is a quality of every constellation of conditions, a quality that "drives" or "lures" toward fulfillment… It is not an additional factor, a miraculous physical or mental interference in terms of supernaturalism. It is the quality of inner directedness present in every situation. [22]

Tillich rejects a "supratemporal divine plan" and rejects "miraculous interference." But, he does affirm a teleological principle as an "inner directedness present in every situation."

But, if a divine plan is truly evident from the laws of nature, how could such evidence for the existence of God be rejected by theologians?

From the earliest days of experimental science the mention of God has been absent from scientific writing—not in scientific memoirs. Heisenberg says:

> In this period [of Galileo] there was in some cases an explicit agreement among the pioneers of empirical science that in their discussions the name of God or a fundamental cause should not be mentioned. [23]

Laplace said, "I have no need of the hypothesis of God," meaning that scientific explanation does not need to include any reference to the name of God. This is not to say that Laplace rejected God or that God is a hypothesis. But, science does refer to natural laws and laws imply design and as Paley said, "There cannot be design without a designer." Is it possible in science to say "I have no need of the hypothesis of design"?

The title of this chapter is *On Beyond Darwin*. Darwin argued that design as a part of the explanation of the evolution of life was not necessary; I would like to go beyond Darwin and remove design as an essential part of the explanation of the evolution of the physical universe.

But, how can design be denied? Hoffman in his biography of Einstein says:

> The supreme task of the physicist is to arrive at those universal elementary laws from which the cosmos can be built up by pure deductions. [24]

There are few physicists who would venture for a moment to say that there are *not* fundamental—or elementary—laws "from which the cosmos can be built up." Are not these laws behind the order we observe in our universe? And without order there would be no science. But, I maintain that it is possible to have order without design. It is my thesis that there is no more evidence for design in the elementary laws of physics than there is in biological evolution, and this book is an attempt to put before you an argument which will convince you of the validity of that statement. I believe that the implication of design evidenced by natural law was introduced by Newton and has remained, almost unmodified, to the present day. When we accept the idea that natural law implies design we are accepting, without realizing it, an argument for the existence of a Designer based on natural evidence. It is my belief that proving the existence of God is not possible from facts about the physical or biological universe. Neither would it be possible to deny the existence of God—or a Designer—if no evidence for design is found in nature.

But, my interest here is not in the religious aspects of this, although these are profoundly important. What I think has happened is that the religious beliefs of scientists in the past, like Newton, have set a pattern for science that may not be entirely appropriate for today. The pattern involves the unquestioning acceptance of the existence of natural laws. I believe that this metaphysical idea has become a basic premise of physical science, just as special creation of each species was a metaphysical idea behind pre-Darwinian biological science. What I found was that, when I gave up accepting the premise of the existence of natural laws, many of the discrepancies I had found in Physics could be resolved.

CHAPTER 3

The Origin of Laws

Since the time of Sir Isaac Newton most scientists have assumed that the orderliness that we find in the universe stems from the fact that there are a number of principles or laws which govern—or describe—the behavior of all things. Newton laid down this philosophy clearly in his *Principia*:

> To tell us that every species of things is endowed with an occult specific quality by which it acts and produces manifest effects is to tell us nothing. But, to derive two or three general principles of motion from phenomena, and afterwards to tell us how the properties and actions of all corporeal things follow from those manifest principles, would be a very great step in Philosophy, though the causes of those principles were not yet discovered.

In this statement Newton indicates a time sequence—properties and actions of all bodies *follow* from principles. The principles have separate—if not prior—existence apart from the bodies whose behavior they govern—or describe. It was Newton's belief, and that of scientists ever since, that man could come to know these principles and that the same principles applied everywhere in the universe. Because the principles applied to all "corporeal things"—bodies—they were general principles or laws. A statement about a specific species of thing was scientifically worthless. Newton said it is "to tell us nothing."

There is no doubt that scientists have made great progress on the basis of the assumption—faith, belief, intuition—that there are general principles—although for some reason they have not tried to discover the causes of those principles. I believe that it is time for a careful examination of this implicit assumption of the scientific enterprise. I believe that the existence of general principles would be strong evidence of design in the universe and, if there is design, there must be a Designer. Since I do not accept the idea that the evidence for the existence—or non-existence—of a Designer can be found from examining nature, either animate or inanimate, I must hold that the existence of general laws or principles is illusory.

But, how is the illusion created? It is, I will argue, mainly due to the natural recurrence of certain specific "species of things"—the fundamental particles of the universe. This means that the order that we experience in the universe, which I do not deny exists, can be accounted for in terms of the specific qualities by which certain species of things "act and produce manifest effects," with no general principles whatsoever. I have dropped the word "occult" in connection with specific qualities—presumably Newton was implying that no natural explanation could be found for specific qualities. Newton was somewhat biased—as you notice he did not label general principles "occult" even though he added "though the causes of those principles were not yet discovered."

If I take the position that the explanation of the order we find in the universe is in terms of specific qualities, rather than laws, any law which we have in Physics must be shown to be either a statement about specific qualities—a fact—or an artifact. By artifact I mean something not based on the real world, a creation of man. Laws or principles must be shown to be either fact or artifact, or a mixture of these two. A scientific fact is a statement such as *the mass of the moon is 73.5 thousand, billion, billion kilograms*—I use one thousand million as a billion. This particular fact about a one-of-a-kind thing like the moon would not be generally useful, but the fact that *the mass of an electron is 9.11 thousand, billion, billion, billionth of a kilogram* is extremely useful, because there are so many natural recurrences of electrons. If you know one, you know them all.

If a law, or principle, transcends a particular "species of thing," I say that it must be explained. So, in a sense, I am taking the exactly opposite point of view from Newton. Newton said that facts about specific things must be explained by showing how they follow from general principles. I maintain that general principles must be explained by showing how they follow from facts about specific things. In the next chapter, I will be looking more generally at what needs explanation.

I have indicated Newton's view of general laws and said that this view has persisted to this day. Here is a quote from a modern university textbook by F.W. Constant called *Fundamental Laws of Physics:*

> The great laws of physics are those that express principles or relations which are independent of the specific properties of certain materials or objects. These laws will therefore be called our *fundamental laws*; they must be distinguished from those *restricted laws* which apply only to certain materials and only under a limited range of conditions. [1]

Sound familiar? Here is a more philosophical statement by Reichenbach:

> The fact that nature lends itself to a description in terms of causal laws suggests the conception that reason controls the happenings of nature;... *if-then-always* is all that is meant by a causal relation. [2]

Reichenbach says earlier in his book, "Generalization, therefore, is the origin of science" and continues:

> All these laws are generalizations; they say that a certain implication holds for all things of a specified kind... What we mean by explaining an observed fact is incorporating that fact into a general law. [3]

He, like Newton, says that facts need explanation—Newton called them "occult"—whereas general laws do not. The explanation of a fact according to Reichenbach consists merely in "incorporating that fact into a general law." So you can see Newton's great influence in our scientific thinking.

We saw earlier that the interest in natural theology by the bug hunting Victorians was an attempt by man "to explore nature in the only way that seemed to make nature, as well as God, intelligible—in terms of design." Charles Darwin showed that the apparent evidence of design or teleology in nature could be explained as far as the animate world is concerned. Quoting Reichenbach again:

> Chance in combination with selection produces order. It was the great discovery of Charles Darwin that the apparent teleology of living organisms can be explained in a similar way by a combination of chance and selection. [4]

But, Darwin was trying to show that there were general principles that governed—or described—the behavior of living things: the principle of evolution, the principle of natural selection, the principle of variation, and so on. His placing of the quotation by Whewell on the title page of the *Origin* shows this ambition.

> But with regard to the material world we can at least go so far as this—we can perceive that events are brought about not by insulated interpositions of Divine Power, exerted in each particular case, but by the establishment of general laws. [5]

The establishment of general laws was presumably by the "Divine Power."

The need for general laws is deeply rooted. It is like the need for a map of the land to let you know where you are. Ernst Mach spent a long time thinking about laws. In his book *The Significance and Purpose of Natural Laws* he writes:

> In our view of the matter, natural laws are the consequence of our psychological need to find our way in nature, and to avoid having to confront it as a confused strange world... The earliest attempts at self-orientation are mythological, demonological, and poetic... the period of Copernicus and Galileo strove for a primarily qualitative, preliminary orientation, and ease of comprehension, simplicity and aesthetic satisfaction were accordingly the principles governing the search for those laws which might contribute to the mental reconstruction of the observed facts... With the accumulation of information... the demand for intellectual economy... and as general an applicability and practicality as possible becomes particularly pressing... It is only natural that in periods lacking in epistemological sophistication the psychological motive for scientific research is projected into nature itself. It is God or nature which strives toward simplicity and aesthetic satisfaction—at a later period toward a firm regularity and specificity—finally, toward frugality and economy in all respects, toward the attainment of every end with the least possible expense. [6]

Mach brings up several themes here that we will have to explore in detail. Beside self-orientation, the laws "contribute to the mental reconstruction of the observed facts." This is an information science point of view of science and is to me, as a computer—or information—scientist, the essence of science—to distil information into a compact form so that it can be stored for retrieval or passed along from generation to generation. Anyone familiar with the information explosion will appreciate the paramount importance of information compression. If we have a compressed piece of information, like a scientific formula, we can explode it—often using a computer—into detailed information about specific situations. From a practical point of view, that is really all science needs to do for us other than to discover new facts. But that is a great deal!

But as Mach continues, there is a "psychological motive for scientific research." Scientists have striven to see in nature "simplicity and aesthetic satisfaction" and later "frugality and economy in all respects." Does it make nature more "intelligible" to see simplicity or beauty? Is there a need to feel the Designer's hand ever-present? Or do we need confirmation that our view must be correct because our laws are simple or mathematically elegant? Listen to Heisenberg:

> Especially in physics the fact that we can explain nature by simple mathematical laws tells us that here we have met some genuine feature of reality, not something that we have—in any meaning of the word—invented ourselves. [7]

Bridgman questions this stand in his book on *The Nature of Physical Theory:*

> The feeling that all the steps in a mathematical theory must have a counterpart in the physical system is the outgrowth, I think, of a certain mystical feeling about the mathematical construction of the physical world. This mystical feeling involves, I think, a feeling for the "real existence" of principles according to which this universe is run. [8]

Very often a scientist will have preconceived ideas of the nature of the principles on which the "universe is run" and if he is the right person at the right time he can make progress by matching his preconceptions to observed facts—using his metaphysics to do physics. Lewis S. Feuer has analyzed the philosophic influences on several outstanding physicists of this century in his book on *Einstein and the Generations of Science*:

> Every great physicist approaches the world of physical phenomena with guiding philosophical analogies that express his innermost emotions and longings. He is fortunate if the objective physical data and problems allow for a fruitful conjuncture with his subjective standpoint. The emotional-intellectual standpoints of creative scientists can be utterly diverse; Newton was enthralled by a vision of a neo-Platonic unity; Einstein was sustained by the spirit of Marxian-Machian rebellion; Bohr felt the dramatic urge of Kierkegaard's qualitative dialectical leaps of the stadia of human existence… Indeed in the history of scientific ideas it is probably the case that the overwhelming majority of such generative emotions underlying the variations in ideas, that is, the novel scientific hypotheses are extinguished by the factual, experimental environment. Yet without such generative emotions, the nisus toward scientific creativity would be gone. [9]

To have a "guiding philosophical" viewpoint is no guarantee of success in science. As with mutations, most "generative emotions" are not productive. But, what is surprising is that scientists like Newton, Einstein, and Bohr, all with revolutionary ideas, have strong philosophic viewpoints; most of them have shared these viewpoints in scientific memoirs after their fame was achieved. The philosophic viewpoint remember is not the science, it is only a guide to creativity in science. It is a heuristic: an aid to guessing a solution. The philosophic viewpoints of different scientists can be diametrically different. Feuer says:

> Einstein sought to subsume all reality within a system; Bohr denied that such a system was possible, and wondered whether "all reality" had a meaning. [10]

Even a single scientist can change his philosophy during his career. Look at Einstein according to Feuer:

> By the end of World War I, Einstein's relativist mood began to subside. His thinking was no longer isoemotional with revolutionary trends. His longing was for harmony, indeed, for a realization of God's mind in nature... Asked by a Rabbi whether he believed in God, Einstein responded: "I believe in Spinoza's God, who reveals himself in the harmony of all being"... He [God] entailed the "inner consistency and the logical simplicity of the laws of nature"... His [Einstein's] Spinozist faith, however, was more than a personal admiration or even religious ethic; it became a regulative principle for discovery of the laws of nature. [11]

Here, Feuer calls Einstein's philosophic viewpoint "a regulative principle for discovery," what we call a heuristic principle.

In an editorial in the *American Scientist,* Melvin Kranzberg stresses the personal nature of a scientist's method of doing science:

> Because the myth of "the scientific method" stresses objectivity and impartiality, we too often lose sight of the human personal element in science. Thus in research reports the passive voice predominates... To depict science as an impersonal body of agreed-on knowledge is to deny the fact that scientific knowledge is constantly undergoing change and correction... The fact is that science possesses a personality or many personalities—because individual scientists approach problems in distinctly different ways. To deny the personality of science is to deprive it of the human element and to deny that the human creative imagination, ingenuity and intelligence have anything to do with enlarging boundaries of scientific knowledge. [12]

Kranzberg is emphasizing that the science itself bears the stamp of the scientist and his philosophic influences.

This is the way that scientists work—but does the science they create validate their philosophic or theological position in any way? Can the theology be wrong and the science right? Mach worries about this with respect to scientists like Newton:

> The question may now justly be asked if the point of view of theology which led to enunciation of the principles of mechanics was utterly wrong, how comes it that the principles themselves are in all substantial points correct. The answer is easy. In the first place, the theological view did not supply the contents of the principles but simply determined their guise, their matter was derived from experience. [13]

Einstein was originally influenced very much by Mach's work and admired Mach's willingness to reexamine physical theory from the point of view that it was "man-made" rather than "God-given." This encouraged Einstein to have revolutionary thoughts about space and time. Einstein wrote about Mach, emphasizing Mach's views about being critical of every theory, law, or principle:

> Notions which have proved useful in the ordering of things acquire such an authority over us that we forget their worldly origin, and accept them as irrevocable givens. [Mach taught us to]... analyze the too familiar notions... by doing so their excessive authority is broken. [14]

But, it is not usual in science to go around "doubting everything" as Descartes advised. Kuhn notes:

> Normal science, the activity in which most scientists inevitably spend almost all their time, is predicated on the assumption that the scientific community knows what the world is like. [15]

And if we "know what the world is like" we must be ultra-conservative if someone comes along with an upsetting new way of looking at things. Kuhn continues:

> ... Maxwell's equations were as revolutionary as Einstein's, and they were resisted accordingly.. a new theory, however special its range of application, is seldom or never just an increment to what is already known. Its assimilation requires the reconstruction of prior theory and the re-evaluation of prior fact, an intrinsically revolutionary

> process that is seldom completed by a single man and never overnight. [16]

Kuhn explains that although new ideas are resisted, and reasonably so, scientists are more open to them whenever their present view encounters facts that it cannot incorporate or when progress seems to be at a dead end:

> Mopping-up operations are what engage most scientists throughout their careers. They constitute what I am here calling normal science... Nor do scientists normally aim to invent new theories, and they are often intolerant of those invented by others... [But] normal science possesses a built-in mechanism that ensures the relaxation of the restrictions that bound research whenever the paradigm from which they derive ceases to function effectively. [17]

I have said that I have a somewhat unusual viewpoint: that the existence of laws, by which I mean general laws or principles, is illusory. I believe that we should seek to unmask the illusion. But, why would I not be happy to leave well enough alone? As I explained, I have found logical discrepancies in the theories presently accepted. This led me to questioning the fundamental laws. In my questioning I was guided by a philosophic viewpoint that rejects natural theology, no matter how well disguised it may be. I believe too, that too much reliance on the laws may be why we have difficulty in moving forward. After all, special relativity and quantum theory were born in the early twentieth century. Perhaps we are making strides in understanding nuclear structure or particle systematics but we have not had any new *general laws* lately. A fresh viewpoint can perhaps be beneficial.

CHAPTER 4

What Needs Explanation

The Newtonian view, held by most scientists practising today, is that there are general laws that govern—or describe—the behavior of things and that a specific fact is considered to be explained if it can be subsumed under a general law. There is no need to explain the general law, other than perhaps to subsume it under a more general law. It is the nature of the universe that there should be such general laws. For Newton, the general laws were those of the Creator of the universe. Since I do not believe in natural theology—that by examining nature we are able to tell, one way or the other, whether there is a Creator—the existence of general laws requires an explanation.

The thesis that I am trying to develop is that the existence of general laws is an illusion—a trick that can be explained. So when I say that general laws need explanation, I mean that what needs explanation is how we are led to believe that there are general laws.

I am going to look now at the notion of explanation in science so that you can see the different points of view that are possible. Explanation is linked with understanding. The reason things are explained to people is so that they will understand. In his *Lectures on Physics* Feynman says:

> What do we mean by "understanding" something? We can imagine that this complicated array of moving things which constitutes "the world" is something like a great chess game being played by the gods, and we are observers of the game. We do not know what the rules of the game are; all we are allowed to do is to *watch* the playing. Of course, if we watch long enough, we may eventually catch onto a few of the rules. *The rules of the game* are what we mean by *fundamental physics*... If we know the rules we consider that we "understand" the world. [1]

This is a clear statement that understanding of the universe comes when we know the "rules of the game" by which he means the general laws that rule—or describe—the behavior of "things which constitute the world." Max Jammer in his book *Concepts of Force* presents this view:

> Science, as understood today, has a more restricted objective; its two major assignments are the description of certain phenomena in the world of experience and the establishment of general principles for their prediction and what might be called their "explanation". "Explanation" here means essentially their subsumption under these principles. [2]

Here, Jammer indicates the fact finding part of science as well as the part that is concerned with explanation. Albert Einstein says much the same thing but adds a few different notes:

> The aim of science is, on the one hand, a comprehension, as complete as possible, of the connection between the sense experiences in their totality, and, on the other hand, the accomplishment of this by the use of a minimum of primary concepts and relations (seeking, as far as possible, logical unity in the world picture, i.e., paucity in logical elements)... We do not know whether or not this ambition will ever result in a definite system. If one is asked for his opinion he is inclined to answer no. While wrestling with the problem, however, one will never give up the hope that this greatest of all aims can really be attained to a very high degree. [3]

Einstein stresses the need to have "a minimum of primary concepts and relations." This means that there should be as few general laws as possible. His hope was for a unified theory in which all general laws were subsumed in a single system. He calls the hope of finding the system "the greatest of all aims" but somehow doubts that it can be found. He himself did not succeed, but the shape of his later work always tended in this direction because he was driven by this as a philosophical ideal. He maintained that scientists must think about the philosophy of science especially whenever things become problematic:

> It has often been said, and certainly not without justification, that the man of science is a poor philosopher. Why

> then should it not be the right thing for the physicist to let the philosopher do the philosophizing? Such might indeed be the right thing at a time when the physicist believes he has at his disposal a rigid system of fundamental concepts and fundamental laws which are so well established that waves of doubt can not reach them; but, it can not be right at a time when the very foundations of physics itself have become problematic as they are now. At a time like the present [the early part of the twentieth century], when experience forces us to seek a newer more solid foundation, the physicist cannot simply surrender to the philosopher the critical contemplation of the theoretical foundations; for, he himself knows best, and feels more surely where the shoe pinches. In looking for a new foundation, he must try to make clear in his own mind just how far the concepts which he uses are justified, and are necessities. [4]

Louis de Broglie agreed with Einstein in saying that scientific philosophy should not be left to professional—academic—philosophers:

> What the scientists still sought in their self-made philosophizing was fructifying world-images and world-ideas—precisely the ingredient expelled in the universities' analysis [academic philosophers tended to be positivists]. [5]

It was not a matter of treating the philosophy as an end in itself but as a way of making the scientist's mind more fertile in new ideas about the world. Does the philosophy make any difference at all? Hanson examines this in his book *Patterns of Discovery*:

> Mach construed dynamical laws as summary descriptions of sense observations, while for Hertz laws were highly abstract and conventional axioms whose role was not to describe the subject-matter but to determine [govern] it. The difference is not about what the facts are, but it may very well be about how the facts hang together. Even this difference would not seem to matter much here, since Mach and Hertz would get the same answers to their problems. The real difference, however, only arises at this

> point: for though they get the same answer to the problem, the difference in their conceptual organization guarantees that in their future research they will not continue to have the same problems...The important differences in conceptual organization, which it has been our aim to illuminate, show only in 'frontier' thinking where the direction of new inquiry has regularly to be redetermined. [6]

Different philosophies lead to different future directions. How they organize existing information really does not make much difference. De Broglie says this:

> Reality consists of many strata of existence which come into view when different methods of investigation are employed. Each generation has its favoured insight and method which in time, as it reaches a region of low diminishing returns, becomes exhausted. [7]

This is a very pragmatic attitude and one that is very scientific. While a particular philosophy is useful, use it—when it shows "diminishing returns," abandon it.

There is some disagreement among scientists about the shape of general laws. The if-then-always shape is one related to cause and effect. Another possibility, discarded by most, is that things behave in certain ways not because they are caused to do so but rather because they have a goal to fulfil. This was a view held by the mathematician Euler as explained by Mach:

> Euler's view is that the *purposes* of the phenomena of nature afford as good a basis of explanation as their causes. If this position is taken, it will be presumed *a priori* that all natural phenomena present a maximum or minimum. But in the solution of mechanical problems by the ordinary methods, it is possible, if the requisite attention be bestowed on the matter, to find the expression which in all cases is made a maximum or a minimum. [8]

In this kind of thinking there is a purpose or telos—things behave so as to achieve certain ends, for example, move so they take the shortest path between two points. Mach is quick to point out that if you work hard enough you can always find some mathematical "expression" in the motion of an object which is a maximum or minimum—such as the shortest path.

As Mario Bunge says in his book *Causality and Modern Science*:

> To say that in behaving the way that they do physical objects move "with the purpose" of minimizing or conserving the intensity of a given quantity is not too different from asserting that things happen as they do "in order that" the laws of nature may be satisfied. Extremum [maximum or minimum] principles are no more indicative of end-seeking behavior than any other physical laws...[9]

Finding a mathematical expression that is a maximum or minimum as an object moves is an act of the scientist—it is man-made—not part of the "order of things." Mach himself doubted that an order of things existed. He believed that it was a scientist's job to systematize the facts about the universe into as small a form as possible, strictly for practical reasons. This is sometimes called empiricism. Reichenbach writes:

> In contrast to the transcendental conception of knowledge the philosophy of the new [logical] empiricism may be called *a functional conception of knowledge*. In this interpretation, knowledge does not refer to another world, but so as to perform a function serving purpose, the purpose of predicting the future. [10]

Here, the reference to "the transcendental conception of knowledge" is to the Newtonian type of philosophy where general laws somehow transcend the things whose behavior they describe. The word empirical, which just means based on fact, has been degraded by many scientists. When a relationship—or formula—is said to be "just an empirical one" it usually means that some arbitrary mathematical equation has been fitted to experimental facts by adjusting some parameters in the equation. Much computer work in science is done to obtain the best fit of certain formulas to experimental data. It is more scientific to have a theory or model behind the mathematical equation because facts can always be fitted by some kind of formula no matter what they are.

Sometimes a set of facts may need two different formulas, one for part of the set, another for the rest, to get a good fit. This makes scientists uneasy. Bridgman says:

> What is the basis for the feeling that a theory should not employ two different sorts of mathematical functions joined by a text instructing us to switch from one to the other? ... I think that there is often a feeling in the background that a mathematical formulation "really exists" and that the chances of our having found it are considerably less good as long as the toolmarks of our handiwork are as evident as they are with two different analytical expressions. [11]

What is usually hoped for in any empirical fitting of facts by a formula is that an extremely simple formula will fit very well. Somehow the empirical then becomes more than empirical. Here is Heisenberg:

> It is difficult to give any good argument for this hope for simplicity—except the fact that it has hitherto always been possible to write the fundamental equations in physics in simple mathematical forms. This fact fits in with the Pythagorean religion, and many physicists share their belief in this respect, but no convincing argument has yet been given to show that it must be so. [12]

This goal of mathematical simplicity was firmly planted by Newton. Randall says:

> Isaac Newton effected so successful a synthesis of the mathematical principles of nature that he stamped the mathematical ideal on science, and the identification of the natural with the rational, upon the entire field of thought. [13]

And that brings me, as I close off this chapter, to a second thing that needs explanation if the Newtonian position of the strong evidence of design in nature is to be countered—Why are there mathematically simple general laws?

CHAPTER 5

The Information Content of Laws

In a letter to a scientific colleague Newton spoke about what he considered to be the best method in natural philosophy—science:

> For the best and safest method of philosophizing seems to be, first diligently to investigate the properties of things and establish them by experiment, and then to seek hypotheses to explain them. [1]

Fact finding comes first, then comes the search for "hypotheses" which will explain the facts. Newton found that the same set of experimental facts could be explained by quite different hypotheses. It was impossible to resolve an argument about which hypothesis was right provided all the hypotheses did was fit the known facts. In the heat of one argument he swore off making hypotheses—in Latin, of course, by "hypotheses non fingo" which means "I do not make hypotheses". In fact, he went right on making hypotheses but avoided arguments. This remark of Newton's is sometimes interpreted as meaning that we should not try to explain laws by devising some underlying mechanism but be content that the facts are explained when the law has been formulated that fits the facts. Newton's law of gravitation is usually taken as the example—we tend to accept the law as the final explanation of gravity without asking further questions as to why this particular law holds. In a way, Newton is pressing for empiricism here, telling us to skip the theorizing because all it does is lead to arguments. Newton himself made many hypotheses. To have a model of what is going on—a theory, if you will—can be useful. Often, a theory—law or hypothesis—not only fits facts that have been found by observation and experiment but also indicates—or predicts—that other facts, not known at the time, should be true. The theory contains then some part that is not strictly empirical—it contains assumptions about what might be the case. Often, we can make a choice between two alternative theories that fit the known facts by looking for consequences of the theories that differ from each other. An experiment is then performed to resolve the argument about which theory is better. Bridgman describes the process:

> If we can show that any of the indirect consequences are opposed to experiment then the assumption is false. But, the concept of true is not applicable. I think we would want to invent a new concept to cover the situation: probably the word "possible" has enough of the required connotations to meet our needs... Doubtless a great many alternative theories will be possible and we shall have to choose between them on grounds of simplicity or convenience of calculation or perhaps on purely aesthetic considerations. [2]

I have already indicated that I am accepting as scientifically *true* any law, or theory that fits the facts. False to me applies to one that does not fit the facts. Several different theories can be true as far as I am concerned. Bridgman wants to call theories that fit the facts "possible theories," thus avoiding the problem of calling two alternative theories true. It is just a matter of words here. He indicates that if we have two equally good—possible—theories, in the sense that they explain the facts, we choose one or the other on some arbitrary grounds such as "simplicity or convenience of calculation." The choice in favor of the simple, or the beautiful law was made originally because scientists, like Newton, believed that it accorded better with the mind of the Creator. It was thus, more likely to be "really" true. Mach also said the simpler explanation should be chosen but for an entirely different reason. This is how Feuer summarizes Mach:

> Natural laws were economical summations of experience, labor-saving devices, that enable the labor of other men to be substituted for one's own...Occam's Razor, the so-called principle of simplicity in scientific method, was no longer to be founded on a metaphysical belief in the simplicity of the universe; rather it was a principle of economy expressive of man's biological aim to do things with the least expenditure of energy. [3]

Or in Mach's own words:

> Science itself, therefore, must be regarded as a minimal problem consisting of the completest possible presentment of facts with the *least possible expenditure of thought*. [4]

It is a pragmatic point of view. Again Mach:

> Those ideas that hold good throughout the widest domains of research and that supplement the greatest amount of experience are the *most scientific*. [5]

This reason of Mach's for choosing a simpler theory over a more complicated one, because the simpler theory is more scientific, has little force when the simpler theory emerges some time after the more complicated one and does not predict anything different from the original theory. Louis de Broglie makes this clear:

> Indeed, we may assert it as a sociological law of the scientific community that no new theory, whatever its appeal of elegance or simplicity, will generally supersede the old unless it leads to new experimental discoveries of fact; such resultant discoveries may, with the help of auxiliary hypotheses, be rendered consistent with older doctrines, but would not have been foretold by the latter's adherents. [6]

A theory becomes established and will not easily be deposed by a new simpler theory which fits the same facts, even though, from Mach's standpoint—and mine—it is better.

The ability of a theory to predict facts that can be later verified is perhaps overemphasized. Certainly, if a theory does predict facts beyond the known facts that it was designed to fit, we should check to see whether or not the additional facts can be verified. If they cannot, we would have to alter the theory or get a new one. The alteration of a theory is quite possible—we could for instance, impose additional restrictions so the theory would not predict the nonexistent facts. Schrödinger, the scientist who invented the wave mechanical model of the atom, is quoted by Feuer as saying:

> The following process is recurrent in physical science. A certain amount of special knowledge, empirically accumulated and asserted, is tentatively cast into a comprehensive

> theoretical aspect. The theory, after having been gradually corrected by further experiments... tends to acquire an unforeseen general validity. But, strangely enough... the knowledge which its proportions are supposed to convey turns out to be more and more tautological.

Schrödinger is indicating that the theory which emerges after the processes of fact fitting and correction are ended begins to seem more than just a "possible' explanation—in Bridgman's terminology. It becomes stamped with an authenticity that makes it practically inevitable, if not obvious, or true by definition. It becomes established, and any change from the established view is taken only if the established view is proved false.

Louis de Broglie hints that the choice between equivalent theories is often made on the basis of personal philosophical beliefs in "hidden harmonies" in the universe—the order of things:

> A few examples don't suffice to prove that there are always an infinite number of possible theories for explaining the same experimental facts, and it seems certain to us that even, when there are a great number of logically equivalent theories, the physicist has the right to believe that one of them conforms more to underlying physical reality, and is more capable of generalization, more apt to reveal the hidden harmonies. [7]

I will be writing in a later chapter about the philosophical beliefs of a number of modern scientists which slanted their science towards certain types of theories and made those theories, to them, seem inevitable. Tzara, a Dadaist philosophically, wrote:

> Science throws me off as soon as it pretends to be a philosophical system; for it loses its useful character... I detest that pat objectivity and harmony with which science finds all in order. [8]

The Dadaists hated the idea of design and logic, and featured chance in all their thinking and art. I must admit that science throws me off sometimes with concepts such as the "wave-particle duality of matter and radiation," as if duality were of the essence of nature.

Sometimes after a theory has been established for a while there are alternative approaches which contain much the same information, in that they explain the same facts that are accepted by the scientific community. For example, the energy point of view in mechanics—which is the study of motion of interacting objects—was formulated a considerable length of time after Newton first devised his laws of motion. There is absolutely no additional information provided by the introduction of the concept of energy, but often greater insight into a physical situation can be gained by using it. It is a labor saving device in some computations. So we have two alternative viewpoints on motion, the force-acceleration viewpoint and the energy viewpoint. Sometimes the new viewpoint leads to the discovery of new information. In studying the electromagnetic interaction, the concept of the electromagnetic field used by Maxwell helped him to add a piece to the theory that was not based on any experimental evidence. Maxwell's enormous success has meant that the field concept has dominated thinking about electromagnetism, and the electric charge, as the source of the field, has been somewhat neglected. Scientists frequently introduce concepts, like energy or electromagnetic field, which are defined in terms of other, more fundamental, concepts. These others are more fundamental only because they are closer to our own sense experiences. Newton introduced the concepts of force and mass which he defined in terms of the prior and more fundamental concepts of position, velocity, and acceleration. Einstein explains this all rather well:

> We shall call "primary concepts" such concepts as are directly and intuitively connected with typical complexes of sense experiences. All other notions are—from the physical point of view—possessed of meaning, only in so far as they are connected, by theorems, with the primary notions. These theorems are partially definitions of the concepts (and of the statements derived logically from them) and partially theorems not derivable from the definitions, which express at least indirect relations between the "primary concepts," and in this way between sense experiences. Theorems of the latter kind are "statements about reality" or laws of nature, i.e., theorems which have to show their usefulness when applied to sense experiences comprehended by primary concepts. The questions as to which of the theorems shall be considered as definitions

> and which are natural laws will depend largely upon the chosen representation. It really becomes absolutely necessary to make this differentiation only when one examines the degree to which the whole system of concepts considered is not empty from the physical point of view. [9]

Einstein indicates that concepts like energy and electromagnetic fields must be connected with primary concepts through definitions. As well as the definitions, there will be other—usually mathematical—statements that can be made. These are often called laws of nature, for example, the law of conservation of energy. But in fact there is always confusion about what is a definition and what is a law of nature. We tend to think that a definition does not contain any information about the physical world in it but that a law of nature does. Einstein points out that it is "the whole system of concepts" that must be thought of as containing information about the world. When I speak of the *information content of laws*, I mean the same thing as what Einstein calls "the degree to which the whole system of concepts considered is not empty from the physical point of view." Here is another opinion, this time from Richard Feynman:

> Although it is interesting and worth while to study the physical laws simply because they help us to understand and to use nature, one ought to stop every once in a while and think, "What do they really mean?" The meaning of any statement is a subject that has interested and troubled philosophers from time immemorial, and the meaning of physical laws is even more interesting, because it is generally believed that these laws represent some kind of real knowledge. [10]

Feynman uses the phrase "some kind of real knowledge" where I speak of "information content."

In the next chapter, I will examine Newton's laws of motion which are one of the expressions of the information about the motion of objects as they interact with each other. In performing this analysis, I must consider the whole system, both laws and definitions, because, as Einstein indicates, the boundary between them is very fuzzy. Then there is the confusion about information content when there are alternative formulations. Because there are alternative systems for mechanics, I would have to say that one is as true as another. That brings up another related problem. If the whole of mechanics can be explained without any reference to the concept energy, is there anything *real* about energy? If you could explain mechanics without the concept of force is there anything "real" about force? And what about explaining electromagnetism without the concept of the electromagnetic field? Then there is the other side of this. Newton said that he would make no hypothesis about the law of gravity. Was he saying that he would not try to explain why the force of gravitation produced by an object depended on its mass and fell off inversely as the square of the distance from the object? Why should it depend on the mass, a concept he introduced to express his laws of motion? And why should it vary as the inverse square of the distance? Explain that Sir Isaac!—Answer: "Hypotheses non fingo."—No, his real answer is that it is the will of the Creator who designed the universe by laying down a set of universal laws from which everything follows. End of explanation. When you have this attitude perhaps you shut doors that should remain open. Newton hated controversy, but science must have differences of opinion, or it cannot survive. Kuhn points this out:

> The resolution of revolutions is the selection by conflict within the scientific community of the fittest way to practise future science… And the entire process [development of science] may have occurred, as we now suppose biological evolution did, without benefit of a set goal, a permanent fixed scientific truth, of which each stage in the development of scientific knowledge is a better exemplar. [11]

Kuhn, like me, doubts that there is an absolute scientific truth to which science is approaching closer and closer.

So that is my program—in the next chapter I will look at Newtonian mechanics and see what I can read into it as far as information content is concerned. Then, in the following chapter, I will examine electromagnetic theory. I will be acting somewhat as a critic in that I will be tearing the laws—and definitions—apart hunting for meaning—content. Bridgman describes this kind of activity as follows:

> The material for the physicist as critic is the body of physical theory just as the material for the physicist as theorist is the body of experimental knowledge. [12]

Remember that my aim is twofold—first, to show that the idea of general laws is an illusion and second, to offer some explanation as to why any specific facts are simple, if they are.

One of the dangers of this sort of exploration is that, in trying to present a coherent world view, I must plug some of the holes with suggestions that I perhaps have not thought out carefully enough. Actually, most of the suggestions have already been made by other people and I am merely selecting ones that fit in with my scheme.

These suggestions have not had widespread interest shown in them because they departed from the orthodox view and were in a sense contradictory to that view, even though they had features that were appealing. At the end of each of the following chapters I will try to list those unorthodox ideas that I am including in my world view, both those of others and my own. It must be remembered that the point of this investigation is to see whether it is possible to construct a world view based on the premise that there are no general laws. Each particular suggestion must not be taken as being the only one that might serve.

I have a somewhat similar aim to Mach who in the preface to his book on the *Science of Mechanics* said:

> The present volume is not a treatise upon the application of the principles of mechanics. Its aim is to clear up ideas, expose the real significance of the matter and get rid of metaphysical obscurities. [13]

By "significance of the matter," I mean the "information content." By getting rid of "metaphysical obscurities," I mean that my aim is to show that there is no evidence in physics for or against an underlying pattern of things.

CHAPTER 6

The Impossibility of Isolation

When we are studying a particular phenomenon in nature, such as the way two objects interact with each other, it is customary to focus attention on the objects, to the exclusion of everything else in the universe. We say that we examine their behavior "in isolation." What I will argue is that isolation is never in practice achievable. This means that the effect of the rest of the universe must be considered. If it appears to be neglected it shows up, in disguise, some other way.

In this chapter, I will be looking at the laws of motion of objects as proposed in the seventeenth century by Sir Isaac Newton in his famous *Principia*. My intention is to determine their information content. Newton's laws mention the term body by which he means an object, or a material thing. Laws in physics should really be restricted to dealing only with fundamental objects if we want to label them as fundamental laws. This is because we believe that, if we know the laws that describe the behavior of the fundamental objects, we can derive all the other laws. In Newton's time the idea of a fundamental object had not been formed so that, in a sense, Newton's laws are not fundamental laws. From our present point of view we can think of the entire universe as being made up of three fundamental objects, or particles as we usually call them. These are electrons, protons, and neutrons. There are other particles, but we can neglect them in this model. The protons and neutrons group together to form the nucleus of an atom and the electrons move about this nucleus. Niels Bohr devised a model of the atom which was like a solar system in which the electrons moved in orbits around the nucleus, like planets around the sun. You often see drawings of atoms showing several electrons moving in orbits. The number of electrons moving about the nucleus in an ordinary atom is always the same as the number of protons in the nucleus.

The simplest atom is hydrogen. It has one proton in the nucleus and one electron moving about it. I do not say "moving in orbit" about it because we now know that the Bohr model of the atom is not true. But, we still believe that the electron and proton are there and are interacting with one another. The electron and the proton are electric charges. We say arbitrarily that the electron is a negative charge, and the proton is a positive charge. The magnitude, or size, of their two charges is equal but opposite so that when they are together in an atom their total electrical effect nearly cancels out unless something is close to the atom.

Atoms that are heavier than hydrogen have more protons in the nucleus and, of course, more electrons moving about. There is always the same number of electrons as protons in an atom. In heavier atoms, there are always neutrons in the nucleus as well as the protons. The number of neutrons varies. The atom with eight protons in the nucleus and eight electrons moving about this nucleus is called an oxygen atom. Most oxygen atoms that we find have eight neutrons in the nucleus as well. But, a small percentage—0.205%—have ten neutrons and a smaller percentage—0.038%—have nine. These different kinds of oxygen atoms are called isotopes of oxygen.

In heavy atoms, there are more neutrons than protons in the nuclei of isotopes found in nature. The isotopes we find around now—the naturally occurring ones—are the stable isotopes. The fittest survive. Whenever we create the isotope of an atom whose number of neutrons is far from those which occur naturally, the isotope is unstable and breaks up. We say it is radioactive. We can judge the relative stability of different isotopes of an atom by their relative abundances in nature.

This has been a bit of a diversion, but it is necessary to point out that Newton's laws do not deal with electrons, protons, and neutrons but bodies made up of complex structures of these fundamental particles. The particles form atoms; the atoms form molecules; and the molecules form solids. The bodies Newton was talking about are solids of various shapes. To keep things somewhat simple we will think of bodies that have a simple shape—spherical like a ball—and bodies that are small enough so that we can think of them as being located all in one place, at a point. We will call these ideal bodies point particles, or just particles. Then our study of the laws of motion will be restricted to particles and the way they interact with one another. We will be looking at what is called particle dynamics. Everything about more complex shapes can be explained in terms of the interaction of the particles that make up the complex shapes.

Now I am ready to bring on Newton's laws of motion. Here they are:

> *Law I*: Every body perseveres in its state of rest or uniform motion in a straight line unless change in that state is compelled by impressed forces.
>
> *Law II*: Change of motion is proportional to the force impressed and takes place in the direction of the straight line in which such force is impressed.
>
> *Law III*: Reaction is always equal and opposite to action; that is, the mutual actions of two bodies upon each other are always equal and directly opposite.

In these laws various terms are introduced: "impressed forces," "change of motion," "reaction" and "action". Really there are only two new concepts—one is force. "Impressed force" is just a force—"action" is a force one body exerts on another—"reaction" is the force the second body exerts on the first. "Change of motion" involves the other new concept, namely, mass. By motion, Newton meant the product of the mass times the velocity. This product is sometimes called momentum. The "change in motion" is the time rate of change of the mass multiplied by the velocity. Since, to Newton, mass was assumed to be a constant independent of how fast the body went, this "change in motion" is just the mass multiplied by the time rate of change of velocity—which is what we call acceleration. The second law is often written as a formula which is

$$F = ma$$

where F is the force acting on a body, m is the mass of the body, and a is the acceleration of the body produced by the "impressed force" F. This formula, as it stands, does not tell the fact that the direction of the acceleration is the same as the direction of the force. This can be indicated by drawing an arrow over both F and a to indicate that the directions are the same.

$$\vec{F} = m\vec{a}$$

The third law is sometimes written as

$$\vec{F}_{12} = -\vec{F}_{21}$$

where what is meant by $\vec{F}_{12}$—with the arrow—is the force exerted by particle number *1* on particle number *2* (there are two particles interacting and we label them *1* and *2*). Then $\vec{F}_{21}$—with the arrow—is the force exerted by particle number *2* on particle number *1*. These two forces are along the same line but point in opposite directions. The minus sign says they are in opposite directions.

I am going to look now at the information content of these laws. Newton tried to define the concepts of mass and force independently of the laws, but failed. For example, he said that the mass of a body was its volume multiplied by its density. He then defined density as the mass per unit volume, which is a complete circle. His definition of force basically said it was the cause of acceleration which is said in the laws. So Newton's three laws must provide a definition of mass and force, concepts that Newton introduced, as well as have some other content.

I have often argued in an elementary class of university physics students that the physical content of Newton's three laws of motion is zero. Here is the argument: Law I is a special case of Law II since it says that if there is no force there is no acceleration. (Remember Law II says that the acceleration is proportional to the force.) So we can eliminate Law I since it adds nothing not given in Law II. Laws II and III are required to define mass and force. If we use the two-body interaction case, Law II says that:

$$\vec{F}_{12} = m_2 \vec{a}_2$$

and

$$\vec{F}_{21} = m_1 \vec{a}_1$$

Then using Law III we get:

$$m_2 \vec{a}_2 = -m_1 \vec{a}_1$$

I can write this last equation as:

$$\frac{m_2}{m_1} = -\frac{\vec{a}_1}{\vec{a}_2}$$

This then defines the ratio of the masses of the two particles as the inverse of the ratio of their accelerations when they interact. Force can be defined by taking this mass and returning to Law II

$$\vec{F} = m\,\vec{a}$$

Since now the mass is known—relative to some standard of mass—acceleration can be measured and force calculated. And so we have absolutely no physical content to the laws! Or do we? Mach, in his *Science of Mechanics*, analyzes Newton's laws at length and comes to this conclusion:

> … its main result will be found to be the perception, that bodies mutually determine in each other *accelerations* dependent on definite spatial and material circumstances and that there are *masses*. In reality, only one great fact was established… Different pairs of bodies determine, independently of each other, and mutually in themselves pairs of accelerations, whose terms exhibit a constant ratio, the criterion and characteristic of each pair. [1]

Mach puts his finger on one piece of physical content when he says "pairs of accelerations whose terms exhibit a constant ratio, the criterion and characteristic of each pair." This gives mass, as defined this way, a physical meaning because the ratio of acceleration is "constant". Constant over what range of circumstances? One circumstance is that no matter how far apart the interacting bodies are, the ratio is the same. For all interactions the actual size of each acceleration decreases as the bodies get farther apart—but the ratio stays the same. The accelerations get smaller in proportion to each other. Another circumstance is that it does not matter how the bodies are moving when they interact. The ratio of accelerations does not depend on the velocities of the bodies. So the concept of mass is one that is velocity independent since its value, as measured by comparing it with another body, does not depend on the velocities of the bodies.

Because the ratio of accelerations is the same no matter how far apart the bodies are, we can get more information: that the interaction seems instantaneous. It does not take any time at all for the effect of a change in position of body *2* to be felt at body *1*, and vice versa. The acceleration of each body changes instantaneously so as to keep the ratio constant.

So let me summarize the information content we have so far. When two bodies interact, each is accelerated and the ratio of the two accelerations is a constant no matter how far apart they are and what their velocities are at the time of the interaction—interaction being instantaneous. We use this constant ratio to assign to each body a mass, a property of the body which is independent of its motion. If the bodies are particles, the accelerations are along the line joining the particles and point in opposite directions. This means that particles either attract each other or repel each other. (All this last information comes from the fact that the ratio a_2/a_1 is a constant.) We seem to be getting more information content now. Is this all? Newton had a second concept in addition to mass, namely force, and he had arranged his definition of force so that the forces of two bodies on each other were equal and opposite. This appealed to Newton. Here is a passage from his *Rules of Reasoning* section of the *Principia*:

> We are certainly not to relinquish the evidence of experiments for the sake of dreams and vain fictions of our own devising; nor are we to recede from the analogy of Nature, which is wont to be simple and always consonant to itself. Nature does nothing in vain, and more is in vain when less will serve; for Nature is pleased with simplicity, and affects not the pomp of superfluous causes. [2]

As far as I am concerned the concept of force is superfluous, but Newton's passion for simplicity in Nature overcame his feeling that "Nature does nothing in vain." If we do allow concepts in addition to what we really need we must label them clearly as artifacts—man-made, not natural. Let us not admire Nature for its simplicity when it is our own—Newton's—creation.

There is a simplicity here though in that the accelerations are oppositely directed along a line joining the particles and have a constant ratio. It is here "explained" by the fact that the particles have a property called mass. But is that an adequate explanation of this simplicity? As I mentioned earlier in the chapter, the fundamental particles that interact are the electron, proton, and neutron. The proton and neutron interact only if they are at close range as they are in the nucleus, and the interactions which Newton was talking about do not in any way involve this close-range nuclear interaction. The electron and the proton interact with each other at any distance so it is this fundamental interaction that accounts for many Newtonian interactions. (I leave gravitational interaction aside here.) The interaction between the electron and the proton, or between two electrons, or two protons is not correctly described by Newton's laws. It is not instantaneous—the accelerations do not have a constant ratio—are not always oppositely directed along a line and are not independent of the velocity of the interacting particles. I will be looking at this interaction in the chapter dealing with electromagnetic interaction but, for the moment, what about Newton? We know his laws do not apply to the fundamental interaction—what, beside gravitational interaction, do they apply to? They apply to large-scale objects pushing and pulling each other in contact with one another. What is more, they are adequate in describing this behavior so that engineers can build cars, airplanes, and bridges. But, they are not information about the behavior of the fundamental particles and thus can be ignored completely as far as additional information content is concerned. This is because we will be able to explain why Newton's laws hold for large scale objects once we have the proper laws for fundamental interactions. We need only worry about accounting for the laws of the fundamental interactions.

But wait! Not so fast! There is more content lurking around. Mach includes it when he says that "different bodies determine independently of each other and mutually in themselves pairs of accelerations." This fact, that the interaction between any two bodies is independent of the presence of other bodies that might be interacting with them, is called the principle of superposition. The principle of superposition is a law which says that the effects of a number of different bodies are just superimposed one on top of the other. They do not interfere with the interactions of one another. The final acceleration that any one body experiences is the resultant of the individual accelerations produced by all other bodies present, each acceleration being computed just as if there were no other bodies there.

The principle of superposition does contain information. It is a basic part of the theory of the interaction between fundamental particles, whereas Newton's laws are not. The principle of superposition was not mentioned directly by Newton; what he did speak about is how the forces are added if more than one force acts on a body. Force has a magnitude and direction—as does acceleration—and thus two forces pointing in different directions are not just added like *2* and *2* to make *4*. In fact, if equal forces are in opposite directions, they add to zero. If they are at right angles, we can represent them as two sides of a rectangle and the resultant is the diagonal of the rectangle starting from the point of application of the forces. In general, any two forces define a parallelogram of forces. Many of you will know all about how to compute the resultant of quantities like forces or acceleration that have magnitude and direction. Such quantities are called vector quantities. We talk about adding vectors.

All this brings me to the most exciting part, the law we threw away so casually—Law I. The first law has the most fundamental piece of information of all. Here is the law again:

> Law I: Every body perseveres in its state of rest or uniform motion in a straight line unless change in that state is compelled by impressed forces.

We know that impressed forces come from other bodies so that we can say that a body will continue to be at rest or move in a straight line at a uniform speed if it is isolated from other bodies which might exert forces on it—cause accelerations. The body must be alone in space. Mach calls our attention to a little problem here:

> When we say that a body K alters its direction and velocity solely through the influence of another body K´, we have asserted a conception that it is impossible to come at unless other bodies A,B,C… are present with reference to which the motion of the body K has been estimated… If now we suddenly neglect A,B,C… and attempt to speak of the deportment of body K in absolute space, we implicate ourselves in a twofold error. In the first place, we cannot know how K would act in the absence of A,B,C… ; and in the second place every means would be wanting of forming a judgment of the behavior of K… [3]

If the body were alone in space we could not tell whether or not its motion were uniform, or accelerated, or if it were standing still. We need other bodies to provide a background against which motion can be measured. We sometimes say that these other background bodies are a frame of reference for making measurements of position. What Mach says is that our error is twofold in neglecting reference bodies. Beside making measurement impossible, we are presuming that the body K under observation would behave the same way with and without the reference bodies. When we make measurements of the motion of a system of bodies that we claim are isolated, they are not isolated at all—isolation is an impossibility. We have the rest of the universe present, and we can never know how a body would behave if the rest of the universe were not present.

When there are no other bodies near a body that we intend to observe, Newton says that the body will be in either of two states: resting or moving at constant speed in a straight line. Either of these two states is a natural state for a body. We can reasonably assume that these two states are equivalent as far as the body is concerned. The information content of this is that the effect of the rest of the universe on a body is identical in these two states. Suppose that we have a frame of reference and in that frame a body is moving at a constant speed. Now imagine that we are on the body and have another frame of reference moving with the body. We would say that the universe was equivalent to us at rest in the moving frame of reference to what it is to a body at rest in the original frame.

A frame of reference in which a body, uninfluenced by any nearby bodies, is at rest—or moving uniformly—is called an inertial frame of reference. Any frame of reference moving at constant velocity relative to an inertial frame is also an inertial frame. In an inertial frame, a body can maintain a resting position.

All this is well-accepted material. Newton knew about it. He wrote down what has become called his principle of relativity. Here it is:

> The motions of bodies included in a given space are the same among themselves whether that space is at rest or moves uniformly forward in a straight line. [4]

The space referred to here is an inertial space. I will call it an inertial environment. I believe, like Mach, that an inertial environment is more than a background against which measurements can be made. Bridgman says this:

> We do not have a simple event A causally connected with a simple event B, but the whole background of the system in which the events occur is included in the concept, and is a vital part of it. [5]

The theory of special relativity is based on the Einstein principle of relativity: that the laws of physics are invariant—the same—from one inertial frame of reference to another. This is usually taken to indicate that inertial frames are equivalent but what does that mean? There must be some effect on the particle in an inertial environment that is very definite and different from a particle "isolated" in an accelerated frame. When a particle is all by itself in an accelerated—non-inertial—frame, it will accelerate just as if there were some other particle causing it to accelerate. But, there is no other particle. Its environment at rest in this accelerated frame must be different in the same way as it is different when another body acts on it in an inertial frame, because in both cases it accelerates.

If we presume that the particle accelerating in the non-inertial frame is in its natural state we would assume that it had achieved an inertial environment. Newton's First Law says that the inertial environment is the natural state of the particle. Is it not reasonable to assume that a particle will always move in such a way as to achieve an inertial environment? This would mean that in an inertial frame the combination of the environment produced by a body that is influencing our observed body and the environment experienced by it accelerating in the inertial frame superimpose to make an inertial environment. The particle accelerating in this way would be in its natural state.

Newton's laws could then be summed up by saying that bodies behave in such a way as to maintain an inertial environment for themselves. In this point of view, the rest of the universe is not inert or benign. How could it be if a particle in a frame accelerating with respect to the universe cannot remain at rest without holding it at rest? But, normally we just ignore the universe and pretend the particle is isolated. One of the reasons for neglecting the effect of the universe is that most people believe in the idea of laws as part of a grand design—and the law of the equivalence of inertial frames seems eminently suitable.

Sir Fred Hoyle says this in an article on *The Future of Physics and Astronomy*:

> There is also a second reason for the astronomer not to remain idle: the universe, in the large, may be relevant to physics. The current and conventional point of view is that, while the universe may set boundary conditions for

> the operation of the physical laws, the laws themselves are independent of large-scale structure and could, in principle, be determined by entirely local experiments. The opposite, unorthodox point of view argues that the physical laws as we discover them in the laboratory already involve the influence of the universe as a whole... There are two clues indicating that the unorthodox, nonlocal point of view may be correct. The first is that by taking account of an influence of the universe it is possible to avoid the assumption that the local laws of physics are lopsided with respect to time... The second clue comes in a somewhat roundabout way, from considering particle masses to arise from interactions with other particles. [6]

The point that Hoyle makes regarding "the local laws of physics being lopsided with respect to time" makes reference to the fact that when we have large numbers of particles—atoms—interacting with each other as we have in gas contained in a box, there is an irreversible nature to their behavior. They always move from a more orderly to a more disorderly state, never the reverse. Bridgman speaks about this too:

> What prevents the following out through all future time of a definite sequence is the walls [of the box], the atoms of which are supposed to be in such a complex state of motion because they are in connection with the entire outer universe and to a certain extent reflect its complexities, that no resultant regularities are to be expected in the motion which the atoms of the wall impress on the atoms of the gas. [7]

As his second clue Hoyle believes that the masses of the fundamental particles may also be connected with their interactions with the other particles in the universe. I am trying to convince you that an inertial environment is not empty. It is the natural environment of particles. If a particle moves in a straight line at a constant speed relative to an inertial environment what it perceives is an inertial environment. This is a property of whatever produces the inertial environment, which I say is the universe. It indicates that the effect of universe is the same when we move in different directions. There is no special frame that we can say is really "the" frame or "absolute space" as Newton called it. Many frames are equivalent. This is a fact about the universe, not a law governing the universe. Heisenberg hints at this active rather than passive nature of the inertial environment—space—here:

> From our modern point of view we would say that the empty space between the atoms in the philosophy of Democritus [the void] was not nothing; it was the carrier for geometry and kinematics, making possible the various arrangements and movements of atoms. [8]

By examining Newton's laws of motion, I have come to the conclusion that the behavior of particles of matter is determined by their environment. Their natural state is to be in an inertial environment. In an inertial frame, that is, one in which a particle at rest experiences an inertial environment, a particle moving at constant speed in a straight line is also in a natural state. This means that a frame of reference moving at constant velocity relative to an inertial frame is also an inertial frame. In it, the moving particle of the original frame could be at rest. This leads to the principle of relativity which Newton stated and which was the basis of Einstein's theory of special relativity: that inertial frames were all equivalent to each other as environments for the interactions between any two bodies. As well, there is no one inertial frame that has a superior status to the others. This is stated by saying that there is no such thing as absolute space. There are an infinite number of equivalent inertial spaces. The environment in these spaces is produced, I believe, by all the matter in the universe. As Heisenberg says it is "not nothing," as space is often perceived to be, but it is "the carrier for geometry [measurements of distance and direction] and kinematics [measurements of motion which include distance, direction, and time]." Heisenberg goes on to say that "this [space] makes possible the various arrangements and movements of atoms" meaning that, without the environment, the atoms would not be what they are. So the examination of the information content in Newton's laws leads me to focus attention on *empty space*. The main point of this chapter is to get you interested in things that might be overlooked. I have maintained that the idea of an isolated body is never achievable so can be of no interest to us. But, the environment produced by the universe should be thought about very carefully.

Mario Bunge in his book on *Causality and Modern Science* has quite a bit to say about the assumption of isolation:

> The isolation of a system from its surroundings, of a thing or process from its context … are indispensable not only for the applicability of causal ideas but for any research, whether empirical or theoretical… Analysis is the sole known method of attaining a rational understanding of the whole: first it is decomposed into artificially isolated elements, then an attempt is made to synthesize the components. The best grasp of reality is not obtained by respecting fiction but by vexing fact and controlling fiction … perfect isolation is a theoretical fiction. [9]

Bunge points out that the uncertainties in quantum mechanics have been considered by some thinkers to be "a result of external perturbations, that is, as a consequence of imperfect isolation." But Bunge adds "However, inertial motion goes of itself in complete isolation and in the absence of causes." I, following Mach, maintain that an inertial environment is not one of "complete isolation".

Summary

1. The environment of any body is produced by the other bodies in the universe. (Mach)

2. The natural state of a body is for it to be in an inertial environment.

3. A body will move relative to a frame of reference in such a way as to achieve an inertial environment.

4. In an accelerating—non-inertial—frame of reference a body, which does not have other bodies nearby, will accelerate. It thereby achieves an inertial environment. Acceleration in any frame changes the environment experienced by the body.

5. If a body is in an otherwise inertial environment—in an inertial frame of reference—but is influenced by another nearby body, it will accelerate either towards or away from that body. Its total environment will thereby become an inertial environment.

6. Moving uniformly in an inertial frame does not change the environment of a body from what it is when at rest. This means that the effect of the remainder of the universe is equivalent in the two states.

7. Because there are many equivalent inertial frames, learning about the behavior of objects in one inertial frame gives us information that is useful in many such frames. The information has generality.

CHAPTER 7

Electromagnetic Interaction

In the last chapter, I revisited Newton's laws of motion and indicated that they were not fundamental laws in that they did not properly describe the interaction between fundamental particles. The fundamental particles that we are considering are the electron, proton, and neutron. The proton and neutron interact only at short range in such a way that they can be bound together in the nucleus of the atom but, as far as long-range interactions are concerned, the interaction between protons and electrons is all that need be considered. These particles are what we call electric charges—some say they *have* electric charge as if it is something that could be placed on an electron, for instance, or removed. When large-scale objects have an electric charge we mean, if the charge is negative, that they have more electrons than protons, or, if the charge is positive, that they have fewer electrons than protons. Since it is the electrons that are forming the outside parts of atoms, net electric charge of an object is a matter of electrons moving on or off the object—the protons are not migratory.

When I talk about the interaction between fundamental particles, I am taking a microscopic view of matter. When I talk of charged objects—which consist of a large number of fundamental particles—I am taking a macroscopic view. Newton's laws apply to many macroscopic situations. It is a belief that is generally accepted that all macroscopic situations can be explained in terms of microscopic situations so that, in explaining laws, I need only concern myself with explaining the microscopic laws.

Darwin was trying to show that there were general laws behind evolution—nowadays we have a somewhat different view. We believe that the behavior of both inanimate and animate things in the universe can be explained in terms of these fundamental physical interactions. Thomas H. Huxley writes about it this way:

> There is a wider teleology which is not touched by the doctrine of evolution, but is actually based on the fundamental proposition of evolution. This proposition is that

> the whole world, living and not living, is the result of the mutual interaction, according to definite laws of the forces possessed by the molecules of which the primitive nebulosity of the universe was composed. [1]

The forces between molecules are the forces described by the interaction between the fundamental electrically-charged particles. I am not sure why Huxley uses the word "teleology" here because that implies direction—or purpose—to which development is tending. As far as I am concerned, all that we can observe is the process. I am maintaining that in this process we cannot discern any evidence of design—there are no general laws. If there are general laws which transcend a large variety of particular things, we should be able to explain why these laws hold. Newton's laws are general laws because they hold for all bodies, no matter what the bodies are made of: lead, or iron, or rubber. Newton believed that the existence of these general laws was evidence of design in the physical world. This is a reasonable conclusion unless you can explain how these laws happen to hold in terms of the behavior of the three basic fundamental particles: electrons, protons, and neutrons. The fundamental particles form atoms, the atoms form molecules and Newton's bodies are made of atoms and molecules. Newton's laws hold macroscopically because of the behavior of the fundamental particles. Newton's laws of motion are not part of some grand design, or scheme of things.

At the present time, we explain the behavior of atoms and molecules using quantum theory. Here is a quotation from Hanson:

> It is an indispensable condition of quantum theory that all electrons, all protons, all neutrons, must be identical; the successes of microphysics rest on this conception. [2]

I will be writing a lot more about quantum theory in later chapters, but one of its important components is the interaction between electrons and protons. This interaction might be called the electric interaction, but is, instead, more commonly called the electromagnetic interaction. If we understand how an electron and proton interact with each other, we can use this information over and over because of the natural recurrences of electrons and protons. What actually is a specific fact about two specific things—electrons and protons—acts like a general law. What exists is a specific fact, yet what we speak about are the laws of electromagnetism. The fundamental order in the universe stems from the fact that it is made up of fundamental particles—all electrons identical to each other, all protons, and all neutrons.

I am going to examine how an electron and proton interact with each other as far as scientists understood the interaction before quantum theory appeared in the 1920's. This knowledge is based on the great synthesis of the information about electric and magnetic phenomena which James Clerk Maxwell published in the 1850's. We call Maxwell's theory classical electromagnetism. Maxwell was a theoretician and systematically organized all the bits and pieces of information available to him through the work of other pioneering scientists like Coulomb, Faraday, Oersted, Ampere, and Gauss.

One of the particularly worrying things about the interaction of two particles has always been—How do they do it? How does one affect the other without touching it? Newton brooded on the subject of action-at-a-distance in a letter to a friend:

> It is inconceivable that inanimate brute matter, should, without the mediation of something else, which is not material, operate upon and affect other matter without mutual contact. [3]

Maxwell was faced with an additional problem when he determined that the electromagnetic interaction between two objects was not instantaneous, as Newton had assumed actions-at-a-distance were, but took a definite time. The speed of electric interaction Maxwell found was the same as what had been previously measured as the speed of light. At that time it was presumed that light travelled at a definite speed through space because it was a wave motion in a medium which was everywhere, a medium they called the ether—or aether. Here is Maxwell writing about electric interaction:

> Now we are unable to conceive of the propagation [of electric action] in time, except either as the flight of a material substance through space, or as the propagation of a condition of motion or stress in a medium already existing in space. [4]

Maxwell decided that the explanation of a definite speed for electric action was that there was a medium in space—the ether—which was the same medium as light travelled in. He identified light as an electromagnetic wave on the basis of the fact that the speed of light waves was identical with what he calculated as the speed of his electromagnetic waves.

Since Maxwell's death, experiments to detect the existence of the ether showed that whether there was an ether or not was an undecidable question. Einstein said that we should not speak about a thing that can never be established one way or the other; it was a waste of time and not scientific. That leaves Maxwell's alternative "the flight of a material substance through space." This explanation of the mode of transfer of electric action has been rejected on a variety of grounds. One reason for objecting to it is that Maxwell imagined that the messengers of the interaction would be "material" and thus would bump into each other and interfere with each other's behavior, whereas the principle of superposition indicated that there was no interference between the actions of different charged objects. If we were seriously going to postulate this mechanism of interaction, we would have to have some non-interfering messengers of the interaction.

One of the present explanations of the electromagnetic interaction is that it is due to the exchange of virtual photons. A photon is a quantum of electromagnetic radiation so that this explanation is somewhat circular. What is being explained should not really be used as part of the explanation. Another reason for dropping the subject of a mechanism for electric interaction might be a general sympathy for Newton's statement about not making hypotheses. But the real reason, I believe, for dropping it is the fact that having general laws like Maxwell's laws of electromagnetism is now accepted as adequate explanation.

I am trying to argue that the general laws of electromagnetism come from the specific facts of interaction of two types of fundamental particles, electrons and protons. Since I believe that we cannot find evidence of design in nature—animate or inanimate—I must worry about an explanation of the specific interaction if that interaction has any sniff of design to it that cannot be explained.

Suppose we have an electron and a proton separated some distance from each other and held there—by what I don't know. If we let go of them, then according to classical electromagnetism they will accelerate towards each other. The ratio of the accelerations will not depend on how far apart they are, and the acceleration of the electron will be nearly two thousand (1,840) times larger than the acceleration of the proton. If you could watch, you would see the electron accelerating towards what would seem like a fixed proton, because its acceleration is so small. The size of the actual accelerations would be smaller the larger the separation. This situation is what we call an electrostatic situation because the particles' accelerations are measured just as they are released from a static position. This interaction was investigated by Coulomb, and the law of electrostatic interaction is called Coulomb's law. Coulomb's law is quite like Newton's law of gravitation in that it is an inverse-square law. The mutual accelerations of the interacting particles decrease inversely as the square of their distance apart—as the distance increases the accelerations decrease.

The electrostatic interaction follows Newton's laws of motion and was one of the interactions, besides gravitation and contact interactions between macroscopic objects, that confirmed the validity of Newton's mechanics. But, when two charges interact while they are moving, Newton's laws do not hold. The interaction is not instantaneous, as is required for Newton's laws to be valid—and it is not independent of the velocities of the interacting particles. For the electrostatic interaction, the fact that interaction is not instantaneous does not show because the charges have been held fixed for a time interval before they are released. Since their velocities are both zero at the interaction time, the velocity dependence also does not show up.

Just as Newton introduced the idea of force in order to speak about the interaction of two objects, the idea of field was introduced to help to make calculations for electromagnetic interaction easier. The Coulomb law, being Newtonian in nature, could be expressed in terms of equal and opposite forces acting on the two charges. The idea of a field was introduced in order to be able to indicate even when there was just one stationary charge present —not two—that there was some kind of entity surrounding it. This entity was called the electric field. The size of the field at a point around the charge was just the force that another charge—of unit size—would experience if it were placed there. So if you knew what force there would be on a one-unit charge you could compute the force on a two-unit charge. It would be twice as much. The field idea introduced computational ease as well as the idea of an electric environment present around every charge, whether another charge was there to experience a force in the field or not. The electric field is called a force field. What the field consists of, if it has any reality, is anybody's guess. Bridgman says:

> The great virtue of the field concept is usually stated to be that it absolves us from accepting that intellectual monstrosity, action at a distance. It is felt to be more acceptable to rational thought to conceive of the gravitational action of the sun on the earth, for example, as propagated through the intermediate space by the handing on of some sort of influence from one point to its proximate neighbor, than to think of the action overleaping the intervening distance and finding its target by some sort of teleological clairvoyance. [5]

The environs of a stationary charge are characterized by this entity called the electric field. What about a moving charge? For one thing, the non-instantaneous character of electric interaction comes into play. When a charge is standing still, you do not care when the field at a point some distance away from the source charge was produced. It will continue to be the same if the charge that is the source of the field does not move. So you can just ignore the travel time of the effect. The value of the field actually depends on the charge as it was a time ago equal to the time for the effect to travel from the source point to the field point. But, since the field now is the same as it was at an earlier time, we just ignore the whole thing and treat it as if it were instantaneous—you get the same answer. But, when the source charge moves, that is a different story! The field at a field point at a certain time—say "now"—depends on where the source charge was at an earlier time. The effect is not instantaneous, but retarded due to the travel time. We call the spot where the source charge was at the retarded time—the time when it produced what is affecting the field point now—the retarded position. The field "now" depends on where the retarded position is relative to the field point and how the source charge was moving at the retarded time.

The field of the moving charge is not described by a simple quantity like the force field called the electric field of a static charge, but is characterized by what is called the electromagnetic field. The electromagnetic field can be given as two—apparently separate—parts, one called the electric field and the other called the magnetic field. When charges move, their field contains the part called the magnetic field as well as the part they have when stationary. Sometimes you hear that magnetic fields are produced by moving electric charges, and electric fields by stationary electric charges. But that is not quite accurate. A charge produces an electromagnetic field all the time. When it is stationary, the magnetic component has a zero value. When it is moving, you might expect that the electric component has a zero value, but this is not true. You might expect that the electric component is the same size, whether it is moving or stationary. But this is not true. And on top of all this the electromagnetic field depends on three things about the source charge at the retarded time—the position, the velocity, and the acceleration.

The acceleration produced by the source charge on a test charge which is at the field point depends on the velocity of the test charge—but not on its acceleration—and on the electromagnetic field at the field point. If the electromagnetic field has only an electric component, the acceleration of the test charge does not depend on how it is moving. Remember, to have only an electric component the source charge must be at rest and then the field at the field point is not changing with time.

Maxwell's equations for electromagnetism are equations describing the connections between the electric and magnetic components of the electromagnetic field. Maxwell's equations say things like: the way that the magnetic component at a field point changes with time depends on what the electric component is like in the neighborhood around the field point, and vice versa. The electric and magnetic components are interrelated. So you can see that the electromagnetic field is really a single entity, described in terms of these two components. As I have already mentioned, when the source is stationary, the electric component varies inversely as the square of the distance from the source point to the field point. When the source charge is moving, the way that the electromagnetic field depends on position, velocity, and acceleration at the retarded time, although more complicated, has this same kind of mathematical simplicity. By this, I mean that the mathematical formula has no factor in it that involves anything but integer powers of variables. As an example of an integer power, the square of the distance is distance to the power *2*—an integer—and as far as we know the value is precisely *2*, not approximately *2*.

When the size of a field component varies inversely as the square of the distance from the source point, it is only one-quarter as large at twice the distance, and one-sixteenth as large at four times the distance. In the formula for the electromagnetic field, we find that the contributions to the components connected with the acceleration of the source charge depend inversely on the distance rather than inversely on the square of the distance, as all the other parts in the formula do. So, at large distances, the effects due to the acceleration of the source charge are by far the largest contribution to the total field. When the distance from the source is increased tenfold, the field contribution due to the acceleration is one-tenth as much—that due to the other parts is one one-hundredth as much. You can see that the part due to the acceleration will dominate as distance from the source increases.

When a charge is oscillating back and forth in a periodic motion it is accelerating a lot of the time. Its acceleration is always a maximum at the ends of its oscillation as it is slowing down and starting up in the other direction, and zero as it passes through the midpoint of the oscillation, because there it has reached its maximum speed and is not accelerating anymore.

The field at a reasonably large distance from an oscillating charge is an oscillating field, where the components are all due to the acceleration of the source. Of course, the value of the field depends on what the source was doing at an earlier time. This particular kind of field we call electromagnetic waves. Electromagnetic waves are produced by an oscillating electric charge. At any point in the field of an oscillating charge there is an electromagnetic field whose electric and magnetic components oscillate together at the same frequency as that of the charge's oscillation. At any particular time, if you move around in the field, the oscillations at different points will be at different stages—some will be at a maximum field, others at a zero field. The separation between nearest points that are in phase at any given time is called the wavelength of the electromagnetic waves. The whole field changes with time as if there were waves travelling out. Naturally, these waves travel at the same speed as the travel time of the electric interaction. This speed is the same for all frequencies of oscillation—we say that electromagnetic waves travel at this speed no matter what the frequency of the waves is. The value of the speed is approximately three hundred million meters per second (186,000 miles per second). Rather fast! This speed is represented by the letter *c* in all physics formulas. For what reason, I do not know.

A small range of frequencies of electromagnetic waves affects our eyes, and these waves are called light—some say visible light. The violet end of the spectrum of visible frequencies has the highest frequency, the red the lowest. Frequencies just higher than violet are called ultraviolet light but are not visible. They are what give us a suntan. Frequencies just lower than those we call red are named infrared and make us feel warm. Frequencies higher than ultraviolet are called various names depending on their source, that is, where the oscillating charges that produced them are. There are x-rays and gamma rays. Both of these radiations are more damaging to human cells than ultraviolet radiation is. Waves of lower frequencies than infrared can be produced by making charges oscillate in man-made electric circuits. We use these lower frequency waves to communicate with each other on radio or television.

Maxwell's equations of electromagnetism tell us about the electromagnetic waves, but the fact of the existence of electrons and protons is not information present in the laws of electromagnetism. Bridgman says in his book *The Way Things Are*:

> Given only Laplace's equation [which can be derived from Maxwell's equations] there would be no way whatever of predicting the physical occurrence of electrons. So far as I can see the same is true of Schrödinger's equation for wave mechanics [quantum mechanics]. [6]

Nor is the explanation of why the electron and proton have equal and opposite charges contained in Maxwell's equations. Certainly, if they were not equal in size, the net electric effect of an atom would be very strong and stability could probably never have been achieved. Possibly there is some interchange of something between charges which ensures that the exact balance is constantly being achieved as a natural consequence of the interaction, rather than by design decree. Certainly that must be one of the open questions for a person who does not believe in discernible design. The concept of behavior that ensures survival is not one that you normally associate with inanimate things like electrons or protons. The contrast between animate and inanimate is expressed by Reichenbach:

> The living organism is a system functioning toward the aim of self-preservation and preservation of the species… Compared with the blind functioning of the inorganic world, the falling of stones, the flow of water, the blowing of the wind, the activities of living organisms appear to be controlled by a plan, to be directed towards a certain purpose. [7]

He goes on to say that the idea of a plan for animate things is erroneous; teleology contradicts causality. To have a future purpose means that things in the future influence the present. With causality, we believe that all the events which influenced the present happened in the past. Darwin is clear that chance events—the cause of which would have happened in the past—coupled with natural selection—the influence of the past or present environment—produces the order that we see in the animate world. Why should the inanimate world be radically different? Could not chance events and natural selection explain the occurrence of electrons and protons?

If the idea of continued existence—survival—is behind the behavior of charged particles, then the way that they accelerate when they interact must be a part of survival behavior. Scientists are inclined to say that they accelerate because a force is acting on them, but we could just as easily say they accelerate so that the environment they perceive remains the same as their natural environment is. Consider the two interacting electric charges, where we arbitrarily called one the test charge and the other the source charge. When the test charge accelerates in an inertial frame, it is subject to the superposition of the environment produced by the source charge, that is, its electromagnetic field, and the environment produced by the acceleration relative to the rest of the universe. If these superimposed environments added up to the same thing as the normal environment when the particle is *at rest* relative to the remainder of the universe, then the particle might continue to survive.

It might be a possibility, that the electric action of a source particle consists of a flow—or flux—of *something* through space. Remember Maxwell suggested this as an alternative to "a medium already existing in space", the ether. The *somethings* cannot be "a material substance" or there would be collisions. To emphasize that they are not matter, I will call them *messengers*. These messengers, if they existed, would move outward, in all directions, from the source charge; some would fall on the test charge, after the retardation time. Perhaps the test charge might also be in receipt of messengers from all sides coming in symmetrically to it from the rest of the universe. How could it move so that this lopsided flux of messengers from the side where the source charge was located at the retarded time might be overcome? If it moved at constant speed in the inertial frame of the universe, we presume the inward flux from the universe to the charged particle would still be symmetric—remember all inertial environments are equivalent. It would have to accelerate in the inertial frame and this might produce just the right result. There would be an asymmetric flux from the universe superimposed on the asymmetric flux from the source charge, and these two might add up to a symmetric flux. All of this presumes that the messengers produced from the universe are indistinguishable from the messengers produced from a local source charge. And why not? What is out there except a lot of other electrons and protons? (I still am ignoring gravity.)

Summary

1. The general laws of electromagnetism come from the specific facts of interaction of the two types of fundamental particles: electrons and protons.
2. The way that charges accelerate when they interact is a part of survival behavior.
3. Charged particles emanate something that then forms the environment for other charged particles.
4. The something that charged particles emanate is probably the same something that is coming in from the rest of the universe and creating inertial environments.
5. The total environment is a superposition of all environments, from local charged particles and from the rest of the universe. This means that the *somethings* do not interfere with each other.
6. Charged particles will move in such a way as to experience a total environment that is inertial.

CHAPTER 8

The Energy Crisis

Newton's studies of the way that objects interact with each other showed that the ratio of the accelerations of the interacting objects was a constant, independent of the distance between them and their velocities at the time of their interaction. In the last chapter, I described the interaction between electric charges and indicated that this interaction does not fit the Newtonian idea of interaction. Because the interaction is not instantaneous, whenever there is a relative motion of the interacting charges, the effect is complicated. In an attempt to try to simplify the calculation about what happens, we introduce the idea of an electromagnetic field. At any time the field at particle number one—if you call the interacting particles "one" and "two"—is due to particle number two's position and motion—velocity and acceleration—at an earlier time, called the retarded time. The position of particle two at the retarded time is called the retarded position. The duration of the retardation is the time required for the electromagnetic effect to travel in a straight line from particle two, at its retarded position, to particle one in its present position. The speed of electromagnetic interaction is a constant—we name it c. Its value, as I said before, is 186,000 miles per second which is 3 hundred million meters per second. This is an extremely high speed, and you can see that, unless particle two is moving fairly rapidly, it will not have moved very far from the retarded position in the interval between the retarded time and the present.

It is very difficult to think about the interaction between charged particles and not think, as Maxwell did, that there must be something travelling from particle number two to particle number one—and, of course, vice versa. This something I have called "messengers" although I have not yet made any attempt to quantify this messenger model of electromagnetic interaction. One of the reasons for putting this off is because there is a competitor for what is travelling in electromagnetic interaction and that competitor is called "energy". I have entitled this chapter *The Energy Crisis* because, if I am to make any serious progress with a messenger model, I must first dispose of the energy model.

Energy started as a concept, like force or field, which helps make calculations about the behavior of interacting particles simpler. But it has, by degrees, been invested with more and more significance until now it has become to many people not only a part of nature, a reality, but, to many, the very basis of all reality. As an example of the most extreme reification—if not deification—of energy I quote Werner Heisenberg:

> Energy is in fact the substance from which all elementary particles, all atoms and therefore all things are made, and energy is that which moves. Energy is a substance, since its total amount does not change, and the elementary particles can actually be made from this substance as is seen in many experiments on the creation of elementary particles. Energy can be changed into motion, into heat, into light and into tension. Energy may be called the fundamental cause for all change in the world. [1]

I quote this to show you just how far very respectable physicists get carried away in their regard for energy. If it is not energy itself that grips scientists, it is usually the general law called the "law of conservation of energy." I will outline how this law fits in with Newtonian interaction and electromagnetic interaction in turn so that you can appreciate just what it is about, but first I quote a typical enthusiast for the law - Professor R.P. Feynman:

> There is a fact, or if you wish, a law, governing all natural phenomena that are known to date. There is no known exception to this law—it is exact as far as we know. The law is called the *conservation of energy*. It states that there is a certain quantity, which we call energy, that does not change in the manifold changes which nature undergoes... It is not a description of a mechanism, or anything concrete; it is just a strange fact that we can calculate some number and when we finish watching nature go through her tricks and calculate the number again, it is the same. [2]

To Feynman, the law of conservation of energy is a fundamental part of nature's bag of tricks. It is to him part of the grand design, one of the rules of the game, perhaps the most basic rule since it "governs all natural phenomena that are known to date."

The law of conservation of energy, and with it the concept of energy itself, must be attacked directly if the notion that the existence of laws governing—or describing—the physical world is to be believed to be an illusion. The metaphysical power of any conservation law is very great. Here is Mach:

> ... the notions of the constancy of the quantity of matter, of the constancy of the quantity of motion, of the indestructibility of work or energy, conceptions which completely dominate modern physics, all arose under the influence of theological ideas. [3]

As Mach says, constancy within change is a deeply rooted theological idea. Do you know the famous hymn "Abide with me"?

> Change and decay
> In all around I see
> Oh Thou who changest not
> Abide with me.

Not only is the unchanging element within a constantly changing environment important to us theologically, it is important to every accountant. Books must balance—if something disappears, it must be explained. Whether it is our orderly accountant's attitude in science or a deep-seated yearning for the eternal, somehow the law of conservation of energy has cast its spell over us and we see it as general and fundamental.

Where did it all start? It started with what is known as the work-energy theorem. This is really a restatement of the definition of velocity and acceleration combined with Newton's second law of motion. I will show you what it is. Suppose that an object is moving along in a straight line with constant acceleration a. This means its velocity is changing uniformly with time. Suppose that it starts at time zero with a velocity zero—from rest as they say. As time goes on, its velocity will increase. At a later time t its velocity v will be $v = a \times t$. This is the definition of constant acceleration. In time t it will travel a certain distance d. If it were travelling at constant velocity v, it would travel a distance $d = v \times t$—that is the definition of constant velocity v. In the accelerated case, the velocity is not constant but changes from 0 to v. The distance travelled will be $d = (\textit{average velocity}) \times t$. The average velocity will be $v/2$. So $d = v \times t/2$. Using the value for the time of the trip from the other equation $v = a \times t$, or $t = v/a$, we get

$$d = \frac{v \times v}{2 \times a}$$

We can rewrite this equation as

$$a \times d = \frac{v \times v}{2}$$

or

$$a \times d = \frac{v^2}{2}$$

If the acceleration is varying, we multiply the instantaneous acceleration by the small distance travelled when the acceleration has that value and add this up over the whole trip. The right-hand side of the equation stays the same. I will just stick with the constant acceleration case because all that adding up of little pieces involves calculus.

Now comes the time to stir in Newton's second law of motion which is

$$F = m \times a$$

I do not write arrows over F and a here because they are both along the straight line where the motion is taking place. From this equation and the previous one we get

$$F \times \frac{d}{m} = \frac{v^2}{2}$$

or

$$F \times d = \frac{m \times v^2}{2}$$

Now we are ready for the work-energy theorem. We define a new concept "work" which is the force exerted multiplied by the distance over which it is exerted. So here by definition

$$Work = F \times d$$

We then define a second quantity which we call the "energy" of the moving object which is its mass multiplied by its velocity squared all divided by two.

$$Energy = \frac{m \times v^2}{2}$$

Having defined these two quantities, we now see that our equation says that the work done—by exerting a force over a distance—is equal to the energy of the object that has been accelerated. Sometimes the energy of the moving object is called energy of motion or kinetic energy.

We have introduced—defined—two new concepts: work done by a force and energy of motion. We say, as if these concepts had some existence independent of these definitions, that if you do work on an object, its energy increases. This has no more information than Newton's law has, namely, that if you act on an object with a force, it will be accelerated. This is well understood by all scientists. Here is a quote from a university physics textbook by Resnick and Halliday:

> The work-energy theorem does not represent a new, independent law of classical mechanics. We have simply *defined* work and kinetic energy and *derived* the relation between them from Newton's second law. The work-energy theorem is useful, however, for solving problems in which the work done is easily computed and in which we are interested in finding the particle's speed at certain positions. [4]

The principal use of this new law is to make calculations about the speed—velocity—of an object that has been subjected to a force where we can make the calculation of the work easily. A force is exerted only if our object is near another object or, as we say, is in the field—of influence—of the other object. According to Newtonian mechanics, if an object is at a certain position in the field of another object and released, it will move in an accelerated manner either towards the object, or away from the object, depending on what the two objects are. If they are both electrons, they will move apart. If one is an electron and one a proton, they will move together.

For certain kinds of fields, called conservative fields, the work done by the force on an object released at one point A in the field and moving to another point B is independent of the particular path that the object takes from A to B. The work done can then be expressed as the difference between two quantities that depend only on the positions of the two points A and B in the field. If we call these two quantities potential energy, then the work done on a moving particle which travels from A to B is just

(Potential Energy at A) - (Potential Energy at B)

This is the definition of the term potential energy (P.E.). Now if we go back to the work-energy theorem we see that, if the object starts from rest at A and is accelerated to B where it has a speed v, then

(K.E. at B) = (P.E. at A) - (P.E. at B)

Since the Kinetic Energy (K.E.), as defined, is zero at A (where $v = 0$), we can write

(K.E. at B) - (K.E. at A) = (P.E. at A) - (P.E. at B)

or regrouping the terms in the equation

(K.E. at B) + (P.E. at B) = (K.E. at A) + (P.E. at A)

This is the first appearance of the idea of energy conservation. If we say that the total energy of the object is the sum of the potential energy and the kinetic energy then this equation says that

(Total Energy of object at B) = (Total Energy of object at A)

The energy of the object is conserved, and this is the law of conservation of energy. As an object moves in a conservative field, there is a quantity —Feynman calls it "a number"—which we have named energy which does not change. We say it is an invariant of the motion. How wonderful nature is! Descartes is quoted by Mach as saying:

> Therefore, it is wholly rational to assume that God since in the creation of matter he imparted different motions to its parts, and preserves all matter in the same way and condition in which he created it, so he similarly *preserves* in it the *same quantity of motion* [sometimes energy]. [5]

Having gone to the trouble of defining all these new concepts: work, kinetic energy, potential energy, total energy, in order to disguise Newton's law of motion, we stand back and pronounce it as part of the grand design.

I said that it is only for certain Newtonian type interactions that this law of conservation of energy holds. These include gravitation and electrostatic interactions and actions of this sort that happen in isolation of other nearby objects. These must of course be the limitations, since conservation of energy is really Newton's second law in disguise. Perhaps I should say that the same facts about interaction can be expressed in different "guises"—but the information content is the same in each guise.

I have said that the conservation law idea is very gripping. You begin to believe that energy is something that really exists. Gradually you are led to believe that an object can possess certain kinds of energy and that the total amount that it possesses does not change. This is the way we analyze what happens when an object moves in the field of another object which itself remains fixed. What happens when both interacting objects can move? How do we analyze the situation then? Suppose object number one is moving at speed v directly toward object number two, initially at rest, and that the two objects repel one another. Suppose also that the two objects are identical. In the interaction, we know, using Newton's third law, that the forces are equal and opposite at all times. This does not immediately mean that the energy lost by one object is equal to the energy gained by the other since the equal forces may be exerted over different distances. We do know that they are exerted for the same length of time—the time for the interaction to take place. So we define a new quantity called "impulse" which is the product of force multiplied by the time over which the force is exerted. If a constant force F is exerted on an object for time t, the impulse is $F \times t$. Using Newton's second law this is $m \times a \times t$. But, if the body changes from a velocity 0 to a velocity v under the influence of the constant force, $v = a \times t$, so that the impulse is equal to $m \times v$ which we call the "momentum" of the object. Just as we had the work-energy theorem, we now have the impulse-momentum theorem. The impulse given to an object equals the momentum of the object.

$$F \times t = m \times v$$

One of the big differences between the two theorems is that work and energy are just numbers that have a certain size—the numbers may be positive or negative. But, impulse and momentum are quantities that have both size and direction.

Using Newton's third law we can show that, if two objects interact, the change in momentum of one object is equal in size and opposite in direction to the change in momentum of the other. This means that the total change in momentum is zero. Momentum is conserved in an interaction. This is called the law of conservation of momentum and is a direct consequence of Newton's laws of motion. It is not new information. It is necessary to use both conservation laws to analyse an interaction since between them they give the same information as contained in both Newton's laws of motion.

Using the conservation laws you can tell that if two identical objects—balls—collide by having one start at rest and the other comes toward it with a speed v that after collision the speeds will be reversed. If each has a mass m, before collision the energy is $m \times v^2 /2$. The potential energy is zero both before and after collision because the objects are assumed to start and finish out of range of any interaction. This means that the only energy before and after is kinetic energy. It seems that the energy of the system is passed from the incoming ball to the outgoing ball during the collision. As far as momentum is concerned, before collision it is $m \times v + 0$—after collision it is $0 + m \times v$. Both velocities are in the same direction so momentum is also conserved. Momentum is passed from the incoming ball to the outgoing ball.

Neither momentum nor kinetic energy are quantities that are independent of the frame of reference that you use for observing the collision. Suppose you imagine the collision between the two identical objects from a frame of reference that is moving along with the incoming object at a speed v relative to the first frame we spoke about. In this moving frame, the incoming object from frame one would seem to be at rest. But, the object that was at rest in frame one would be moving towards the first object with a speed *v*. The whole collision would seem to be the other way around. If you think of energy—in frame one the kinetic energy of object one is passed over on collision to object two—in frame two the kinetic energy of object two is passed over on collision to object one. How can energy as we have described it be anything real when, depending on our frame of reference, it is passed in opposite directions? And one frame is as good as another for viewing the event. They are both inertial frames, and inertial frames are equivalent.

The same remarks can be made about momentum although, strangely enough, no one seems to speak of momentum as a thing. Perhaps the reason is that we introduce a great many properties all called energy, the sum of which remains constant in an interaction. I have already spoken about kinetic energy and potential energy but there are more. Another is heat energy. Kinetic energy *shows* because the object is moving—potential energy *shows* because the object is in a certain position in the field. But, heat energy does not *show*—it is internal to the object. The object is hotter. We now know heat is related to the internal motions of the constituents that make up the object. The constituents of the object have an increase in kinetic energy which shows up as a higher temperature of the object.

An example of where energy apparently disappears, is when two identical objects collide, as before, but stick together after collision. The law of conservation of momentum tells us that the stuck-together objects must move off with speed $v/2$ in order that the momentum after collision, namely $2 \times m \times v/2$, is the same as the momentum before, namely, $m \times v$.

The kinetic energy before collision is $m \times v^2/2$ whereas after collision it is $(2 \times m) \times (v/2)^2/2$ since the mass of the outgoing object is $2 \times m$ and its speed is $v/2$. (Remember kinetic energy is the mass multiplied by the velocity squared all divided by two.) If you simplify this expression for the energy after collision you see that it is $m \times v^2/4$, only half of what it was before collision. It would seem that energy had disappeared. We call this kind of collision an inelastic collision which just means one in which the total of the potential and kinetic energies is not conserved. These two kinds of energy are called mechanical energy. I said that it was found that, when mechanical energy disappeared, heat appeared. This was discovered by Joule; he found the exact relationship between the unit for measuring mechanical energy and the unit for measuring heat, the calorie. We now call the unit for measuring any kind of energy after Joule.

Joule's discovering where energy disappeared to in an inelastic collision was very important and made scientists believe that the law of conservation of energy was very fundamental. Since it is merely a restatement of some of the information in Newton's laws of motion, we would expect that it holds as long as Newton's laws hold. But, I guess they forgot about Newton and began to put their trust in energy conservation. The reason that energy conservation includes heat energy is that if you look microscopically at the collision it is not between two objects but between two systems of particles which are moving about randomly as well as having their centers of mass move along systematically. When we say that object number one moves at speed v, we really mean that the center of mass of the system of particles that we call object one is moving at speed v. The other object is at rest before collision, but its particles are also moving about at random—but their center of mass stays fixed. After collision, each center of mass moves at speed $v/2$, but the random motions of each system are intensified. This shows up as heat, but is really mechanical energy of the particles. So, in fact, mechanical energy is conserved, at the microscopic level, even when it seems that it is not when we just look macroscopically.

So we emerge from all this with an alternative way of expressing the information in Newton's laws: as the laws of conservation of momentum and energy. But more than that, scientists found the conservation law form of the information more appealing. It is undoubtedly good to have alternative ways of reasoning about physical situations, but this alone would never have been enough to raise conservation laws to the prominence they now enjoy without metaphysical feelings on the part of scientists. The idea of conservation seems to support the idea of design in the physical world.

I have indicated in the last chapter that Newton's laws do not describe the interactions between electric charges. We need Maxwell's laws of electromagnetism or their information equivalent. Newton is just plain incorrect as far as the interactions between fundamental particles go. Does that mean that the laws of conservation of energy and momentum are also incorrect? The answer is yes, if we stick to the same definitions of momentum and energy. But, if we are willing to change the meanings of the words we can get laws that have the form of the old laws.

I will concentrate first on the law of conservation of energy. The person responsible for manipulating Maxwell's laws of electromagnetism into a conservation of energy law was Poynting. His equation is sometimes called Poynting's theorem—like the work-energy theorem. Poynting defined energy in such a way that it was a property of the fields—electric and magnetic—rather than a property of the charges causing the fields. If the fields were static, that is, not changing with time, the energy just stayed in space wherever there was a field. When the field changed with time because a charge was moving, the energy stored at any position could change and this according to Poynting was accompanied by a flow of energy from one point to another. If an electric charge were oscillating back and forth there would be a flow of energy from it outward into space.

I did not write down Maxwell's equations as I did Newton's equations because they are mathematically more difficult. But remember they are equations that relate the way that the electric and magnetic field components, which describe the electromagnetic field, depend on each other and on the source of the fields, namely, electric charges. The emphasis in Maxwell's equations is the field and when you perform mathematical operations on these equations just as we did on Newton's equations, to get a theorem that can be given an energy interpretation, it is natural that the energy will be associated with the field rather than with the charges. Jammer describes it this way:

> [Maxwell and Poynting have shown that] the field is the seat of the energy and matter ceases to be the capricious dictator of physical events. [6]

An earlier energy interpretation which involved only static electric or magnetic fields, found that a valid conservation law could be obtained either by associating the energy with the charges or with the field. But, Poynting's assignment to the fields is necessary in the most general case.

The main thing to realize is that the law of conservation of energy for electromagnetic fields does not contain any information whatsoever not contained in Maxwell's equations. From the point of view of worrying about whether or not the energy conservation law proves the existence of design in nature, the question can be decided by looking at Maxwell's equations.

The fact that energy is an artifact, an invention of man and not a part of nature is made completely explicit in the high school textbook on physical science prepared for non-science students (by PSNS project staff):

Much of the usefulness of the energy concept arises from the fact that, when properly defined, the total energy in the Universe is constant. This statement is so fundamental to man's model of the world about him that it has become known as "the principle of conservation of energy." We will discover that if this principle is to apply to all physical interactions and to all situations whatsoever, it will be necessary to invent a number of different kinds of energy. We will also see the need to invent rules for assigning numerical values to the various forms of energy we invent. These rules will tell us how to compute the values of each kind of energy in terms of the properties of objects under any situation imaginable

The rule for determining this number has already been set for kinetic energy:

$$K.E. = \frac{m \times v^2}{2}$$

But, we must establish other kinds of energy and give the rules for determining a given amount of each kind if we are going to be able to develop the principle of conservation of energy. That principle is the accounting system of the energies as objects interact with one another. If we assume that energy is conserved in each interaction, then if objects do interact in such a way that the energy of one decreases, the energy of some other must increase. It is possible, of course, for the energies of each of the interacting objects to decrease, but only if they lose energy to the surroundings. Objects can also gain energy from the surroundings.

By this reasoning, we are at liberty to invent as many energies as we wish and in any way we see fit in order to accomplish our objective of producing an energy conservation principle. The principle will only be useful, however, if the number of separate rules necessary to specify all kinds of energy is reasonably small. Generating the law would not be worth the effort if every new phenomenon investigated

> required a new kind of energy calculated by a new rule. If, however, we can describe all interactions in terms of the exchange of only a few kinds of energy, then the energy conservation principle would provide a new relationship between properties of interacting bodies. Fortunately, it is possible, by identifying only six or eight distinct kinds of energy, to arrive at a principle which turns out to be enormously powerful as an aid in thinking about how bodies interact. Once we are persuaded we have established a principle that is valid for all events, we can use it with confidence to predict what results we shall obtain from experiments we have not yet performed. [7]

From this you can see that my point of view about energy is completely orthodox—but I am not sure that it is the view held by most scientists. It is certainly not the view held by the general public, particularly when the words "energy crisis" are on everyone's lips. Energy becomes more than a concept when we think of running out of fossil fuels.

If you take the scientific view, energy is always conserved—it can neither be "destroyed nor created" as is often said. Why are we constantly being told to conserve energy? The reason is that some things that we *assign* energy to are more useful than others as a source of energy. It is easier to *transfer* energy from oil to a motor car to accelerate it than to *transfer* energy from air. The energy from oil is more available. When we lose energy from our houses to the air we say it is dissipated—it is not concentrated in a way that keeps our bodies warm. That is why we insulate our houses—to prevent the transfer. There are different classes of energy. High class energy, like that assigned to oil or to the heat in a warm house, is more useful. We call energy that is dissipated by nuclear power plants into the lake water used to cool them "thermal pollution." The energy is unwanted.

There is no doubt that the concept of energy is a very good way to describe the changes that are occurring around us but we must constantly remember its roots as an invention of man—as the PSNS book says:

> Energy itself is a creation of the human mind. Our confidence that we can find a small number of simple rules for assigning energies so that the sum of all kinds is constant

> has established the conservation principle as a basic premise of science. [8]

Conservation laws are a form that we want, and we give meaning to all kinds of things like work, potential energy, kinetic energy, energy density, energy flow, and so on to keep our beloved form. And so far we have been successful. But, the thought that we have a general law of nature is an illusion.

Summary

1. All the ideas expressed in this chapter are orthodox although perhaps not uniformly held by all scientists.

CHAPTER 9

Cosmic Noise

I am embarked on a program to show that there are no general laws that govern—or describe—the physical universe. The laws that we have are either (*1*) man-made, as I believe that the conservation laws are, or (*2*) like Newton's laws of motion, they are not fundamental and can be derived from other more fundamental laws, or (*3*) they are descriptions of the way that specific things, like electrons and protons, behave. The laws of electromagnetism I believe, fall into this last category. The other laws—Newton's laws of motion and the conservation laws—can be derived from the laws of electromagnetism. The fact that all these laws can be unified provided scientists like Einstein with encouragement to work for a complete unification of all of our scientific information. But, no one has yet been successful in this enterprise. In my analysis, I have said that general laws imply design. The fact that laws, like Maxwell's laws, summarize the information contained in a number of other laws does not make them general laws. But, I do have an outstanding problem that requires an explanation if I am to claim that there is no discernible design in the universe—Why are the laws of electromagnetism as mathematically simple as they are? I have never written down these laws for you either in the form of Maxwell's equations or in the form of the interaction between two charges because, although I say they are mathematically simple, they are far more complicated than Newton's laws of motion. They are often not even presented in their full form in the first university course in Physics taken by Physics majors. In the simple case of two interacting stationary electric charges, the accelerations depend on the inverse square of the distance between the charges. It is this kind of simplicity that I think must be explained, or it will seem that a designer has been at work.

The order that we find in the physical world, as I see it, stems from the natural recurrences of the three fundamental particles: electrons, protons, and neutrons. Why there are natural recurrences needs explanation but it is not unreasonable that, if we can explain, by a theory of evolution, natural recurrences of plants and animals, the explanation of recurrences of fundamental particles should also be possible.

So far I have ignored gravitational interaction, and I will continue to ignore it for a while. I have ignored nuclear interaction—the interaction between protons and neutrons in the nucleus of an atom. We do not yet have a really clear description of this interaction except to realize that when nucleons—protons and neutrons—are close enough together there is some mechanism which holds them together. The electromagnetic repulsion between protons continues to exist but a different mechanism, superimposed on the repulsion, causes them to be attracted at short-range. This nuclear attraction is the same between proton and proton, neutron and neutron, or proton and neutron. We say it is "charge-independent" meaning that it exists whether the nucleon is electrically charged or not. This seems to indicate that it is a distinct nuclear mechanism which coexists with the electromagnetic interaction. Whatever the nuclear interaction is, the "Law of nuclear interaction" will be of the same type as the "law of electromagnetic interaction" and will be explainable, in the same sort of way, as a description of the behavior of fundamental objects that recur naturally.

Another whole set of facts that I am ignoring, because they seem tentative, are the investigations going on about fundamental particles. This means that I am ignoring all the observed spectrum of particles: the leptons, hadrons, and baryons, as well as the more fanciful quarks, gluons, and so-ons. It is not that I do not think this particle research is extremely important, but I do not believe that we have really settled on any laws. Even if we had, they would again fall into my category of descriptions of specific objects that recur naturally. The simplicities would require an explanation, but that is what many of the attempts to systematize the spectrum of observed particles are concerned with. All sorts of concepts are introduced like "color" and "charm" to try to make it easier to analyze particle physics but, of course, these are man-made.

Perhaps it would be a good idea to record a list of all the laws of physics that I must come to grips within this exploration of mine. F.W. Constant wrote a textbook in 1963 called *Fundamental Laws of Physics*. Here is his list (Some of the laws have not yet been mentioned):

I. Newton's law of motion (second).

II. Newton's law of action and reaction (third).

III. Newton's law of gravitation.

IV. The conservation of energy principle.

V. The degradation of energy principle (or second law of thermodynamics).

VI. Huygens' principle of wave propagation.

VII. Coulomb's law of electrostatic force.

VIII. Ampere's law of magnetic force.

IX. Faraday's law of electromagnetic induction.

X. Maxwell's law of magnetoelectric induction.

XI. The relativity principle.

XII. The quantum principle.

XIII. Pauli's exclusion principle.

XIV. Conservation of matter principle.

XV. The law(s) of nuclear force. [1]

First of all I must point out again that, to Constant, a fundamental law means something very specific:

> The great laws of physics are those that express principles or relations which are independent of the specific properties of certain materials or objects. These laws will therefore be called our fundamental laws; they must be distinguished from those *restricted laws* which apply only to certain materials and only under a limited range of conditions. By their nature, fundamental laws are not derivable from anything else; they are our starting points in the various branches of physics. [2]

I have been putting forward the thesis that there are no "principles or relations which are independent of the specific properties of certain objects." My fundamental laws are in fact, the description of the behavior of objects—objects that are fundamental in the sense that the whole universe is composed of these objects.

I will refer in turn now to the different laws in Constant's list of fundamental laws. I have said that Newton's laws—if we ignore the law of gravitation—can be explained by referring to the more fundamental laws, the laws of electromagnetism, which Constant separates into the four laws: VII to X. These four are summarized in Maxwell's laws of electromagnetism, or the laws of interaction between two electric charges. Law IV, the conservation of energy, I have indicated to be only an alternative formulation of other laws. The relativity principle (XI) is partly contained in Newton's first law of motion which was extended by Einstein to relate to the laws of electromagnetism. I will be writing in detail about this in the chapter called *Trapped Inside*. The *inside* referred to is inside the universe. We can only observe the behavior of objects inside the universe and, as I indicated in the chapter on *The Impossibility of Isolation*, the universe is more than a background for observing behavior. In the present chapter, which I have given the science-fiction style title *Cosmic Noise*, I want to explore a second facet of the influence of the universe—cosmos—on the fundamental objects.

This investigation will deal first with what Constant calls the "degradation of energy principle (or second law of thermodynamics)" and here the influence of the immediate surroundings on systems of objects—atoms or molecules—is described. Then I will look at the influence of the universe as a whole on the particles, as individuals, and will be coming to terms with part of the information contained in what Constant calls the "quantum principle." Number XIII, "Pauli's exclusion principle," will have to wait until after the next chapter when I discuss *The Stochastic Atom*.

Just to complete the examination of Constant's list of fundamental laws, I will mention the others. The one he calls "Huygens' principle of wave propagation" will be discussed in the chapter on *The Two-Slit Mystery*. There, I will show that it is information contained in Maxwell's laws. That leaves the "Conservation of matter principle." Again, this is not a general law really but a description of the universe—that the numbers of electrons, protons, and neutrons do not seem to change with time. They are extremely durable. I have already hinted at the possibility that this durability may not be a static situation, where a particle just continues to exist in perpetuity, but perhaps a dynamic situation, in which the particle is constantly decaying —disintegrating—and constantly being renewed—rebuilt.

In this chapter, I will concentrate then on "the law of degradation of energy" and "the quantum principle." For both of these, I will invoke the influence of the environment on a particle or a system of particles. By environment, I mean the rest of the universe, excluding the system of particles itself. It is not usual to pay very much attention to the rest of the universe as far as environment is concerned. Resnick and Halliday say this:

> The motion of a given particle is determined by the nature, and arrangement of the other bodies that form its environment. In general, only nearby objects need to be included in the environment, the effects of more distant objects usually being negligible. [3]

This clearly states the position that the effect of distant objects is usually ignored. What Resnick and Halliday call the environment is what we think of as the interacting objects. The effect of any one interacting object decreases as its distance from the particle, whose environment it creates, increases. Since the effect of any one object becomes negligible it is not unreasonable to assume that the effect of the totality of all the objects out there, that form the rest of the universe, is negligible. What I will argue in this chapter is that the effect of all those objects, which of course are made of electrons, protons, and neutrons, is not negligible but is taken into account in four different ways. None of the ways in which the objects *out there* affect a particular object is directly attributed to those objects by most scientists. I have already discussed the fact that it is those objects that create inertial frames of reference. In this chapter, I will attribute to those objects what is called the degradation of energy principle and the quantum principle; in a later chapter I will indicate that, if the effect of the objects out there is interfered with by some sizable nearby object, the result is an attraction to that nearby object. The nearby massive object casts a shadow, if you will, on the particular object under study and makes the effect of the rest of the objects of the universe asymmetric. That is how I will explain gravity.

Before I launch into a discussion of these different effects, I want to tell you of an incident that happened in 1961. Dr. Donald Ivey and I were asked by the Physical Science Study Committee to make a film titled *Universal Gravitation*. We wanted in it to show the motion of a planet around a sun graphically, by animation. We were told that this would be possible by using an analog computer at the Lincoln Laboratory of the Massachusetts Institute of Technology. One afternoon we went to the laboratory and were given a demonstration. One spot on the screen of a cathode ray tube was stationary while a second spot was moved about it to represent a planet moving around the sun—or a satellite moving around a planet. The position of the moving spot was calculated, according to Newton's law of gravitation, using the analog computer. Analog computers were, at that time, much faster machines for making this kind of calculation than digital computers. They could move the spot along reasonably quickly and give a lively display. But, analog computers are not as accurate as digital computers in that they effectively work only to an accuracy of 2 or 3 significant digits—digital computers can operate with six or more significant figures. This meant that the planet's orbit on the screen of the cathode ray tube did not behave as it should behave according to Newton's laws of motion and law of gravitation. It should have moved in an elliptic orbit with the sun at one focus and repeated this orbit time after time. What always happened was that the orbit changed its orientation all the time—it precessed. If the same thing had been done using a modern digital computer, the effect would not have been as noticeable, but it would still have been there.

All calculations that we can do on real numbers have, in the end, a limit to their precision and, as time goes on, the orbit would get *out of whack*. This demonstration made an indelible impression on me. Why doesn't a real planet get *out of whack*? Is there no limit to the accuracy with which *nature* operates?

The limited precision with which any computer represents real numbers introduces a random element into the results of its calculation. This random element can be made smaller and smaller by using greater precision, but it *cannot* be eliminated. It occurred to me that this must also be the case with the way the universe operates. There must be an end, a limit to the precision of the operation of laws and, in this limit, there must be a random element operating. Real planets do not behave as our graphical planets did. Why not?

There are two places in physics where random elements are admitted to be present and where the future is not precisely predictable, but is instead probabilistically predictable. These two places are in the second law of thermodynamics and in the quantum principle. But, where does the randomness arise? The laws that we have looked at so far have no such element in them—they are deterministic. If a known situation exists, what happens next is precisely predictable. We say there is a causal connection between the present state and a future state. A law will let you calculate the future state precisely, if you know the present state precisely. And, in fact, the law will tell you precisely what the past states were. Danto and Morgenbesser wrote in their book on the *Philosophy of Science*:

> The initial state is sometimes spoken of as *determining* every other state of a physical system (it being arbitrary which state we chose as initial)—assuming the system to be isolated. The concept of "isolated system" is difficult to explicate, and many argue that the only instance of an isolated system is the universe itself. [4]

The implication of this is that any departure from deterministic behavior might be attributed to the fact that isolation is impossible. But, we have happily assumed that systems that we were studying, whether they be two particles colliding, many particles colliding, many particles in a cluster breaking up, or two particles in an atom, were able to be isolated or maintained in an environment with which there was no net exchange of energy. Mach indicated that it was essential for progress to focus on part of the whole universe, not on everything at once:

> It is certainly fortunate for us, that we can, from time to time, turn aside our eyes from the overpowering unity of the All, and allow them to rest on individual details. But, we should not omit, ultimately to complete and correct our views by a thorough consideration of the things which for the time being we left out of account. [5]

Surely, it is time to consider "the things which for the time being we left out of account."

We seem to be getting along very well without taking the environment into account. But, to get along we must attribute a probabalistic—random—element to the system under study. David Bohm, in his book *Causality and Chance in Modern Physics*, suggests that the random influences—contingencies—might better be related to all the rest of the universe:

> Every real causal relationship, which necessarily operates in a finite context, has been found to be subject to contingencies arising outside the context in question... For example, in the motion of the planets, contingencies are still quite unimportant for all practical purposes... Now here it may be objected that if one took into account everything in the universe, then the category of contingency would disappear, and all that happens would be seen to follow necessarily and inevitably. [6]

Bohm explains that we resort to probabalistic calculations and speak of randomness and chance because we do not have enough information about all the details of the interaction with the rest of the universe. The events do not really happen by chance—we use chance as a cover for our own ignorance.

In this book, I am trying to maintain that the question of whether the present state of the universe is the result of chance or design—or a combination of chance and design—is an unanswerable question. Most of my effort so far has been spent in trying to show that the evidence for design, through the existence of general laws, is illusory.

Now, in this chapter, the general laws have in them the element of chance. I must show both how the general laws arise and that the element of chance in them is due to ignorance on our part and not due to something in the universe that is inherently random. In this way, they can neither be construed as evidence for design nor for—radical—chance.

I am going to look first at the degradation of energy principle. This is often called the second law of thermodynamics because it appears in the study of heat, which is one of the forms of energy. The law can be stated many different ways, but it is always the same information. Before I say what the law is, I must explain the idea of a closed system. I have shown that if you define different kinds of energy: potential, kinetic, heat, etc., in the right way, energy in an isolated system—sometimes called a closed system—is always conserved. If you calculate the energy at any time by adding up the energy of all the components of the system, you get exactly the same number, no matter how the components of the system interact with each other.

Suppose that the closed system is a large number of atoms of a gas, say helium atoms. To contain such a system we must enclose the atoms in a box—or container. The box must be maintained at a constant temperature, that is so the atoms in the box will have a constant average energy. The temperature of the box must be arranged so that the average energy of the atoms of the gas is the same as the average energy of the atoms of the box, so that there will be no net interchange of energy between the box and the gas contained in it. Then we say the gas in the box is a closed system. Its energy will remain constant with time. The first law of thermodynamics is that in a closed system, energy will remain constant. But, more needs to be said about the behavior in a closed system—energy is not enough to describe what happens. The second law of thermodynamics indicates that there is a direction in which a closed system will change as time goes on; it will not, of itself, change in the opposite direction. We say the process of change is irreversible—it cannot run backward in time. As far as a single interaction between two isolated particles is concerned, everything is reversible. If you saw a movie of two colliding particles run backward, you would not say that it was at all unusual, provided there was no change of mechanical energy into heat. If there is such a change, running the film backwards would look impossible to you. For instance, suppose you took a movie of a ball bouncing on a table where the bounce gradually dies out. Energy is conserved here (first law of thermodynamics) but gradually mechanical energy of the ball —potential and kinetic—changes into heat energy—the ball and the table are warmer. A bouncing ball shows the second law of thermodynamics in action. It is why we believe that macroscopic perpetual motion is impossible. If no energy is fed into the system, all macroscopic mechanical energy gradually is transformed into heat energy.

But, what about a system with no macroscopic mechanical energy, like our gas in a box? What goes on there? The energy is heat energy and stays as heat energy. Is there any direction to processes there? The answer is yes, there is. Suppose you arranged the atoms in the box so that all the faster moving ones were in the left side of the box and all the slower ones in the right side and then photographed the action—if you could. It would not be very long before the atoms were all mixed together with no separation between fast and slow. Showing this movie backward would look ridiculous.

In the actual process the order, namely, separation by velocity—faster atoms at one end, slower at the other—would disappear; disorder would be the final result. This idea can be written many ways. One way is to say that in any natural process order tends to disorder. Another way to record the facts is to notice that if the left end of the box contains faster moving atoms, that end must be at a higher temperature than the right end of the box. After a time the whole box is at the same temperature. We say heat energy flows from the hotter to the colder end. Or put another way, heat does not of itself flow uphill from a colder to a hotter part.

The usual way to justify the second law of thermodynamics is to say that a system that is isolated tends to the state that is most probable—or has the highest probability. Suppose you were playing a game called "locate the atom in a box" by running some wheel of fortune to decide randomly where it should be located and you had atoms, some of which were fast moving and some were slow moving. At each spin, you would place one atom in the box and carry on spinning until all atoms were located. The number of different ways of doing this is enormous, just as the number of different bridge hands that can be dealt is. Many of the ways look the same, sort of jumbled up, disorderly. Only a small number of arrangements would have fast atoms at one end and slow at the other. It is like finding bridge hands with two all red hands and two all black hands. It is very improbable compared to a mixture of black and red in each hand.

So scientists have come to accept the fact that all processes tend to an arrangement that is more probable; and in the end to the one of greatest probability. It is possible, on the basis of probability calculations alone, to predict the actual distribution of velocities of atoms in a gas at equilibrium. The distribution is predictable even though it results from random events. All probability calculations imply randomness, that is, unpredictability which, when you deal with large numbers of things or events, yields virtual predictability. The predictability is not precise predictability but, as the number of individual objects making up the system increases, it might as well, for all the difference it makes, be precise predictability.

So the second law of thermodynamics indicates that there is a randomizing influence on the behavior of systems like gas in a box. Why do we call the law the "principle of degradation of energy." I have indicated that mechanical energy tends to "disappear" and heat energy "appears". The second law of thermodynamics tells us also that you cannot transform heat energy back 100% into mechanical energy, although it is perfectly possible to get some mechanical energy from heat. Think of the steam engine running a train. Just as macroscopic perpetual motion is impossible so too is the perfectly efficient conversion from heat to mechanical energy. You always have some heat left, and this is often just wasted in an engine's exhaust for instance, or given off by a radiator to the air. We think of mechanical energy as first-class energy and heat as second class energy. So the principle of degradation of energy is that all first-class energy naturally degrades into second class energy. We never lose energy, but it becomes less useful to us. What people mean when they tell you to conserve energy is to conserve first-class energy, since, of course, energy is automatically conserved always. It is defined that way. The energy crisis people talk about, is that we are depleting our sources of first-class energy.

To *explain* the principle of degradation of energy (the second law of thermodynamics) we must either say that there is absolutely no information in it, beyond the laws of interaction of objects (Newton and Maxwell) or to account for the random influences on a system of objects by pointing to the apparently innocent bystander—the box in which the system is contained. Since the box is connected with the rest of the universe, its influence contains the random influences of all the particles in the whole universe. If we could deal with the whole universe, we might not have to worry about these apparently random influences. But, if we try to do this, Bohm says:

> Of course, by broadening the context, we may see that what were chance contingencies in the narrower context present the aspect of being the results of necessary causal connections in the broader context. But, then, these necessary causal connections are subject to still newer contingencies, coming from still broader contexts. [7]

We cannot expect to know what it would be like to get outside the universe but what we must do is build up information about what it is like inside.

To me the second law of thermodynamics can be summed up by saying that, although a system can be kept in such a way, relative to the rest of the universe, that there is no gain or loss of energy of the system on the average, it cannot be isolated from the microscopic random influences of the rest of the universe. This means as well that there must always, microscopically, be a give and take of energy between the individual elements of the system and the environment even for what we call an isolated system. The net overall result of this give and take is zero energy flow one way or another—energy is conserved macroscopically. Here is a summary of this in the Physics text that D.G. Ivey and I wrote:

> In thinking about gas molecules bouncing around in a container, we know that individually they make collisions with the walls in which they gain or lose energy. However, for a system in thermal equilibrium we assume that on the average there is no net gain or loss, and the total energy of the gas is constant. Therefore, we can think of the collisions with the walls as being perfectly elastic (or think of the walls as being perfectly reflecting) and speak of the gas as isolated, exchanging no energy with its surroundings. It is, however, because the system is not really isolated that the concept of thermal equilibrium exists. [8]

I would say then that microscopic energy conservation is impossible. And this is what I mean by "cosmic noise." I call it cosmic because the effect is an interaction with the cosmos—the rest of the universe. I call it noise because it appears to the system as a random influence. As Sir Fred Hoyle says:

> … by taking account of an influence of the universe, it is possible to avoid the assumption that the local laws of physics are lopsided with respect to time. [9]

We explain the irreversible part of thermodynamics by noting that the effect of the rest of the universe on the system appears to the system as a random influence. I quoted Bridgman as agreeing with this point of view:

> What prevents the following out through all future time of a definite sequence is the walls, the atoms of which are supposed to be in such a complex state of motion because they are in connection with the entire outer universe … [10]

The last film that Donald Ivey and I were to make for the PSSC group we called "Energy is not enough." It was to be a film about the second law of thermodynamics from a microscopic point of view. This view is usually called the statistical mechanics point of view. This is because ideas of probability, or statistics, are applied to the distributions of position, velocity, and energy of atoms or molecules. In the script for the film, we had suggested that the random influence that resulted in the unpredictability of the behavior of individual atoms or molecules had its root in the walls of the container. In the conference with a group of scientists that always preceded the making of any PSSC film, it became clear that no two of those scientists agreed about the basis of statistical mechanics. In the end, the film was never made. I had not before really encountered a situation where it became so obvious that beneath the formulas in science there were so many interpretations. It seems that there is superficial agreement about what we—scientists—all should believe but I found that underneath this is not the case. Kuhn says:

> Though there still is a paradigm few practitioners prove to be entirely agreed about what it is. [11]

That brings me to the second fundamental law that I want to talk about in this chapter, what Constant calls the "quantum principle." I am going to divide this quantum principle into two parts. The whole principle attests to the dual, wave-particle nature of matter and radiation. I will address only the dual nature of matter in this chapter. Radiation's dual nature I question, and for this reason put it off until the chapter on *The Two-Slit Mystery*.

Perhaps I should begin by saying where the word quantum comes from. It means *a certain amount*. Originally, it was applied to electromagnetic radiation. It was decided that the energy in electromagnetic radiation came in certain amounts as a sort of package—a quantum. The amount of energy in a radiation quantum was determined to be proportional to the frequency of the electromagnetic waves. This development took place at the beginning of this century. It was due to the work of Planck and Einstein.

When, in the early 1920's, there appeared to be indications that the idea of a dual, wave-particle nature could be ascribed to particles of matter, like electrons, protons, and neutrons, the theory that included this property was called quantum mechanics.

Just as the second law of thermodynamics can be stated in several ways, there are several ways of describing what I have called the wave-particle duality of matter. One way was originated in 1923 by Louis de Broglie. He said that there was a wavelength associated with every particle of matter that is moving. This wavelength L was inversely proportional to the momentum $m \times v$ of the particle. Thus

$$L = \frac{h}{m \times v}$$

The constant h in this formula was Planck's constant. It had appeared earlier when Planck and Einstein had said that the energy E in a quantum of electromagnetic radiation—a photon—was proportional to the frequency f of the electromagnetic wave

$$E = h \times f$$

This is perhaps the most striking evidence of design in the universe—that the constant h, Planck's constant, should appear in both these formulas and that they both should be so simple. I will have a lot of explaining to do to eliminate proof of a Designer here.

Then, in 1924, the same constant turned up again. This time Werner Heisenberg used it in his uncertainty principle. This principle stated that there was a limit to the accuracy with which the position and velocity of a particle could be measured simultaneously. For a particle constrained to move along a line, the uncertainty in the measurement of position x we call *U(x)*, the uncertainty in velocity v we call *U(v)*. The Heisenberg uncertainty relationship for a particle of mass m is

$$U(x) \times U(v) \geq \frac{\hbar}{2 \times m}$$

This is a more complicated relationship—or law—than de Broglie's formula for wavelength. The constant $\hbar$ in the formula is not Planck's constant but is Planck's constant h divided by 2 times pi. (Remember pi? The area of a circle is pi multiplied by the radius squared.) The uncertainty relation says that the product of the uncertainty in position and the uncertainty in velocity is greater than (>) or equal to (=), $\hbar$ divided by two times the mass of the particle.

It can be shown that, although de Broglie's and Heisenberg's relations are stated quite differently, they contain the same constant and they really have the same information content. One can be derived from the other.

Actually, it is easy—but not really easy—to derive both Heisenberg's and de Broglie's relations from a third statement of the same information. If you want to see this done, and are mathematically ready, take a look at Chapter 18 of my textbook *Physics* (John Wiley and Sons). The actual statement of the relation from which the others can be derived is that the amplitude of the probability density of position for a steady state of a system of particles and the amplitude of the probability density of momentum for that same steady state is that of a Fourier pair *(x, k)* provided that the momentum is related to *k* by the relation

$$m \times v = \hbar \times k$$

where $\hbar$ is, as before, Planck's constant h divided by *2* times pi.

So there is no need to "explain" all three of these relations —Heisenberg, de Broglie, and the Fourier pair relation. If you explain one, you explain them all.

I am going to suggest that the uncertainty that exists in measuring the position and velocity—or momentum—of a particle (which is really why we say it has a dual nature of wave and particle) is because the motion of a particle has a jitter to it which is the result of the random—uneliminable—influences on it from the rest of the universe. Heisenberg's relationship has often been presented in terms of the uncertainty in our knowledge of the state—position and velocity—of a particle. Heisenberg has this to say:

> Certainly, quantum theory does not contain genuine subjective features; it does not introduce the mind of the physicist as part of the atomic event. But, it starts from the division of the world into the "object" and the rest of the world, and from the fact that at least for the rest of the world we use the classical concepts in our description. This division is arbitrary...[12]

Heisenberg is saying that we want to treat the rest of the universe as classical (deterministically) and this leads us arbitrarily, to assign to the particle itself this uncertainty or dual nature. We say that its behavior can only be calculated probabilistically. But, if we say that there are random influences from outside, the particle is in fact behaving classically (deterministically). Because we can never know all the influences in detail, we are compelled to make probabalistic—or statistical—calculations. Heisenberg speaks about the random influences on the nucleus of an atom which cause it to disintegrate and emit an alpha-particle, apparently at random:

> We know the forces in the atomic nucleus that are responsible for the emission of the alpha-particle. But, this knowledge contains the uncertainty which is brought about by the interaction between the nucleus and the rest of the world. If we wanted to know why the alpha-particle was emitted at that particular time we would have to know the microscopic structure of the whole world including ourselves, and that is impossible. [13]

The mechanics that we use to predict what will happen in the nucleus of the atom or in the atom is called quantum mechanics. It is called this because it incorporates the element of uncertainty in the behavior of the particles that constitute the atom. The predictions that can be made using quantum mechanics are probabalistic in nature. There is absolutely no possibility that they can be other than this. Most scientists would say that this is because of the uncertainty principle or because of the dual nature—wave-particle—of all the constituents of the atom. Since I cannot accept the idea of a general law governing—or describing—the behavior of all objects, and that is what either of these implies, without looking for an explanation, I must go further.

I believe that the effect of the universe on each particle is what produces the result that we are noticing here. I believe that the laws of electromagnetism describe accurately how charges would interact if they could be isolated from the random fluctuating influences of the microscopic structure of the universe. Of course, the laws of electromagnetism do in themselves already incorporate the steady part of the influence of the rest of the universe in producing the inertial environment. As Heisenberg says, the division we have now is arbitrary. We assign the randomness to the particles and claim it is part of their nature.

I am going to claim that the behavior of particles is very similar to the behavior of particles of pollen suspended in water which were observed under a microscope in 1827 by the botanist Robert Brown. It was first thought that the random jumpy motions of the pollen particles was due to the fact that they were "alive". Then it was observed that all tiny particles showed this same kind of motion.

It might have been possible for scientists at the time to say that the particles of pollen, or whatever, had a dual nature or that their behavior was described by an uncertainty principle. But, instead scientists began to attribute their zigzag motion to the influence of their environment. Even though they could not see what was going on, they imagined that the environment was made up of other much smaller particles, moving about in a similar zigzag fashion, bumping into each other and into the pollen particles. The smaller particles were called atoms. Here are Resnick and Halliday:

> The earliest and most direct experimental evidence for the reality of atoms was the proof of the atomic kinetic theory provided by the quantitative studies of Brownian motion. [14]

The "atomic kinetic theory" was that atoms in a gas were moving about randomly and bumping into each other and the walls of their container. In doing this, they caused the suspended particles to move about as well. As Resnick and Halliday continue:

> The suspended particles are extremely large compared to the molecules of the fluid and are being continually bombarded on all sides by them. If the particles are sufficiently large and the number of molecules is sufficiently great, equal numbers of molecules strike the particle on all sides at each instant. For smaller particles and fewer molecules the number of molecules striking various sides of the particle at any instant, being merely a matter of chance, may not be equal; that is, fluctuations occur. Hence, the particle at each instant suffers an unbalanced force causing it to move this way or that. [15]

For Brownian motion, it has been shown that a relationship of exactly the same form as Heisenberg's uncertainty relation exists for all Brownian particles.

From the Brownian motion, we concluded that atoms were present. Bohm says:

> Thus, in the case of the Brownian motion, the postulate was made that the visible irregular motions of spore particles originated in a deeper but as yet invisible level of atomic motion. [16]

Now we know that an uncertainty relation describes the motion of particles like electrons and protons, which we cannot see. Are we wrong to imagine another invisible level—say of messengers—bombarding the fundamental particles from all sides giving them a Brownian-like motion?

So I turn to cosmic noise to explain the behavior both of systems of particles and now of individual particles.

Summary

1. The natural recurrences of the fundamental particles might be explained by a theory of evolution in much the same way as we explain the natural recurrences of plants and animals.
2. The randomizing influence on a system of particles that is evidenced by the second law of thermodynamics is due to the effect of the atoms in the walls of the container and the entire rest of the universe. The system cannot be isolated from the environment.
3. Microscopic energy conservation is a physical impossibility because isolation of the system is impossible.
4. The behavior of a particle that is described by the uncertainty principle is similar to Brownian motion and is due to the fluctuating influence of the rest of the universe. The fluctuations are describable as random, but the chance element is just an ignorance cover, not radical chance. The randomness cannot, however, be eliminated.
5. Particles have a wave nature only in that their motion, as particles, has a jitter due to the fluctuating effect of the rest of the universe.

CHAPTER 10

The Stochastic Atom

At the end of the last chapter I suggested that we might think of particles of matter like electrons and protons as undergoing a random, jittery, zigzag, Brownian motion just as a spore or smoke particle can be observed to execute when you look at it under a microscope. This seems reasonable because a relationship between the uncertainties of position and momentum exists in both cases. In this chapter, I will describe a model of the atom called the stochastic atom in which the electron moves about the proton in a Brownian-like way.

Brownian motion has played a very interesting role in physics. The theory of Brownian motion was developed by Einstein. He showed that the average energy of the Brownian particles was the same as the average energy of the atoms of the gas that was causing the motion. Mach was convinced finally by the theory of Brownian motion that atoms did exist. For many years he had thought that atomic theory was nonsense and said so many times:

> However, well-fitted atomic theories may be to reproduce certain groups of facts, the physical inquirer who has lain to heart Newton's rules will only admit those theories as provisional helps, and will strive to attain, in some more natural way, a satisfactory substitute. [1]

It seems rather strange that Brownian motion finally won Mach over to the idea of the reality of atoms and has led me to doubt wave-particle duality. But, I have been unsatisfied for many years with quantum theory and have longed for some *more natural* substitute. I do not seem to be alone in wanting to explain quantum theory in a less mystical way than invoking a dual wave-particle nature to matter and radiation. Bridgman says this:

> There is a sense in which all the revolutionary aspects of quantum theory can be subsumed under the single point

> of view that the operation of isolation always fails eventually. [2]

Bridgman finds quantum mechanics "revolutionary" and suggests that environmental influences might explain everything much more simply. Others find that the wave-particle dual nature of matter and radiation point of view is very natural and satisfying. Feynman says:

> One of the consequences [of quantum mechanics] is that things which we used to consider as waves also behave like particles, and particles behave like waves; in fact everything behaves the same way. [3]

Feynman rejoices in this unity of nature. Wave-particle duality to him accords with the idea of design in the universe. But, I am set against this point of view and must explain the facts in a way that does not imply design.

Before the wave-particle duality of matter and the uncertainty principle were introduced in the 1920's, Niels Bohr had devised a model of the hydrogen atom in an attempt to explain the spectrum of light which hydrogen gas produces when it is excited. The spectrum of hydrogen consists of a series of lines of different colors rather than the continuous spectrum you get from the sun's light. This means that the hydrogen atom is producing light of a number of discrete frequencies. In Bohr's model, an electron moved in orbit around a proton which was the nucleus of the hydrogen atom in much the same way as the earth moves in orbit around the sun. The big difference is that it is an electric attraction between the electron and proton rather than a gravitational attraction as it is with the earth and sun. As I said, the spectrum of hydrogen consists of a number of particular frequencies of light. Bohr said that these were produced by the electron first being given energy, and thus excited to move in an orbit farther away from the proton, then eventually jumping back to the original orbit where it normally moved—the ground state. The different spectral frequencies corresponded to jumps between different possible excited orbits and the ground state

Bohr had a formula for prescribing exactly where the excited orbits might be. It was called a quantum rule. The permitted orbits were called "stationary" states because they were believed to be semi-stable. The electron would stay in an excited orbit for some little time before it jumped to some other "stationary" state or to the ground state. The ground state was truly stable. The frequency f of radiation emitted when the electron jumped from an orbit of energy E_2 to an orbit of lower energy E_1 he gave by what became called Bohr's frequency condition

$$f = \frac{E_2 - E_1}{h}$$

Here, the constant h is Planck's constant. Planck's constant had been introduced into physics a decade before Bohr's work. Remember—Planck and Einstein said that a quantum of electromagnetic radiation of frequency f has an energy equal to h times f. If we rewrite Bohr's frequency condition as

$$h \times f = E_2 - E_1$$

We can interpret it as a statement that energy is conserved in what Bohr called a quantum jump. The equation says the energy of the quantum of radiation ($h \times f$) given out is equal to the change in energy of the electron as it moves from orbit *2* to orbit *1*. Here are Bohr's own words:

> 1. That energy radiation is not emitted (or absorbed) in the continuous way assumed in the ordinary electrodynamics, but only during the passing of the systems between different 'stationary' states.
>
> 2. That the dynamical equilibrium of the system in the stationary state is governed by the ordinary laws of mechanics while these laws do not hold for the passing of the systems between the different stationary states. [4]

Although the Bohr theory has now been discarded completely as being wrong, the Bohr frequency condition with its energy interpretation is maintained. I call this Bohr's "legacy."

I believe that the second law of thermodynamics says that microscopic conservation of energy is not possible so I must reject the interpretation of Bohr's frequency condition as an expression of microscopic energy conservation. How can I do it? I must say that I believe that radiation quanta are artifacts and have absolutely no correspondence with reality. I do not believe that it is appropriate to say that $h \times f$ is the energy of a quantum of radiation.

There has been, from the beginning, something very wrong about Bohr's original idea that radiation only emerges when the electron jumps from one allowed orbit to another allowed orbit. According to electromagnetic theory, an electron in an orbit should radiate at a frequency equal to the frequency of the motion in orbit. L.I. Schiff in his book *Quantum Mechanics* notes the contradiction in Bohr's theory:

> It was difficult to understand why the electrostatic interaction between a hydrogen nucleus [in a Bohr atom] and an electron should be effective when the ability of the accelerated electron [in orbit] to emit electromagnetic radiation disappeared in a stationary state. [5]

Bohr wanted electrostatic interaction to hold the electron in orbit but, he did not want the radiation field due to its acceleration in orbit. He just said baldly that an electron in a stationary orbit did not radiate. The argument went: If it did radiate it would lose energy and gradually spiral into the nucleus and collapse. So scientists became convinced that atoms would all collapse if they did radiate all the time.

Well, the Bohr picture of the atom was discarded when the new wave-particle uncertainty view appeared. The idea of orbital motion keeping the electron from moving right into the proton was abandoned. The present picture of the atom is much vaguer. Here is Feynman speaking of the current view:

> What keeps the electrons [in an atom] from simply falling in [to the nucleus]? This principle [the uncertainty principle]... We cannot know where they [the electrons] are and how fast they are moving, so they must be continually wiggling in there! [6]

This explanation says that atoms do not collapse because of a principle —really! Even Feynman is not convinced and ends by saying "they must be continually wiggling in there." Why do they wiggle? Two answers—They are born wigglers, or, they are being buffeted about. Take your pick—I pick the latter. As you might expect I am not alone in this choice. David Bohm says this:

> Indeed, a rather similar behaviour [to an electron in an atom] is obtained in classical Brownian motion of a particle [like pollen in a container of water] in a gravitational field, where the random motion which tends to carry the particle into all parts of the containers is opposed by the gravitational field, which tends to pull it towards the bottom. In this case, the net effect is to produce a probability distribution [formula], which describes a tendency for the particles to concentrate at the bottom and yet occasionally in their random motions to be thrown up to great heights. [7]

I call the model of the atom which treats the motion of the electron as due to a superposition of the electric attraction of the proton as described classically, and random influences from the rest of the universe, the stochastic atom. It might equally well be called the Brownian motion atom. *Stochastic* applies to things in which there is a random input, an element of chance. For such an atom, probabilistic or statistical predictions are all that would be possible.

I became interested in this stochastic model of the hydrogen atom a long time ago and thought that I might be able to simulate its behavior on a computer. I remembered how difficult it was to model a planet going around the sun by computer; because the errors—or uncertainties—in the precision with which the calculations were being carried out were not negligible, the orbit precessed. I imagined that if uncertainties or random influences were increased—rather than decreased—the motion would not be like an orbit at all but at least the atom would not collapse.

When I ran the program for the model on the computer I had hoped to find that it would take up stable—or semi-stable—states with various average distances of the electron from the proton just as Bohr's atom did. I would then be able to predict the frequencies of the radiation spectrum. But no such thing happened. There was no sign of equilibrium—in fact, my atom, instead of collapsing, just got larger and larger. The longer I ran the simulation model, the farther the electron got in its drunken motion from the proton. Failure.

I came again at the whole project after several years in an entirely different way. But let me digress. The quantum mechanical model for the atom which incorporates the uncertainty principle was developed by both Erwin Schrödinger and by Werner Heisenberg. I will concentrate on describing Schrödinger's approach, which is often called wave mechanics. The two formulations have been shown to be equivalent even though they look very different. In Schrödinger's model all calculations about the atom are probabilistic and are made by computing a function called the probability amplitude function—sometimes called wave function. Using the probability amplitude function, average values can be calculated for the distance the electron is away from the proton, the energy the electron has, and so on. The probability amplitude functions are found by solving Schrödinger's equation for them. Since the solutions of the equation were to be interpreted as giving the probability of finding the electron in a particular region around the proton, only certain mathematically possible solutions would make acceptable solutions as far as the probability interpretation was concerned. For one thing, the function had to predict that the electron was somewhere. The total probability, added up over the whole region surrounding the proton, had to be equal to one. That meant it was somewhere. This restriction, placed on all possible solutions, yielded a set of functions which were called proper functions or, in German, eigenfunctions. For each one of these acceptable solutions, the average energy could be calculated and this was found to give a precise value, not a value with any uncertainty about it.

Using these average energy values, which were put into a one to one relationship with Bohr's orbits, and the Bohr frequency condition, the observed spectrum of hydrogen was predicted—or I should say fitted. Bridgman comments on the naturalness of using probabilistic methods:

> It is perhaps not too surprising that particles are so easily treated by probability methods, for having come to the end of the effects of structure we have also come to the end of the possibility of explanation in causal terms. [8]

I do not object to probabilistic laws any more than causal laws as long as they can be shown to record the facts about specific things like the fundamental particles or the universe as a whole. I cannot tolerate general laws that cannot be explained. I had attempted to explain the uncertainty principle, from which Schrödinger's equation can be derived, by seeing a particle as having, as well as its usual classical electromagnetic interaction with other local particles, a random influence from the rest of the universe that buffets it about in a Brownian-type motion.

There were two problems: Why had my Brownian computer model not shown these special privileged states predicted from Schrödinger's equation and how could I keep my atom from exploding—rather than collapsing? The solution to my problems lay in rejecting Bohr's legacy to quantum mechanics, his quantum jumps. But how? Let me again go back a bit.

Niels Bohr was very interested in philosophy and was influenced by the philosopher Hoffding. Feuer indicates Hoffding's position:

> [Hoffding] was affirming that a personal choice was as operative in the ultimate methodological commitments of scientists and in their analogies, as it was among religious philosophers and metaphysicians... Hoffding's unique contribution to scientific thought was his insistence on the heuristic potentialities of the notion of discontinuities in existence. [9]

You can see how quantum jumps would appeal to Bohr if he shared Hoffding's enthusiasm for "discontinuities in existence." Bohr changed scientists' thinking radically. Hanson describes the difference in his Patterns of Discovery:

> Pianistic thinking cannot allow violinistic glissandi: pianos allow a C sharp, or a D, but nothing in between. Classical physics regarded nature as a complicated violin: that is, differential equations were always in place; but we cannot think of the atom thus. [10]

Bohr had introduced discontinuous stationary states of the atom and the idea of jumps from one state to another. When his orbital model of the atom was discarded, his quantum jumps survived. Bohr was quick to embrace the new quantum mechanics of Schrödinger and Heisenberg which incorporated de Broglie's wave nature of particles and Heisenberg's uncertainty principle along with his quantum jumps. He led a group in Copenhagen to give quantum mechanics an interpretation which emphasized the duality of nature. This "Copenhagen interpretation" dominated and is generally accepted today. There are a few scientists beside Einstein who question this interpretation of quantum mechanics, among them de Broglie and Bohm.

I myself for many years delighted in the many exciting and mysterious ideas in physics. When Donald Ivey and I were preparing television programs we marvelled at the great material we had at our disposal. Duality and uncertainty have a strong dramatic appeal. So much so that I began to suspect that we, as physicists, were indulging ourselves in a pseudo-religious experience, finding the universe so mysteriously contrived. That is when my real doubts began. I fell out of step with the orthodox view of things.

Heisenberg tells of how he became interested in finding a theory for the atom. He was put off by a textbook illustrator's view of molecules:

> In order to explain further just why one atom of carbon and two atoms of oxygen form one carbonic acid molecule, the artist had given the atom hooks and eyes... To me this seemed wholly senseless, because hooks and eyes are—as I saw it—quite arbitrary forms, which can be chosen in different ways according to their technical usefulness. But, atoms are supposed to be the result of natural laws, and guided by them in forming molecules. [11]

The natural laws—such as the uncertainty principle devised by Heisenberg—to me, need explanation, and that is why I am attracted to a stochastic model of the atom. Nelson, in an article in the Physical Review in 1966, describes such a model:

> If we have, for example, a hydrogen atom in the ground state, the electron is in dynamical equilibrium between the random force causing the Brownian motion and the attractive Coulomb [electrostatic] force of the nucleus. Its trajectory is very irregular. Most of the time the electron is near the nucleus, Sometimes it goes farther away, but it always shows a general tendency to move toward the nucleus, and this is true no matter what direction we take for time... the electron has states of dynamical equilibrium at the usual discrete energy levels of the atom. [12]

In the article Nelson shows that a stochastic model leads to the Schrödinger equation but he runs into a little trouble trying to explain the character of the probability function for excited states of the atom. The problem is that the function that describes the probability for position of the electron in any excited state has certain places where it becomes zero. We call these positions nodes in the function. There is a definite probability that the electron will be found on either side of the node but no probability that it will be at the node. How does the electron get from one place to another without passing in between? Here is Nelson struggling with the problem:

> For real solutions of the time-independent Schrödinger equation, other than the ground-state solution, the probability functions have nodal surfaces… However, it can be shown that the associated Markoff [stochastic] process is well defined in each such region, and that a particle performing the Markoff process never reaches a nodal surface. [13]

Nelson seems to believe that the particle stays in one or other of the compartments between nodes. The answer the Bohr disciples give is that the electron is not really a particle, it has a dual nature and as such can perform this difficult feat. It is like going from one room to another without passing through the connecting door. But that is nature for you, mysteriously contrived. After all, the electron is not to be considered as a particle. But, look at Schrödinger's equation and what do we see—the expression for the energy of a particle—not a wave-particle. We use the law of Coulomb to compute the electrostatic energy of position of the electron relative to the proton. Now it is, now it is not a particle!

But that is the beauty of the Copenhagen interpretation—we can have it both ways. Bridgman does not mind:

> The celebrated remark of Wm. Bragg that we seem forced to use classical [particle] mechanics on Monday, Wednesday and Friday and wave mechanics on Tuesday, Thursday and Saturday may prove not to be a reductio ad absurdum as it is usually taken to be but an ultimate and necessary procedure. [14]

Although he also says this:

> The ultimately important thing about any theory is what it actually does, not what it says it does or what the author thinks it does, for these are often very different things indeed. [15]

Schrödinger's equation gives the right frequencies of the spectrum of hydrogen but that does not mean that what he or Bohr or anybody says about its interpretation need be accepted. After all, Bohr's theory of orbits gave the right frequencies for the spectrum too.

I was beginning to suspect that the problem might be that there were no quantized excited states of the atom at all. First, my own computer model did not show any. The Schrödinger probability functions for excited states had nodes and would not square with a real particle—as contrasted with a wave-particle—undergoing a Brownian motion, superimposed on motion under the attraction of the proton. But, how would you get a discrete frequency spectrum without quantized excited states?

I now had the answer. Bohr's assumption about there being no radiation in the ground state or the atom would collapse was unnecessary. My atom did not collapse in fact, it expanded. I needed some way to keep it from expanding. The atom could radiate. If I went by classical electromagnetic theory, the radiation from the ground state would have all frequencies in it, from the random motion of the electron. That would mean a continuous spectrum of frequencies even from the ground state, presumably for any other state as well. But, no one has ever reported observing such a continuous spectrum. Well not exactly true. We know that all macroscopic bodies radiate a continuous spectrum all the time called blackbody radiation. That is what Planck was studying when he stumbled on the idea for the quantization of energy of oscillators. It would be like looking for a needle in a haystack to find the continuous radiation from the ground state of hydrogen. So I did not worry about supposing that one existed. But, what about the discrete spectrum? Even though I thought that the probability functions for excited stable states did not correspond to anything real and rejected them as not proper functions because they had nodes, I knew that any non-equilibrium state of the system could be expressed mathematically as a combination of these functions.

Wait a minute—this is getting rather complicated. I am trying to explain how a spectrum at discrete frequencies can be produced even though the atom never stays in any one of the excited stationary states. First of all let me be clear about what I expect the atom to do. In the ground state it will radiate a continuous spectrum—all frequencies more or less all the time. The motion of the electron is a complex zigzag motion which mathematically is analyzable as the sum of oscillations of every frequency. When the electron in the atom is given additional energy, by being bumped for example, the atom is excited. It has more energy than it has in the ground state. Its motion is similar to what it is in the ground state, and it gradually loses energy and returns to the ground state. In the process, it produces a continuous spectrum as it does in the ground state, but in addition it produces the discrete frequency spectrum. The electron does not necessarily oscillate at these discrete frequencies, but its motion is analyzable as the sum of oscillations at these frequencies.

Perhaps an analogy here would be helpful. I quoted Hanson earlier in the chapter as saying that "Classical physics regarded nature as a complicated violin ... but we cannot think of the atom thus..." . There is a sense in which we can relate a violin to an atom. If we keep our finger off a violin string and bow it carefully it will produce a particular discrete frequency just the way one of the strings of a piano does when it is struck. This frequency is produced by the vibration of the string. The two ends of the string are held fixed, and the center part moves back and forth. We say there is a node at each end and a loop at the center. The wavelength associated with this frequency is twice the length of the string. This is one mode of vibration for the string. It is the fundamental mode. But, the mathematical equation which describes the vibrating string has other solutions—other modes of vibration. One such mode has a node in the center as well as at each end. This mode of vibration has a frequency which is exactly twice the frequency of the fundamental mode. We call it the first harmonic of the fundamental. All the modes of vibration that are solutions of the mathematical equation have frequencies that are integral multiples of the fundamental. We call them the normal modes of vibration of the string. But that does not mean that they are the only ways that the string can vibrate. Most of the time it vibrates in a more complicated way, but the more complicated vibration can always be analyzed as a sum of the normal modes of vibration. We get a mixture of the fundamental and its harmonics. Just as a prism separates light vibrations which are a mixture of different frequencies into the spectrum showing the different lines, the ear of a listener can separate the complex sound vibrations into the different frequencies. We can hear the fundamental and the harmonics. The ground state of the violin string is no vibration at all—in the atom there is perpetual motion.

I hope this analogy will help you understand how a discrete spectrum at frequencies predicted by Schrödinger's equation might exist for hydrogen. In any non-stable state, radiation would be expected at all the different possible discrete frequencies as well as a continuous spectrum. The system if excited would produce the whole observed spectrum. The more the atom is excited, the more prominent the radiation at higher frequencies would be.

As the atom is left alone, it returns to the ground state where the discrete frequencies die out. So you see I reject the idea of quantized excited states in an atom with an electron jumping from one to another thereby producing a photon of a discrete frequency on each quantum jump from higher energy state to lower energy state. Even Schrödinger hoped to do away with quantum jumping. At the beginning of quantum mechanics he said:

> If all this damned quantum jumping were really here to stay, I should be sorry I ever got involved with quantum theory. [16]

Bohr was quick to disagree with him:

> ... remember the Einstein derivation of Planck's [blackbody] radiation law. This derivation demands that the energy of the atom should assume discrete values and change discontinuously from time to time... You can't seriously be trying to cast doubt on the whole basis of quantum theory! [17]

I will be looking at an explanation of blackbody radiation that does not require quantized energy states in the chapter called *The Two-Slit Mystery*.

The stochastic model of the atom answers another kind of question—how is it that atoms are so durable. A stochastic atom would be durable because it has adapted to the environment. In fact, it exists because of, not in spite of, the environment with all its random influences. Heisenberg wondered at the great durability of atoms:

> … chemical elements displayed in their behavior a degree of stability completely lacking in [classical] mechanical systems. [18]

On large scale systems like planets, the random influences are not significant but as we go to smaller objects they are dominant. The atom works, I believe, by a combination of deterministic influence, of the proton on the electron, and by random influences, of the rest of the universe on it. C.S. Smith says this:

> Significant structure is a mixture of perfection and imperfection. [19]

Summary

1. The model of the atom that is consistent with my world view is one called the stochastic atom. (Nelson et al)
2. If microscopic energy conservation is impossible, which I believe is evidenced by the second law of thermodynamics, then the Bohr frequency condition cannot properly be given an energy interpretation.
3. The idea of a quantum of radiation is thus not supported by the line spectrum of atoms.
4. The natural motion of an electron in an atom is perpetual motion due to the fluctuating effect of the rest of the universe. Collapse of the atom is not likely even if the electron is producing electromagnetic radiation in the ground state.
5. Radiation produced by an electron moving in a Brownian-like fashion under the attraction of a proton, as in the stochastic model of the atom, would be a continuous spectrum of radiation in the ground—unexcited—state.
6. This continuous spectrum might not be observed because all macroscopic bodies radiate a continuous spectrum, known as blackbody radiation.

7. If the stochastic atom is a valid model and is described by Schrödinger's equation, then solutions of the equation which have nodes cannot be proper solutions. A real particle cannot have a probability density function of position which becomes zero between places where it is non-zero.

8. The only stationary state for a stochastic atom is the ground state. This is the only state whose probability density function has no nodes. Although no excited state is stable, every excited state may be described as a combination of the solutions of the Schrödinger equation that possess nodes.

9. The discrete line spectrum of hydrogen can be explained by the fact that excited states are describable as a combination of the solutions of the Schrödinger equation normally considered proper solutions.

10. An excited atom produces radiation which, when analysed by a device such as a prism, should contain both a continuous spectrum and radiation at certain discrete frequencies simultaneously.

CHAPTER 11

The Two-Slit Mystery

This chapter is called *The Two-Slit Mystery*. What are the two slits and what is the mystery? The two slits are just that, two slits cut parallel to each other in an opaque screen. They are used to perform the two-slit experiment, an experiment devised by Thomas Young, the early nineteenth century physicist who solved the mystery of the Rosetta stone and disentangled Egyptian hieroglyphics. But, Young left behind him his own mystery, the two-slit mystery.

In the last two chapters, I have been concerned principally with an explanation of the wave-particle duality of matter. In this chapter, I will look at the wave-particle duality of electromagnetic radiation. And that is where the two-slit experiment comes in. It was Niels Bohr who stressed the dual nature of matter and radiation. He spoke about complementarity, saying that the wave and particle aspects of matter were like two sides of a coin. A coin may be seen as either heads or tails but not both at the same time. According to Bohr, the reality of particles like electrons, protons, and neutrons must be described using the complementary models of wave and particle. Perhaps we should refer to them not as particles but as *wavicles*. This notion of complementarity seemed to Bohr to be very fundamental. As Feuer reports:

> When Niels Bohr formulated his principle of complementarity in 1926, he proposed that physicists renounce the hope of achieving a system or theory based on one model, either wave or particle... This duality of complementaries seemed to Bohr "a fundamental feature" in the nature of all human knowledge. [1]

I suppose you might say that he thought that there is ambiguity in nature and our knowledge of it must reflect this uncertainty. This gives rise to the big question of whether this uncertainty is subjective, connected with the state of our understanding of the real world, or objective, as I have suggested. I have attributed the apparent dual nature of particles to the fact that all particles suffer random influences from their environment which are superimposed on whatever influences there are, due to other nearby particles. If there are no other particles nearby we would get completely random motion, much like Brownian motion.

But, my explanation would probably be much too mundane for Bohr. He was greatly influenced by the philosophy of Kierkegaard as presented by Hoffding. This is Feuer's account:

> From the proposition that theology is psychology, Kierkegaard (as Hoffding expounded his views) argued that we must simply drop the idea of truth-in-itself, the objective truth; all that we can have is psychological truth, hence subjectivity is truth... Thus were sown the first seeds of the notion that theoretical perspectives on physical experience which seemed contradictory were but complementary standpoints, depending... on the personal decisions of an experimenter, on the particular, experimental arrangement he devised to measure and report on his physical experiences. [2]

This philosophical—or theological—point of view played a profound role in Bohr's vision of physical truth. Bohr's idea was that ultimately, precise knowledge of physical reality was not possible. Always there would be uncertainty. Actually, this particular philosophy comes very close to my own thesis—shades of Kierkegaard perhaps. But, I must try to clarify the difference. Bohr was concerned about whether our knowledge of the universe was subjective or objective. I maintain that we should not be able to tell from our knowledge of the universe whether it arises by chance or by design. If there were laws this would be evidence for design so I believe that there are no general laws, only facts about specific things that recur naturally. The wave-particle nature of all particles of matter looks dangerously like a general law, whether it appears as the Heisenberg uncertainty principle or de Broglie's wave nature of particles, and I must explain it. Heisenberg himself struggles with the subjective-objective nature of these facts concerning uncertainty in his book *Physics and Philosophy*:

> ... such a description [of a measuring device] contains all the uncertainties concerning the microscopic structure of the device which we know from thermodynamics, and since the device is connected with the rest of the world,

> it contains in fact, the uncertainties of the microscopic structure of the whole world. These uncertainties may be called objective insofar as they are simply a consequence of the description in the terms of classical physics and do not depend on any observer. They may be called subjective insofar as they refer to our incomplete knowledge of the world. [3]

In a way, Heisenberg's attitude is not very different from mine when he mentions "the uncertainties of the microscopic structure of the world" as being at the root of the uncertainty in our knowledge. But, the fact is that we do not need to know the details of the influences of the rest of the universe. We assume that they are random and use probability ideas to compute average behavior. We stop concerning ourselves with what we can never know in detail and carry on. And it turns out that it does not really matter. The behavior of atoms, although subject to random influences, is probabilistically predictable. The predictions will never be otherwise—but that is good enough for all our purposes.

The reason that I go into all this wave-particle discussion is that many scientists believe that it is somehow connected with the nature of reality. Reality they believe, is designed that way. Bohr did not say this—he said that it was "a fundamental feature in the nature of human knowledge." If I were to make any statement about "the nature of human knowledge", I would say that it is strictly limited by the fact that we are trapped inside the universe and we must recognize that what we know of the universe cannot be considered to be unaffected by this. Have you ever heard people say that they do not like an "I" novel, where everything that is written is what is known to one person. They feel trapped, limited in what they can know about other characters in the novel. As individuals we are all trapped inside our own bodies and what we know of the universe must come into us, through our senses. We are all trapped inside the universe. We cannot step outside and have a look. We were recently able to step outside the earth—vicariously—and looked back at it—but we can never get outside the universe. Nor can our space ships. Our information is strictly from inside and if you are inside something, it is not a strange idea that the something—the rest of the universe—is affecting the objects you are observing. It would be strange if they were not affected in any way. Classical physics does not take into account the effect of the universe. Bohm says:

> This error [uncertainty] arises essentially not because of a lack of knowledge on our part, but rather because of the neglect of objective factors existing outside the context under investigation. [4]

What, I believe, we have done is to assign to the particles themselves a nature that really is the result of influences on them from outside. These influences are basically classical, that is, describable by Maxwell's laws—or Newton's laws. Bohm says:

> In physics, the influence of any process on its "background" is even more strikingly brought out by Newton's law that action and reaction are equal. From this law, it follows that it is impossible for any one body to affect another without itself being affected in some measure. Thus, in reality, no perfectly constant background can exist. [5]

Now it is time to move to the wave-particle nature of radiation which to me is a more complicated riddle than the wave-particle nature of matter. Electromagnetic radiation is the name we give to the effect that is produced by an electric charge that is accelerating. The radiation field associated with the acceleration decreases in magnitude inversely as the distance from the source charge to the field point so, at appreciable distances from the source charge, it is the dominant component of the field. If the charge is oscillating, the radiation field oscillates at the same frequency and we say that there are electromagnetic waves. The speed with which the wave pattern travels away from the oscillating charge is the speed with which the electromagnetic interaction travels. The frequency of the oscillation has nothing whatever to do with the speed of travel. We say that electromagnetic waves of all frequencies travel at the same speed, which we call *c*. The waves travel at speed *c* because the electromagnetic interaction travels at speed *c*. If we ask what is travelling in an electromagnetic wave, we should equally well ask what is travelling in any electromagnetic interaction. What additionally is travelling in a wave that is not travelling in any electromagnetic field is a pattern—the wave pattern.

An analogy that might help here is to imagine a hose squirting water out of a nozzle. When the nozzle is held still, the water follows in a certain path. The path would be a straight line if it were not for gravity and wind. If there were no wind it would go in a parabolic path landing on the ground, eventually. If, instead of holding the nozzle still, you moved it back and forth you would see a pattern move out. Each drop of water would move as before in a parabolic path, but a moving wave-like pattern would be formed by the stream.

When the idea of energy conservation was worked out by Poynting for electromagnetic interaction, energy was said to be stored in the field. In a static field, the energy just remains in position but, in a dynamic field which is changing with time, it moves around. It flows outward from an oscillating charge into space. The charge sends energy out. This energy "comes" from whatever is accelerating to produce the waves. All very pretty but, since I say that energy is "all in the mind" and is just an alternative way to describe some of the information in Maxwell's laws, there is no need to ask what carries the energy or whether it is "pure energy" as Weinberg calls it. We can really just forget all about it. Its conservation is assured—it was all defined so that, if Maxwell's laws hold, energy is conserved. But, unfortunately, it gets dragged into a lot of the discussion about electromagnetic radiation. In particular it gets dragged into the particle picture of radiation.

After Maxwell's work, up until the early years of the twentieth century, everyone was convinced that there were such things as electromagnetic waves and that light was simply a range of frequencies of these waves that happen to stimulate our eyes. Our primary source of light is the sun, and we call its light "white light." As Newton had showed, white light can be dispersed into colors, the colors of the rainbow, by letting it pass through a glass prism. This spectrum of colors from the sun is brightest in the green part of the spectrum and tapers off in intensity as you go to the extreme ends of red and violet. The brightness of the green is not just because the eyes are most sensitive to this color, but measuring instruments show that it is really the most intense. The intensity of light, as measured in say energy units, for sunlight has a very typical relationship to color. We know now that the sensation of color that we experience is related to the frequency of the light waves. The violet light has the highest frequency of the waves in the visible spectrum—the red, the lowest. You can plot a graph of energy density against frequency for sunlight, and it is always the same. It is the characteristic mix of frequencies produced by our sun. If we use instruments—not the eye—that are sensitive to all frequencies, we *see* that the sun produces ultraviolet and infrared radiation as well and the graph of energy density against frequency always shows the results for the full spectrum, not just the visible part of it.

The graph of the sun's radiation can be described by an equation, and this same equation can describe the graphs of radiation from many different hot objects, like furnaces or incandescent light bulbs. We call these bodies black bodies, although you might call them hot bodies. The graphs for all blackbody radiation are describable by the same kind of equation. The equation shows that the radiation depends on the temperature of the hot body. Any hot body at the same temperature as the sun produces white light, with its highest intensity in the green. Cooler bodies peak in the red—they look red hot, not white hot. At lower temperatures, the peak is in the infrared—you can feel the radiation as heat, but you cannot see it. Think of a wood stove.

I tell you all this, which you probably know, because it was in trying to explain the graph for blackbody radiation that Max Planck in 1901 reluctantly offered the suggestion that the oscillators producing the radiation in a hot body change energy by an amount that is proportional to the frequency of the radiation. If the change in energy of an oscillator is E then

$$E = h \times f$$

where the constant h, multiplying the frequency f, has come to be called Planck's constant. Energy is packaged or quantized. An oscillator's energy does not change continuously but in jumps. Abrupt transitions were not part of classical physics. With Planck, modern physics was born. This is the origin of the quantum theory. Planck said that the energy of an oscillator changed by a quantum, not that the radiation energy was quantized. It was left to Einstein to nail down the quantization of energy in radiation. Feuer notes this:

> Einstein was consciously trying to develop a new foundation for physical science; his intent was revolutionary. Whereas Planck was a reluctant revolutionist, unwilling but compelled by the sheer weight of experimental facts to break with the traditional mode of thought... [6]

It is interesting that Einstein was unhappy with the shape of quantum theory—the moment it became connected with probabilistic prediction as it did with Heisenberg. He constantly said, "God does not play dice," to which Bohr is said to have replied "Who are you to tell God what to do." But in 1905 Einstein was young, with revolutionary ideas, questioning everything. He worked on the theory of the photoelectric effect. This effect had been discovered by Hertz when he produced electromagnetic waves, of frequencies lower than the visible, from oscillating electric circuits. Hertz found that light falling on metal surfaces caused electrons to be emitted from the metal—this became known as the photoelectric effect. The effect did not occur, no matter how brilliant the light, unless the frequency was high enough. Einstein said that the amount of energy required to permit the electron to escape had to arrive all at once and could not be dribbled in gradually. He said low frequency light would not produce the effect because the radiation itself was packaged with the energy E in the package being related to the frequency f by the equation

$$E = h \times f$$

This is Planck's equation, but it now applies to a quantum of radiation rather than to the energy jump of an oscillator. Just as it requires a certain energy to get a rocket away from the earth, it requires a certain energy to get an electron away from the metal. If the radiation energy quantum, called a photon, was large enough it could free the electron from the metal—if the frequency of the radiation were lower than this threshold the electron would not come out. No one low frequency quantum would be big enough, and the effect was not cumulative. Even though you provide lots of quanta below the threshold size, nothing happens. Higher energy quanta than threshold size give the electron a speed when it comes out. Einstein's photoelectric equation is very simple. It is

$$h \times f = \textit{threshold energy} + \frac{m \times v^2}{2}$$

It says: the energy of the incoming quantum $h \times f$ is equal to the threshold energy plus the energy of motion of the electron ($m \times v^2/2$). This is a statement of energy conservation on the microscopic level. (Remember: the second law of thermodynamics seems, to me, to imply that microscopic energy conservation is impossible due to the random influences of the rest of the universe. But, I leave that for the moment.)

Einstein's explanation of the photoelectric effect convinced people of the quantum nature of electromagnetic radiation, and with it the reality of photons. Planck's work started it but was perhaps too hard to understand.

Einstein's 1921 Nobel prize was given for the theory of the photoelectric effect, not for his theory of special relativity. Relativity was hard to understand and seemed "unproved" at the time.

Now it is time to get down to the two-slit mystery. Before Maxwell there was considerable controversy about the nature of light. Newton believed that light was a stream of particles—Christian Huygens, Newton's contemporary, believed that light was a wave. Huygens was Dutch and often observed the ripples in water produced by stones dropping in the canals. If the path of the ripples were obstructed by a barrier, the waves were reflected from the barrier just as light is reflected by a mirror. If the barrier had a hole in it, the waves were obstructed—and reflected—except where the hole was. As the unobstructed part of the wavefront went through the barrier, instead of proceeding like a sort of slice of the original wave pattern, it fanned out, just as if the hole were a new source of waves. This phenomenon is called diffraction, which means spreading out, and is thought to be characteristic of waves. Huygens said that if you could isolate any point on any wavefront, as you do when you obstruct all but a small part, you would find that it acts like a source of wavelets moving out in circles from it. These wavelets, called Huygens' wavelets, do not show in an ordinary wave spreading out because they interfere with one another to produce the overall effect of circular wavefronts moving out from the real source of the waves. If there were two holes in a barrier, the waves emerging from the two holes would interfere with each other and produce an interference pattern.

That brings us to Young and the two slits. Young believed that he could demonstrate that light was a wave by letting it pass through two slits. If it were a wave, each slit would act like a new source of waves just like a hole in the barrier for water waves. The waves from the two slits would interfere with each other, just like the waves from two holes in a barrier for water waves. In certain directions the waves would reinforce and there would be light—in others they would cancel each other and there would be darkness. If you put a second screen up on the side of the opaque slit-screen away from the source, you would see strips of light and dark called interference fringes, parallel to the slits themselves. Young did the experiment, saw the fringes, and settled the argument about the nature of light. It was a wave.

But, if you think of light as a stream of photons as Einstein suggested, what is happening in the two-slit experiment? This is when the trouble starts. Here is an account by Dicke and Wittke in their book *Introduction to Quantum Mechanics*. They describe the two-slit experiment of Young where the slits are called A and B and the screen where the interference fringes are observed is replaced by an array of photoelectric detectors. They say:

> The result is paradoxical in several ways... The photoelectric effect [at the detectors] can be understood only on the basis of the photon picture of light. However, a photon sufficiently small to affect only one electron could presumably not go through both slits A and B. In fact, a photon detector placed at either A or B catches only whole photons or none, never a part of a photon. This raises the question of how a photon which passes through A can be influenced by the presence of B. One obvious possibility is that some photons pass through A and some through B, and that the separate photons act on one another in such a way as to arrive only at the bright fringes on the screen P. This explanation must be incorrect, as can be seen by reducing the intensity of the light to the point where on the average only one photon per minute passes through the system. Even in this case the photons continue to arrive at only the bright fringes!
>
> One striking thing about this experiment is that the behavior of any given photon is largely unpredictable... The intensity distribution over a fringe merely serves to give a probability distribution for the arrival of any given photon; it does not allow an exact prediction of where the photoelectron will appear... If either slit A or B is closed, photons begin to arrive at locations where there were previously dark fringes: a decrease in the number of paths by which a photon can get from S [the source] has resulted in an increased probability [of arrival]. [7]

You can see that it certainly is not simple. Here is Heisenberg himself on exactly the same theme, this time with a photographic plate as a detector:

> If one describes this experiment in terms of the wave picture, one says that the primary wave penetrates through the

> two holes; there will be secondary spherical waves starting from the holes that interfere with one another, and the interference will produce a pattern of varying intensity on the photographic plate.
>
> The blackening of the photographic plate is a quantum process, a chemical reaction produced by single light quanta. Therefore, it must also be possible to describe the experiment in terms of light quanta. If it would be permissible to say what happens to the single light quantum between its emission from the light source and its absorption in the photographic plate, one could argue as follows: The single light quantum can come through the first hole or the second one. [8]

One way often used to get around this perplexing problem is to say that the photon picture of radiation applies only to the emission process, as Bohr claimed, and to the absorption process, as Einstein claimed, and has no validity in between. What happens during the transmission remains a mystery. Not very satisfactory as far as I am concerned. I can remember when I first studied interference, wrestling with light's dual wave-particle nature—I could not reconcile the duality no matter how I tried. It all seemed like double-talk. Many scientists welcome the mysterious—it makes science more fascinating. It makes me uneasy. I always feel that I have somehow just been stupid in not getting the point.

Huygens' principle is used to explain the behavior of light waves at a barrier. But, where did Huygens' principle come from? From the observation of water waves? It should be possible to derive it from Maxwell's laws of electromagnetism. Maxwell's laws are consistent with an alternative formulation which focuses on the electromagnetic interaction between charges. In this alternative formulation, it is clear that all electric effects travel at speed *c* and in straight lines. How can light be diffracted if it comes to an opaque screen with a slit in it? It seems to go through the slit and then spread out—some light seems to go straight through—some changes direction. This is completely inconsistent with Maxwell's laws. The same things could be said about the refraction of light as it passes through a prism. Its direction is changed. How can this be consistent with the idea that light travels in straight lines? Most scientists will say that light travels more slowly in a medium like glass and this is why it changes direction. Different frequencies of light travel at different speeds in a medium. This is why light is spread out in a spectrum by a prism—different frequencies are refracted different amounts. We call it the dispersion of light into a spectrum. What about diffraction? The explanation you often get is that light changes direction at a narrow opening because it is a wave, and waves bend around corners.

For many years, I had always happily used Huygens' principle to "understand" the behavior of light waves in a medium and passing through small openings and never questioned what was necessary to justify such a principle. The apparent slowing down of light in a medium, other than vacuum—or air which is not very far from a vacuum compared to solids like glass, or liquids like water—can be explained by considering that the atoms of the medium are caused to produce secondary electromagnetic waves by the incoming waves. The total electromagnetic field in the medium is the result of the superposition of the incoming field and the secondary waves produced by the atoms of the medium. These secondary waves have the same frequencies as the incoming waves but are not exactly in phase with them. The net result is the illusion that the wave is travelling more slowly in the medium. It is an illusion however since each wave that interferes to produce the resultant wave is actually travelling at the speed *c*. The incoming wave continues through the medium at speed *c* and superimposed on it are waves from the atoms of the medium, all of which travel at speed *c*. They all add up, by superposition, to a resultant wave that seems to be traveling more slowly than speed *c*. Very tricky! What is more, the resultant wave can be in a different direction from the incoming wave, depending on how the incoming wave is oriented to the interface between the air and the medium. This is the refraction or bending that we observe. No wave is actually bent. The incoming wave keeps right on going. The secondary waves from the atoms of the medium move straight out in all directions from their source atoms. You will recall that one of our basic facts about electromagnetic interaction is that different fields superimpose but do not interfere with each other. What we call the interference of waves really should be called the superposition of waves.

What about diffraction—do waves bend then? Of course not. The wave that comes up to the screen goes right through the screen. As it does, it sets the atoms in the screen oscillating so that each is a source of secondary waves. There are no secondary waves along where a slit is. The resultant of all these waves superimposed is exactly the same as if there were no incoming wave or secondary sources in the screen but instead a series of secondary sources where the slits are. It is an illusion but a completely convincing one.

The simple mathematical argument for this is not very difficult to understand. Imagine an opaque screen with two slits cut out, but instead of throwing away the parts that you cut out you leave them in the openings. So the screen really has no holes in it. I will call the hole fillers "plugs". On the shadow side of the screen the total electric field E is zero—there is no light. Remember—it is an opaque screen. But, this field is the sum of the fields of the light source E (source) and the field due to the atoms in the screen E (screen). This latter field is the sum of two parts, the field of the screen with slits E (slit-screen) and the field of the plugs E (plugs). So we can write the equation

$$E\ (source) + E\ (slit\text{-}screen) + E\ (plugs) = 0$$

The electric field on the shadow side with the source and plugged screen in place is zero. The fields of the source and screen are superimposed and canceled exactly. Now what is the field when we remove the plugs from the holes? It is

$$E\ (source) + E\ (slit\text{-}screen)$$

But we know by looking at the other equation that this must be

$$-E\ (plugs)$$

The field on the shadow side is the same size as if there were just oscillating charges in the plugs. The intensity of light depends on the square of the field so the minus sign does not matter.

So Huygens' principle, which says that the wavefront across the slit opening acts like a series of secondary sources, is right because it is exactly the opposite of what is there, that is, secondary sources all along the screen everywhere but at the opening.

It makes quite a difference to your view of what is happening when you realize that a principle works because it is completely wrong, as far as light is concerned. Light waves do not ever really change speed or direction.

If they appear to, it is always an illusion produced by a cooperative effect of many atoms. I found this interpretation quite shattering when I first read it. It is like hearing that black is white. I am sure that it opened my eyes to the possibility that other ideas I accepted might be exactly opposite to what I had been told.

If we go back now to the photon picture, where does that leave us? L.I. Schiff in his book on *Quantum Mechanics* addresses the problem:

> From the point of view of the particle picture [of light], we may then ask how it is that a stream of independent photons, each of which presumably can go through only one of the slits, can produce a diffraction pattern that appears only when both slits are open... In this question is implicit the assumption that the photon actually does go through a particular one of the two slits. [9]

The waves that produce the effect go right through the whole screen including the slits and secondary waves are produced by the atoms in the screen. It is difficult to see how a single incoming photon can produce the effect. It really must spread out over the whole screen and interact with all the atoms. The two-slit mystery gets much worse. But after all this trickery and illusion, perhaps the existence of photons is an illusion. Perhaps it is useful because it is exactly wrong. There are scientists who believe in a semiclassical quantum theory. They believe that light is a wave only and that particles of matter give rise to the peculiarity we label uncertainty. These semiclassical theory (SCT) people say that the reason photons can be successfully used to describe the emission and absorption of energy is because the matter does not behave classically. This is basically my position—I would say because microscopic energy conservation is impossible. Semiclassical theory has actually been successful in explaining the photoelectric effect although I cannot give the argument here. It is rather a shock again to learn that the photoelectric effect which is supposed to have proved that photons exist can be explained without any reference to them whatsoever. In SCT it is assumed that quantum mechanics describes the behavior of atoms and that light is adequately described as a wave. Most of the arguments about the need to have radiation quantized involve the assumption that, in microscopic processes, energy is conserved. This is, from my point of view, a weakness since I believe that microscopic energy conservation cannot be a fact because of the impossibility of isolating the system from the random influences of the rest of the universe.

It is very easy to confuse the statements "that Einstein's theory of the photoelectric effect proved the existence of photons" and "that scientists became convinced about the reality of photons by Einstein's arguments concerning the photoelectric effect." Semiclassical theory explains the photoelectric effect without any reference to the idea of photons or to the idea of microscopic energy conservation. Does this mean that we can dispense with photons? Not quite so fast! What about Bohr's relation for the frequency spectrum of hydrogen? His relation is

$$f = \frac{E_2 - E_1}{h}$$

If it is rewritten as

$$h \times f = E_2 - E_1$$

it becomes a statement of microscopic energy conservation. The energy of the photon emitted by the atom $h \times f$ is equal to the difference between the initial energy state of the atom E_2 and the final energy state of the atom E_1. Again, we find the two ideas coupled—photons and microscopic energy conservation. But, Bohr's relation too can be derived without any reference to either photons or energy conservation, using semiclassical theory. What you use is Schrödinger's equation for the atom and Maxwell's equations for the electromagnetic waves.

My idea that microscopic energy conservation is not true can actually be argued from Schrödinger's equation. Rather than speaking about the hydrogen atom I will refer to the linear harmonic oscillator. In a classical oscillator, like a pendulum bob swinging back and forth, the energy of the oscillator depends on the amplitude of the swing. If the swing is bigger, the energy is bigger. A classical oscillator can be stationary and have zero energy. A quantum oscillator cannot be stationary. A quantum oscillator of frequency f has, as its lowest energy, the energy

$$h \times \frac{f}{2}$$

This is called the zero-point energy of the oscillator because if a group of quantum oscillators could be cooled to a temperature of absolute zero, where all motion is supposed to cease, they would still each have this energy. In the Brownian motion picture of quantum mechanics the oscillators would still be in motion—Brownian motion is a perpetual motion. (Of course it is not a macroscopic perpetual motion.)

If you examined the probability distribution function for the quantum oscillator in its ground state you would find that the probability of the particle in the oscillator being at the equilibrium position, at the center of its oscillation, would be the highest and then it would taper off on both sides of the equilibrium position. If a classical oscillator had an energy of $h \times f/2$ there would be a limit to how far away from equilibrium the particle would get. The probability of the quantum particle being outside this classical limit, as determined by solving Schrödinger's equation for the harmonic oscillator, is not zero, even though it tapers off rapidly outside the classical limit. But, how can energy of position be larger than the total energy, which it must be if the particle is outside the classical limits of oscillation? Certainly, the energy of motion cannot be negative. The energy of the oscillator must in fact be greater than the average energy $h \times f/2$ whenever it is outside the classical limit. Many say that there is an uncertainty relation between energy and time that is similar to the one between position and velocity. They argue that the particle can have an energy larger than permitted by energy conservation, but only for a limited time. This sounds to me suspiciously like saying that, on the average, energy is conserved, but energy is not conserved microscopically. The microscopic system, the quantum oscillator, has an average energy of $h \times f/2$ but from time to time has more or less energy. Energy is not constant in a microsystem.

If we accept as a basic premise that, in reality, microscopic energy is not conserved then the picture, begun by Bohr and taken directly into quantum mechanics, that his frequency relation describes an electron jump is a lot of nonsense. The Bohr condition is a clear statement of energy conservation in a microsystem. You can't have it both ways. So I reject Bohr's interpretation. I reject quantum jumps, and I reject photons. This means I reject the particle picture of electromagnetic radiation.

Let me summarize all this. Although I reject a particle picture of radiation, I affirm a particle picture of matter. If an electron is really a particle, the probability amplitude for it in the stable excited states in an atom or an oscillator cannot be right. Recall that I said that each of these has nodes, places where the probability becomes zero. The probability amplitude is non-zero on either side of each node. So the particle, if it is a particle and cannot disappear and reappear like a Cheshire cat, cannot be in such a state. It can be in a ground state because that has no nodes. But, we know that the frequencies in the hydrogen spectrum are related to the average energies associated with the stable excited states as described by the Bohr frequency condition. How can this be reconciled with a view that the stable excited states are exactly those states where the electron cannot be?

Mathematically the wave function for any dynamic state of the quantum system can be described as a combination of the wave functions for the stable excited states. But, I would say that no pure stable excited state is possible. The electromagnetic radiation produced by an atom then will be related to the energies associated with the stable excited states exactly according to Bohr's relation, but the system cannot ever be in any of these states. It is a situation just like Huygens' principle—Bohr's relation is right because it is exactly wrong. Bohr said the particle can only be in one or other of the set of stable excited states that are proper solutions of Schrödinger's equation. I say these stable excited states are all improper in that they contain nodes which means that, unless the particle is an escape artist, it cannot exist in such a state.

I tried to simulate the Brownian-motion atom on the computer, you may remember, and found no excited stable states. In fact, my atom kept expanding. How do you prevent this? In terms of energy, you need to radiate some energy all the time. In equilibrium you should radiate just as much as is coming in from the rest of the universe to keep the Brownian motion going. And that must be what happens if there is such Brownian motion of the electron in the atom. It must be radiating all the time because it is being accelerated all the time. In the ground state it radiates a continuous spectrum. In any disturbed condition which you get if you give it extra energy, it radiates discrete frequencies, as given by the Bohr relation, as well as a continuous spectrum of frequencies due to the continuing Brownian motion.

The radiation from atoms even in the ground state could be exactly what is producing the Brownian motion in other atoms. And that brings me to the other cornerstone of the dual picture of radiation—Planck's blackbody radiation equation. Many believe that Planck's blackbody radiation proves the need for quantized energy states in atoms. It has been shown by Boyer and Theimer that Planck's equation could be derived instead by assuming a zero-point energy of $h \times f/2$. It is clear from what I say where this would come from. Theimer says:

> Some fascinating new ideas concerning the physical meaning of the quantum theory have been developed in a series of papers by Boyer and a related paper by Nelson. In Boyer's work the main new concept is the existence, at the absolute zero of temperature, of a classical fluctuating, electromagnetic background radiation which is, in some unknown fashion, equivalent to the ground state of the radiation field in quantum electrodynamics. Boyer demonstrates that incorporating this radiation background into classical statistical physics makes possible a classical derivation of Planck's blackbody spectrum. He also suggests that the universal background radiation might be the source of the random perturbations, postulated by Nelson, which transform continuous classical particle motion into an equivalent random-walk [Brownian] process.

He continues:

> What is the origin of the zero-point radiation? … The zero-point radiation is a self-consistent radiation field in dynamical equilibrium with all the electrically charged particles in the universe. These particles perform a complicated Brownian motion, in the spirit of Nelson's work, which is caused by random absorption and emission of the self-consistent zero-point radiation. And this radiation has such an energy density that there is no net time-averaged energy exchange between matter and radiation at the absolute zero of temperature. [10]

So the continuous radiation spectrum from atoms that I believe exists even in the ground state is not just hiding in the blackbody radiation—it is necessary in order to give it the distribution that it has. This makes Planck's notion of quantized energy transitions for oscillators as an explanation of blackbody radiation unnecessary.

In this chapter I have been looking at the great difficulty that I have encountered over the years with the dual, wave-particle picture of electromagnetic radiation. In my undergraduate education a wave picture was always used to explain the reflection, refraction, and diffraction of light. Young's double-slit experiment on the diffraction of light by a screen with two slits was offered as conclusive proof that light was a wave. You have seen from my quotations what a tangle various physicists get into when they try to understand the two-slit experiment in terms of the particle, or photon, picture of light. Most of these explanations refer to the photon passing from source to screen by way of one or other of the two slits.

But, the present wave view of the two-slit experiment—which many physicists are unaware of—is that the source waves pass right through both the screen and the slits. These source waves have superimposed on them waves from the atoms in the screen that are *forced* to vibrate in sympathy with the source waves passing through. The net result of all these waves, as they superimpose—or *interfere*—is a pattern of light and dark fringes. As it happens, there are just as *many* waves of light passing through a dark fringe as a light fringe, only at a dark fringe they are out of phase and cancel, at a bright fringe they are in phase and add.

It is important to notice that light does not appear to be diffracted unless there are a lot of sources present—the primary source and the secondary sources in the screen. Light always travels in straight lines from its source to the point of observation. It is an illusion that light goes from the source to a slit and then changes direction as it proceeds to land on a bright spot on the screen.

To me it is a contradiction to say that a single photon interacts with many atoms in the slit screen—especially when you say that a single photon, at least, is necessary to trigger a detector in the second screen. (This latter is held to be true whether the detector is an atom of a photographic plate or a photoelectric detector.)

You probably have heard it said that light travels in straight lines unless it passes through a narrow opening in which case it is bent or changes direction. This bending is an illusion provided by the presence of matter in the electromagnetic field of the primary source of the waves.

Exactly the same situation holds for refraction. You probably have heard that light travels at speed *c* in a vacuum but, in a medium, it travels at a lower speed. This "explains" how it changes direction—is bent or refracted—as it enters a glass prism. But, this is also an illusion. The superposition of the primary source waves and the waves from the atoms in the glass give the illusion of a wave slowing down as it enters the glass and changing direction. When a prism produces a spectrum of light, it is foolish to imagine a red photon being emitted from the source, travelling at speed *c* until it reaches the surface of the prism then slowing down and changing direction in the glass and finally emerging, speeding up, changing direction again and landing on a spot where the red of the spectrum is. The photon picture is absolutely inconsistent with the wave picture.

When I was young, I often asked my Mother how a magician had done a certain trick. My Mother's stock answer was "It's all done by mirrors." When you have an object, say a candle, in front of a mirror there is an illusion created that there is a second candle, the image, behind the mirror. If the object candle is hidden from your view, you might believe that the image candle was a real object. No doubt, many magic illusions do involve the use of mirrors. But, the explanation you usually get about the reflection of light by a mirror is really an illusion. Light from the candle we say goes up to the mirror and is bounced off—reflected—to your eye. It then seems—if we assume light always travels in straight lines—to be coming from behind the mirror, from the image. But, the bouncing is an illusion. Light from the object candle passes right through the mirror. In the mirror, secondary sources, excited by the incoming light, radiate what comes out in front of the mirror, superimposing to seem like waves from the image. The light from the secondary sources that goes behind the mirror cancels the waves from the primary source and there is the illusion of darkness. But, remember—there are many light waves behind the mirror.

In this book, I have been looking for explanations of physical laws. I cannot be satisfied with answers that tell me "It's all done by mirrors." Wave-particle duality of radiation is such an answer.

Summary

1. Semiclassical theory treats electromagnetic radiation as a wave, and it treats particles of matter as described by the uncertainty principle—meaning to most that particles have a wave nature. The photoelectric effect and Bohr's frequency relation can be explained by semiclassical theory. I accept a wave theory of radiation and a particle theory of matter. For me, the wave nature of a particle is due to the random fluctuations in its motion.

2. The energy distribution in blackbody radiation can be explained on the assumption that atoms radiate even in the ground state, rather than that there are quantized excited states. Quantization of energy in radiation is, I believe, not necessary to the explanation of any phenomenon.

CHAPTER 12

Trapped Inside

In this century, two very startling and revolutionary changes took place in our thinking about the universe. One of these changes is the idea that at the microscopic level there is inherent unpredictability in the behavior of particles. This unpredictability is negligible with macroscopic objects so that for a long time it was not evident that the uncertainties were of any importance. Newton's deterministic mechanics was perfectly adequate to describe the behavior of baseballs and planets. The second revolutionary change was called the theory of relativity and was devised by Albert Einstein in 1905. All Einstein did in his theory of relativity was to accept, as true, Newton's principle of relativity for the interaction between charged particles. I have said that Newton's laws of motion, his mechanics, do not properly describe the interaction between the fundamental charged particles except in the special case where the interacting particles are released from rest and then interact. Newton's laws can be used for the electrostatic interaction. But, the fact that the interaction is not instantaneous means that any mechanics that says that at every instant the forces of the interacting particles on each other are equal and oppositely directed, as Newton's does, cannot possibly be right.

Einstein did not begin directly by trying to develop new laws of motion but instead started to examine the situation by using the principle of relativity as devised by Newton. This principle comes from Newton's first law of motion:

> Law I: Every body perseveres in its state of rest or uniform motion in a straight line unless change in that state is compelled by impressed forces.

The important piece of information in the law is that the natural state of a body is either rest or uniform motion. These two states must be equally natural. It was discovered that only certain frames of reference provided an environment in which an uninfluenced body could stay at rest. These were called inertial frames of reference. A frame moving at uniform speed relative to an inertial frame must also be an inertial frame, or Newton's first law would not be true. Newton stated the principle of relativity this way:

> The motions of bodies included in a given space are the same among themselves whether that space is at rest or moves uniformly forward in a straight line.

In this statement Newton claimed that it is a fact that the interaction between two bodies is the same in all inertial frames. Of course, Newton thought of the interactions as being the kind he described in his other two laws of motion: instantaneous, and either attractions or repulsions along the line joining the interacting bodies. Einstein stated his principle of relativity by saying that the laws of Physics are invariant from one inertial frame of reference to another. But, to work out the theory, he basically used only one set of laws—Maxwell's laws of electromagnetism. And from these he used only the piece of information that the interaction between charged particles is not instantaneous but retarded. The interaction is straight-line with speed *c* and independent of the motion of the source particle. Einstein said that, in all inertial frames of reference, the behavior of interacting charges is the same.

The next step in the development is to try to relate observations of a single interaction as made in two different inertial frames. It is easy to appreciate that the position coordinates of objects relative to two different frames will be different. What was not as obvious is that the times of the events as measured in the different frames will be different. Suppose that we are observing two particles; I will speak first of the description of the interaction in frame *1*. To describe the position of an object in a frame, we specify three numbers called coordinates. The frame of reference can be thought of as three rods stuck together so that each is at right angles to the other two, the way the edges of a box come together at a corner. The three rods are called coordinate axes and labelled by the names: *x*-axis, *y*-axis, and *z*-axis. To specify the position of an object relative to this frame, we give the three distances of a trip you take from the point where the rods meet, which we call the origin of coordinates, up to the object. We are describing a trip with three legs, all at right angles to each other. You travel first along the *x*-axis, then in the *x–y* plane parallel to the *y*-axis, then out of the plane in a direction parallel to the *z*-axis. The three distances are written as (x, y, z) and they describe the position of the object. We must also write the time at which the particle has this position because the times for the two interacting particles will be different; remember the interaction is retarded. So, in frame *1*, particle *1* is at (x_1, y_1, z_1) at time t_1 and is being influenced by particle *2* at (x_2, y_2, z_2) at time t_2. The time t_2 is earlier than t_1 by the amount of time the interaction takes to travel from (x_2, y_2, z_2) to (x_1, y_1, z_1) at speed *c*. In terms of the coordinates—which by the way, are called Cartesian coordinates after Descartes—the distance *d* between the two particles is

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2}$$

You may know this fact about Cartesian geometry; it is nothing magic. It all comes from Pythagoras' theorem—Remember, the square on the hypotenuse is equal to the sum of the squares on the other two sides of a right-angled triangle. The relationship between the two instants of time is thus

$$t_1 - t_2 = \frac{d}{c}$$

The difference in time is the time required for the interaction to travel the distance *d* at speed *c*. Sometimes the coordinates of the particles are written to include the time as a coordinate. We say that particle *1* being at (x_1, y_1, z_1) at time t_1 is an event described by the coordinates (x_1, y_1, z_1, t_1). We can call it event *1*. The event *2* is described by (x_2, y_2, z_2, t_2); this means that particle *2* is at position (x_2, y_2, z_2) at time t_2. In frame *1*, event *2* is influencing event *1*; we say that there is a causal connection between event *1* and event *2*. (The talk gets quite fancy.)

Now suppose we look at exactly the same two events from frame *2*. We will call their coordinates:

$$(x'_1, y'_1, z'_1, t'_1) \ and \ (x'_2, y'_2, z'_2, t'_2)$$

The two events must still be causally connected. This means that

$$t'_1 - t'_2 = \frac{d'}{c}$$

where

$$d' = \sqrt{(x_1' - x_2')^2 + (y_1' - y_2')^2 + (z_1' - z_2')^2}$$

The two basic premises of Einstein's relativity are: first, that a particle moving at constant velocity in one inertial frame of reference, and thus judged to be uninfluenced, will be observed as moving at constant velocity in another; and second: that two events judged as causally connected in one frame will be so judged in another. Nothing whatsoever about either of these two premises is weird. Where do we get the idea that Einstein's relativity is weird? We get it when we try to find the mathematical relationship between the coordinates of an event in one frame, and the coordinates of the same event in another. We find that this relationship, which is called the Lorentz transformation, says that the time *t'* of an event in frame 2 depends not only on the time *t* in frame *1* but also the position *(x, y, z)* of the event in frame *1*. Events that happen at the same time in frame *1* are not assigned the same time in frame *2*, unless they also happen at the same place. This means that we may judge events as simultaneous in frame *1* and find that they are not simultaneous in frame *2*. This leads us to say that time is not absolute; it depends on your frame of reference. This is in conflict with the Newtonian point of view. Here is Newton's statement in the *Principia*:

> I. Absolute, true, and mathematical time, of itself and from its own nature, flows equably without relation to anything external, and by another name is called duration; relative, apparent, and common time, is some sensible and external (whether accurate or unequable) measure of duration.

He went on to say this about space:

> II. Absolute space, in its own nature, without relation to anything external, remains always similar and immovable. Relative space is some movable dimension or measure of the absolute space.

You can imagine, if time in frame *2* depends on position as well as time in frame *1*, that position in frame *2* depends on time in frame *1* as well as position. This means that the length of an object depends on the frame. If it is at rest in one frame and has a certain length, in the second frame it will have a different length; it will be measured to be contracted. If two events in frame

1 have a time interval between them and happen at the same place—think of a pendulum bob swinging out and back—the time interval, as measured in frame *2*, will not be the same. It will be longer—we say that the time is dilated. If I call the pendulum swinging in frame *1* a clock, its tick, as judged in frame *2*, will be longer. It appears to be running slow. You have often heard that clocks in moving frames run slow compared to clocks at rest. And what is more, all these effects are relative. If in frame *1* you made measurements on a clock or a distance (a ruler) held fixed in frame *2*, you would say that the clock was running slow and that the ruler was contracted.

Newton's mechanics was based on the idea that the measurement of time and space (distance) was independent of the frame as long as it was inertial. Maxwell used the same notion:

> We shall find it more conducive to scientific progress to recognise, with Newton, the ideas of time and space as distinct, at least in thought, from that of the material system whose relations these ideas serve to coordinate. [1]

How did we get to the point of having to mix time and space in a sort of four-dimensional world where we must give (x, y, z, t) instead of (x, y, z) for every event? We got to this point, I believe, because the things we are using to make measurements involve what we are trying to measure. We are trapped inside the universe and cannot stand outside with an independent clock and a ruler and make measurements. Schlegel says this in his book *Completeness in Science*:

> Physically, we come to strong and hitherto unknown limitations on our knowledge of nature when the object of investigation and physical entities by which we study the object become the same. [2]

But, what are we using for a clock or a ruler? Larmor notes this in the appendix to Maxwell's book *Matter and Motion*:

> It is impossible to ignore the rays of light as messengers of direction and duration from all parts of the visible universe. [3]

Rulers must be straight. We use light—or electric interaction—to define straight lines. How do we judge whether or not light—or electric interaction—travels in a straight line? That is the definition of a straight line. That is how we tell if something is straight; by sighting along it or shining a laser along it; light is the messenger of direction. So it is not surprising that electric interaction travels in straight lines. What about the speed of electric interaction—light? Why is it the same in two frames of reference?

Imagine an experiment in one frame to measure the speed of light by timing light as it goes along a ruler from one end to a mirror at the other and back again. I will call this the "speed" ruler. To time it we would need a clock. As a clock let us use another ruler with a mirror at each end. Start a beam of light at one end and say that one tick of the clock is the time it takes the light to go down to the far mirror and back. (Remember a tick must be a motion that comes back to the same place.) Perhaps you can see that if the two rulers are the same length that it takes exactly one tick of the clock for the light to go down and back on the speed ruler. How could it be otherwise, since they are really identical instruments: one for the speed of light experiment, and the second a clock for the measurement of time? With this experimental set up you can easily see that no matter what inertial frame you are in, you get the same value for the speed of light. But is it *really* the same in all frames? Again, we are trapped. We could never tell whether it was or not.

But, you may say, why not use a different kind of clock? There are no different kinds of clocks. All clocks are basically electromagnetic, with the possible exception of radioactive decay clocks.

So the peculiar results of Einstein's relativity stem from the fact that we assume that, in all inertial frames of reference, light—or electric interaction—travels in straight lines at speed *c*. We come to recognize that there is no independent clock—or ruler—or else we could tell whether light really travelled in straight lines at constant speed or not. We admit that we are trapped inside with instruments that depend on the thing that we are measuring. We assume light travels at a uniform speed but how do we know? This is Mach on the subject, some time before Einstein formulated his special relativity:

> ... time is an abstraction, at which we arrive by means of the changes of things... A motion may, with respect to another motion, be uniform. But, the question whether a motion is *in itself* uniform, is senseless. [4]

As he points out, we judge that light travels at a uniform speed by comparing it with something that we believe travels at a uniform speed—with light of course. Sometimes we say light can never overtake light; it all travels at the same speed. The electric interaction is simple as far as these two facets of it are concerned because they define our universe. They are the basis of all our knowledge, and the basis cannot be independently checked.

It is generally accepted that there is no such thing as time apart from the ticking of clocks and clocks are only judged as good time keepers relative to each other. Feynman says:

> ... "best" clocks are those which we have reason to believe are accurate because they agree with each other. [5]

I have tried to explain why the speed of electromagnetic interaction is the same in all inertial frames, because that is the really peculiar thing about Einstein's relativity. If you accept the idea of laws of nature you say—How reasonable it is that a law which says the speed of light—electric interaction—is constant, is the same—invariant—in all inertial frames! That is the nature of nature. But if you are, like me, unable to accept the idea of general laws you must ask for an explanation of this fact. Otherwise, it seems like a design feature of the universe. I have not tried to explain in detail about time dilation because it is not central. The Berkeley text on relativity says this:

> There is nothing mysterious about clocks. If there is anything mysterious about special relativity, it is the constancy of the speed of light. Granted that, everything else follows directly and fairly simply. [6]

I cannot just grant "the constancy of the speed of light." I must explain it to myself. Then I can see why the speed is invariant from one inertial frame to another. Here is Feuer on the subject:

> The logical content of the principle of relativity was indeed an absolutist one, a statement of a principle of invariance. Given the requirement, however, of the conformity of laws of nature to the Lorentz transformation, and the principle of the constancy of the velocity of light, there followed the remarkable consequences of the relativized status of time and spatial distances... The startling relativist consequence

> rather than the absolutist postulate was what affiliated Einstein's theory emotionally with the relativist school. [7]

It is the "absolutist postulate" that to me must be explained, not all the relativistic consequences. They are easily explained once the invariance of the speed of light—electric interaction—is explained.

So we end up with two facts—first, that as far as fundamental particles alone are concerned one inertial frame is equivalent to another. Second, when two particles interact we just assume that the interaction travels in straight lines at constant—or uniform—speed and take the speed to be, by definition, the same in all inertial frames. In this way, we get distance and time measurements all interwoven with rather bizarre consequences like time dilation and length contraction.

But, Einstein's principle of invariance of the laws of physics from one inertial frame to another is, in itself, a general law. He says all laws are invariant. In order for me to show that it is not a general law but really a specific fact, either about electromagnetic interaction or about the universe, I must be sure that there are no other general laws to which it has been found to apply. It does apply to the wave-particle duality of matter. De Broglie used relativity to derive his wavelength of a particle of matter. I have argued that the uncertainty which gives rise to the appearance of a dual nature of matter can be attributed to a fluctuating influence of the rest of the universe on the particle. I indicated that this produced a Brownian type of motion, in which the product of the uncertainties in position and velocity were characterized by a constant h, Planck's constant.

Einstein's principle of invariance would say that this law is the same from one inertial frame to another and that the constant h would also be the same. This to me must be a fact about the universe—that the inertial effect on a particle is the same in all inertial frames, and that the fluctuating effect is also the same. If it were not a fact, we would be able to distinguish one inertial frame from another on the basis of a quantum mechanical effect. If we assume that the fluctuations are due to the continuous radiation of atoms in their ground states, the Planck blackbody radiation graph can be derived from the fact that the radiation environment is the same from one inertial frame to another. It is, as they say, "Lorentz invariant." This means that the fluctuations are the same in all inertial frames. So the real information content of the blackbody radiation distribution curve is that atoms radiate in the ground state—at absolute zero—and this radiation is the same from one inertial frame to another. This explains why radioactive clocks agree with electromagnetic clocks.

Einstein believed that the laws of physics were invariant from one inertial reference frame to another. Newton's mechanics was not invariant so Einstein discarded it and substituted his own mechanics—relativistic mechanics. To quote myself:

> Underlying the principle of relativity is the idea that what happens in a physical situation [say two particles interacting] should not depend on the frame of reference in which the happening is described. This means that the same laws that analyze the behavior of bodies interacting among themselves relative to one inertial frame can be used to analyze their behavior relative to any other inertial frame. For the purpose of analyzing motions one inertial frame is as suitable as another; that is, there is no preferred frame. [8]

What Einstein was doing in producing relativistic mechanics was designing a set of generalities that could be used to analyze interactions in different inertial frames and which would themselves remain the same. One set of laws would be used for all frames. So he set about to find this set of laws. Again quoting myself:

> Newton's laws of mechanics are not invariant under the Lorentz transformations. This is most obvious from the fact that the acceleration of an object is not invariant under these transformations. Acceleration [remember $F = m \times a$] must certainly lose the position on center stage that it had in Newtonian mechanics. Force, mass, and momentum too are quantities that are intimately linked with Newton's laws and, as understood by Newton, cannot be of service. But, Newton's laws had certain features which would be good to perpetuate if possible. For one thing, the ideas of force, mass, momentum and later energy have been built up as strong intuitive notions over the centuries of thinking in Newtonian terms. Another and absolutely invaluable

> feature is the fact that Newton's laws enabled us to treat a system of interacting bodies as a single entity whose interactions with other such systems could be calculated. In this way we could ignore, if we wanted to, any internal complexities of a system. [9]

This analysis is too involved mathematically to present here, but two of the results are simple enough. We redefine mass so that it is no longer a constant independent of the velocity of a body but is a quantity which increases as velocity increases, approaching infinity as the particle's speed approaches the speed of light. This *explains* for some people why things cannot travel faster than light. I prefer to think that a charged particle accelerates in response to the presence of another charged particle and that it could not be accelerated to a greater speed than the speed at which the electric action between them travels. How could it be induced to go any faster?

In trying, to obtain conservation laws for relativistic mechanics Einstein found that the laws of conservation of momentum and energy must go as a pair. In Newton's mechanics they were separate. Also, the quantity which would be called energy by Einstein is given by the famous formula

$$E = mc^2$$

This is sometimes construed as saying that mass can be converted into energy. But, it is no different from the expression for kinetic energy in Newton's mechanics

$$E = \tfrac{1}{2}mv^2$$

In fact, at low speeds Einstein's formula becomes Newton's formula but with an additional term which is called the rest energy of the particle.

The rest energy is always there since we cannot destroy electrons or protons; so it is not much use. In Einstein's mechanics, the total mass of two interacting particles can be different when they are close from what it is when they are far apart. This sometimes is construed as changing energy to mass. It takes energy to bring them close if they repel, and the mass will be greater together than apart. If they were held together as protons are in the nucleus by an attraction at short range then energy would be available if the attraction were broken. This is what happens in nuclear fission. A neutron entering a uranium nucleus breaks it into pieces which repel each other electromagnetically, and energy is released. There is, in fact, a mass difference between the nucleus and the final pieces that agrees with Einstein's formula ($E=mc^2$) but the energy released does not require relativity to understand. Einstein's mechanics applies equally well to any chemical reaction. In a chemical reaction the amount of energy released in each interaction represents a very small mass equivalent. So we do not notice the difference between the mass before and after the reaction. In chemistry, we use the law of conservation of mass, but it is not precisely correct. The need to use relativistic mechanics is more evident in nuclear reactions. Perhaps that is why we associate Einstein more with nuclear energy than with chemical energy.

There is a law in the list I gave from Constant's book on the *Fundamental Laws of Physics* that I have been ignoring—besides the law of gravitation—that is the Pauli exclusion principle. The reason I have left it until now is that I needed to have looked at both Schrödinger wave mechanics—quantum mechanics—and the theory of special relativity. Here is a summary of the situation as described in a book *Fundamentals of Quantum Mechanics* by Persico:

> The necessity for this refinement [to use relativistic mechanics rather than classical mechanics for the electron in a hydrogen atom] becomes evident when we consider that the results of Schrödinger wave mechanics are not invariant under a Lorentz transformation.
>
> Another fact which was partly neglected… is the existence of an intrinsic angular momentum (*spin*) and a magnetic moment both in the electron and in the proton… At first, an attempt was made to deal separately with these two causes of inexactitude of quantum mechanics… Pauli succeeded in introducing the spin hypothesis into (nonrelativistic) quantum mechanics, constructing a remarkable theory… But the most satisfactory solution of both these questions was found by Dirac who showed that the two modifications—the one concerning relativity and the one concerning the spinning electron—are conceptually reduced to one and the same modification… When wave mechanics is given a suitable relativistic form, there fol-

> lows the existence of the spin and of the magnetic moment, with their correct values and rules... without the necessity of introducing them by an *ad hoc* hypothesis. From the Dirac theory we may then obtain the Pauli theory as a first nonrelativistic approximation. [10]

From my point of view, the Schrödinger equation is a good representation for the stochastic atom in which the electron and proton are charged particles subject to their mutual electromagnetic interaction and a Brownian motion due to the influence of the rest of the universe. Dirac was able to use relativity, which remember incorporates the finite speed of the interaction between the electron and proton, and produce from Schrödinger's equation the idea of a spinning electron—and proton—with a magnetic moment that he could calculate. Where did it come from? It needs explanation as far as I am concerned. A magnetic moment comes when a charge spins or moves around in a circle. Certainly in the atom the electron is moving about. Its motion is complex, but it can be resolved into a number of basic motions. That is what I believe happens. There is one component that corresponds to a spinning motion, and one corresponding to an orbiting motion as well as the random motion. If the interaction between the electron and proton were instantaneous, there would be no velocity dependent part to the interaction, but it is not instantaneous, so that the velocity dependent part is apparent and is identified as a magnetic interaction. We get spin-orbit interaction and so on. The proton also is not standing still; it is jiggling about and creates a magnetic effect. It has a spin.

The Pauli exclusion principle is used most often to try to understand atoms that are more complex than hydrogen. In a many-electron atom, the electrons repel each other in addition to being attracted to the positive nucleus. We try to understand their behavior in terms of the solutions of the Schrödinger equation for the hydrogen atom. As I said, the Schrödinger equation has stable—non time-dependent—solutions for the ground state and for a series of excited states. Each of these solutions has a set of integers associated with it. These integers are called quantum numbers. When there are a number of electrons in an atom, we say that each one is associated with a hydrogen stable state. We assign quantum numbers to the electrons and Pauli's exclusion principle says that no two electrons can have the same set of quantum numbers. This means that each electron is described by one of the stable excited state wave functions for the hydrogen atom. Here is Feynman:

> … in a situation where there are many electrons, it turns out that they try to keep away from each other. If one electron is occupying a certain space, then another does not occupy the same space. More precisely, there are two spin cases, so that two can sit on top of each other, one spinning one way and one the other way. But after that we cannot put any more there. We have to put others in another place, and this is the real reason that matter has strength. [11]

For complex atoms, the probability functions for electrons are built up from hydrogen-like probability functions, and the reason for insisting that only one of a kind must be used is said to be that electrons are all identical. Since, in fact, you cannot keep track of any one electron in order to say it has such and such a probability distribution—with a given set of quantum numbers—it is really just a way of describing the behavior of all electrons present. From my point of view, there cannot be a precise one-to-one correspondence between excited state wave functions and electrons because of the nodes. It is just that, as a group, the set of wave functions represents the set of electrons. Certainly, the Pauli principle has to do with electrons being identical. This fact—that all electrons are identical should be explained. Hanson says this:

> It might be objected: No two things are ever perfectly identical. Identical twins can be remarkably similar, but they can always be distinguished ultimately. Two postage stamps, fresh from the same block, will be quite different in detail under a microscope. The finer the scale of observation, the more discrepancies will be found. What is the physicist claiming? That two particles of the same kind are *completely* alike, with no possible difference between them whatever? Even were they created perfectly identical, could they remain thus? They 'collide' with their neighbours millions of times a second. Would they not become deformed with all this pounding? [12]

I have already suggested that a fundamental particle may constantly be being renewed. That is why they do not become "deformed with all this pounding."

Dirac made the Schrödinger theory relativistic but in the 1950's work was done to show how the quantization of radiation—which I reject—causes certain deviations from Dirac's theory. The theory is called quantum electrodynamics (Q.E.D.). In an article on *The Concept of the Photon* in 1972 Scully and Sargent indicate that Q.E.D. is necessary to explain certain things:

> The quantized field is fundamentally required for accurate description of certain processes involving fluctuations in the electromagnetic field: for example, spontaneous emission, the Lamb shift, the anomalous magnetic moment of the electron, and certain aspects of electromagnetic radiation... Perhaps the greatest triumph of the photon concept to the explanation of the Lamb shift between, for example, the $2S_{1/2}$ and $2P_{1/2}$ levels in a hydrogenic atom. [13]

According to the relativistic Dirac theory these hydrogen levels have the same energy, in contradiction of the experimentally observed frequency splitting of 1057.8 MHz. We can understand the shift intuitively by picturing the electron forced to fluctuate about its "Dirac" position because of the fluctuating vacuum field. The situation is clearly complicated and I do not pretend to be able to disentangle it. But, there does seem to be room for ambiguity. Quantum electrodynamics is very difficult to understand and is certainly not part of a low-level course in Physics. Some Physicists would swear by it; most do not understand it.

Must our explanation be quite so esoteric?

Summary

1. In an inertial frame, light—electromagnetic interaction—travels in straight lines by definition; light travels at a constant speed by definition. These define distance and time in any inertial frame.
2. The fluctuating effect of the rest of the universe on a particle of matter is the same in all inertial frames.

CHAPTER 13

Shedding Light on Inverse-Square Laws

The peculiar results of the theory of special relativity arise, I believe, because the clocks and rulers that we have to use for making measurements are themselves composed of the very thing we are measuring. There is no possibility of obtaining instruments that are independent and there is no such thing as absolute time that is independent of the clocks, or absolute space that is independent of matter. We have somehow been led to believe that we can stand outside the universe and record how it behaves, but we are actually trapped inside. All that we know about the universe and its components is gathered from inside. We have developed what must be admitted to be local physics—it is universal only insofar as local conditions elsewhere in the universe are similar to those in our own locality. Because the spectra from stars are similar to those obtained from atoms on earth, we believe that this is a reasonable assumption. Most physicists assume that there are universal laws which hold everywhere in the universe, but according to my view, this is an illusion. I would say that the same particles are elsewhere, and the environment is similar elsewhere. When we observe the spectra of distant stars, they are generally shifted toward the red end of the spectrum. This is usually explained as a Doppler shift due to their receding motion, and we conclude that our universe is expanding. But, it is possible that the value of Planck's constant h is not the same out there as it is in our locality. Perhaps the universe is not expanding as rapidly as scientists think. We do assume that the same kind of law holds out there and this can be explained by saying that conditions out there are similar, if not exactly the same. So our explanations of our local conditions have universal usefulness just as if there were universal laws.

We have been very successful in amassing information about our universe. Many of the pieces of information have been in the form of mathematical formulas and this mathematical form has given most scientists confidence that they were true. If there were a design in the universe, they say to themselves, it would be in terms of universal laws and the laws, if made rationally, would be mathematical. I have been arguing that the appearance of having general universal laws is an illusion which stems from the fact that the universe is composed of three fundamental particles: electrons, protons, and neutrons. A question remains: If there were no detectable design, why should the descriptions of the nature of electric interaction be mathematically simple? One principal example of a mathematically simple description is that the electric field of a stationary charge—electron or proton—is an inverse-square field. This means that the size of the field, at twice the distance from the charge, is only one-quarter as large—at ten times the distance, it is only one-hundredth as much. Why this simple relationship? What is the explanation if it is not design? And there are other inverse-square laws. Hanson says this in his book *Patterns of Discovery*:

> The great unifications of Galileo, Kepler, Newton, Maxwell, Einstein, Bohr, Schrödinger and Heisenberg were pre-eminently discoveries of terse formulae from which explanations of diverse phenomena could be generated as a matter of course; they were not discoveries of undetected regularities. It is this which now drives theorists to search for the root of all of our inverse square laws, dynamical, optical, electrical, and which spurs them on towards a formalism in quantum physics which will not be quite so productive of procedures which are, mathematically, quite ad hoc. [1]

I have already indicated how the mathematically *ad hoc* procedures of quantum mechanics might be explained in terms of a Brownian motion of the particles produced by the rest of the Universe. I have suggested a modification in choosing what stationary states would be allowed if we believed that electrons are really particles subject to random influences from the rest of the universe.

In this chapter, I particularly want to look at inverse-square laws. The three referred to by Hanson are "dynamical, optical, electrical." The dynamical one is the law of universal gravitation which was proposed—or discovered—by Newton. The optical one is the law of illumination. The electrical one is the one I mentioned before about the electric field of a static charge. This last law is called Coulomb's law.

I have called this chapter *Shedding Light On Inverse-Square Laws* because I believe that the key is the law of illumination. There is really no mystery to the law of illumination which is that the intensity of light from a point source decreases inversely as the square of the distance from the source. You can explain it by assuming that light travels straight out in all directions from the point source and is not lost as it goes—unless you block it. If you hold a piece of paper at a distance of one meter from the light source perpendicular to the path of the light, then at two meters the shadow of the piece of paper would cover four pieces of paper the same size. If you take the paper blocking the light away, you can see that the intensity of the light at two meters is only one-quarter what it would be at one meter. The same amount of light must spread out over an area four times as big. The electric inverse-square could be explained in a similar way. Here is Feynman:

> That the field [electric field of a static charge] varies inversely as the square of the distance seems, for some people, to be "only natural," because "that's the way things spread out!" Take a light source with light streaming out: the amount of light that passes through a surface cut out by a cone with its apex at the source is the same no matter at what radius the surface is placed... The amount of light per unit area the intensity must vary inversely as the area cut by the cone, i.e., inversely as the square of the distance from the source... If we had a "model" of the electric field in which the electric field vector represented the direction and speed say the current of some kind of little "bullets" which were flying out, and if our model required that these bullets were conserved, that none could ever disappear once it was shot out of a charge, then we might say that we can "see" that the inverse square law is necessary... No one has succeeded in making these "bullets" do anything else but produce this one law. After that, they produce nothing but errors. That is why today we prefer to represent the electromagnetic field purely abstractly. [2]

I believe Feynman is harsh on the "bullet" model. The model was suggested by Page in his book *Introduction to Electrodynamics* published in 1922. In a later edition with Adams they say:

> The line of force [from an electric charge]... has exactly the configuration of a stream of water issuing from a nozzle kept pointed to the right and caused to oscillate up and down. The picture is not merely approximately correct, but is an exact representation of an electromagnetic wave. In fact the entire group of Maxwell's field equations... has been shown to be merely the kinematical equation of motion of the lines of force of the field as represented here. [3]

This model was formulated more precisely in 1960 by Lowry in an article in the *Physical Review*. In it the charged particle is visualized as a sphere from which emerge streams of bullets moving straight out in all directions at speed *c*. Lowry emphasizes that this is only a model, not to be taken literally—the bullets to him only trace the geometrical structure of the field —they are my messengers. There are two kinds of bullets: positive and negative corresponding to the sign of the source charge. The acceleration of a second charged particle, at rest relative to the first, is proportional to the number of bullets intercepted by it per second. The acceleration is along the line of travel of the bullets. We assume that the particle has a finite cross section for intercepting bullets. So far just like Feynman. But there is more!

A particle moving in a stream of bullets *sees* as instantaneous those bullets intersecting a plane which passes through what, in relativity, is called its world line at the moment of observation and has an orientation conjugate to the particle's present velocity. These are the bullets which are simultaneous in the frame in which the receiving particle is at rest. This model is shown by Lowry to give the complete result of classical electromagnetism. It produces Maxwell's laws, not just Coulomb's law. Lowry shows in particular that electromagnetic radiation can be understood simply as the flux of bullets from an oscillating charge. Not only does this simple model explain Coulomb's inverse-square law, but it explains, in a unified way, all of electromagnetic interaction. From my point of view, such an explanation is absolutely essential. It shows that nothing more is being emitted by a particle that is radiating electromagnetic waves than one that is just sitting at rest. For photon lovers this poses a major problem but, since I have already exorcised photons from my world view, I find no difficulty.

But, I am avoiding the third inverse-square law—the law of gravitation. It must be explained too. Are there other kinds of bullets than electrical bullets? Why have I been just ignoring gravity completely? The reason I have done this is that it could be explained as essentially electromagnetic in origin if we adopt what I will call the shadow theory of gravity. You know we can cut down illumination by placing a slightly opaque object between the source of light and the place where the illumination is being observed.

Suppose we had a situation where, instead of light spreading out in all directions from a point source, we had light coming in from all directions to a small spherical detector. If a piece of paper were held perpendicular to the light at a distance one meter from the detector, the illumination on the detector would be decreased on the side facing the piece of paper. If the same piece of paper were held at a distance of two meters, its shadow would be in the same place but this time it would only cut down one-quarter as much on the incoming light. The shadow theory of gravity is that nearby massive objects absorb some of the incoming flux of bullets from the universe. The balanced flux is what gives an object its inertia and so the object will move to maintain a balanced flux. This means it accelerates towards the object causing the shadow. The size of the acceleration will be inversely proportional to the distance squared from the shadowing object. This shadow theory of gravity is very old. Feynman has something to say about it:

> Many mechanisms for gravitation have been suggested. It is interesting to consider one of these, which many people have thought of from time to time. At first, one is quite excited and happy when he "discovers" it, but he soon finds that it is not correct. It was first discovered about 1750. Suppose there were many particles [bullets] moving in space at a very high speed in all directions and being only slightly absorbed in going through matter. When they are absorbed, they give an impulse to the earth. However, since there are as many going one way as another, the impulses all balance. But, when the sun is nearby, the particles coming towards the earth through the sun are partially absorbed, so fewer of them are coming from the sun than are coming from the other side. Therefore, the earth feels a net impulse toward the sun and it does not take one long to see that it is inversely as the square of the distance... What

> is wrong with this machinery? It involves some new consequences which are not true. This particular idea has the following trouble: the earth, in moving around the sun, would impinge on more particles which are coming from its forward side than from the hind side (when you run in the rain, the rain in your face is stronger than on the back of your head!) Therefore, there would be more impulse given the earth from the front, and the earth would feel a resistance to motion and would be slowing up in its orbit... so this mechanism does not work. No machinery has ever been invented that "explains" gravity without also predicting some other phenomenon that does not exist. [4]

It is part of my model that the universe does affect any object and that this effect is natural—essential to survival—even at rest in an inertial frame. It is an identical effect when the object is moving at constant velocity. But not when it accelerates. The flux of bullets is not like rain.

The fact that the gravitational effect of a nearby object is related to its inertial mass is the basis of Einstein's theory of gravity—his theory of general relativity. He noted that all objects in a gravitational field exhibit the same acceleration. An artificial gravity could be obtained in a non-inertial frame of reference that is accelerating with respect to an inertial frame. All objects uninfluenced in such a frame would exhibit the same acceleration. This is just what happens in a gravitational field—all objects no matter what their mass have the same acceleration due to the gravity. Remember the old experiment with the guinea—English coin—and the feather in a glass tube. When the tube was evacuated, the coin and the feather fell at exactly the same rate. So the artificial gravity in an accelerated frame of reference would be just like real gravity. This is Einstein's principle of equivalence: that gravity is equivalent to an acceleration. One particular non-inertial frame is a spinning frame—the frame is accelerated toward the axis of spin. In the frame, objects are accelerated outward as if there were a force on them causing them to flee from the center. We call this a centrifugal force. There is no cause of this force as there are no nearby objects. Heisenberg says this:

> Since the centrifugal forces had to be considered as due to physical properties of empty space, Einstein turned to the hypothesis that the gravitational forces are due to the prop-

> erties of empty space… If therefore gravitation is connected with properties of space, these properties of space must be caused or influenced [modified] by the masses. [5]

The inertial mass of an object which resists acceleration is, I believe, the result of the effect of the rest of the universe on that object. Bondi says that Einstein believed Mach's idea that it was the rest of the universe that produced the environment that we call an inertial environment. This is called Mach's principle and as you see I believe it too. Newton claimed that accelerations were absolute. He said that you can tell that a bucket of water is spinning because the surface of the water takes on a curved dish shape. Mach said, "fix Newton's bucket and rotate the heaven of fixed stars" the result would be the same dish shape of the water surface. Of course, we cannot perform this experiment. Bondi says:

> Mach's principle was perhaps put most beautifully by Einstein himself when he said that in a consequential theory of relativity there can be no inertia of matter against space, only an inertia of matter against matter.
>
> With this formulation, Einstein clearly identified the sources of the inertial field as being material. However, there are grave difficulties in identifying and finding these sources… The fact that Newton's theory describes the motion of the planets and satellites so very closely proves that the inertial frame is effectively one rigid frame throughout the solar system. In other words, the inertia-causing effect of the bodies in the solar system—the sun and the Earth and Jupiter and the moon must be completely negligible… If we have a law of force varying say, inversely with the distance, then certainly the very distant bodies would win hands down over the near ones because their total mass is so very much greater. With an inverse square law the effects of near and distant bodies are neatly balanced—with an inverse fourth power law the near bodies are vastly more important than distant bodies. [6]

We know that the radiation field of electric charges varies inversely as the distance from the source so would be an appropriate field to provide the inertia of bodies. The effect of the distant masses would be the dominant one. This would mean that the inertia of bodies is due to the electromagnetic interaction with the rest of the universe.

We have assumed that the principle of superposition holds for electric interaction, but our shadow theory of gravity requires that the nearby masses absorb some of the effect. So what gravitation is to me is the failure of the principle of superposition for electromagnetic interaction. Einstein's general theory of relativity differs from Newton's gravitation in form. It is very complicated mathematically but Bondi points out that there are only two basic differences:

> I have mentioned the fact that general relativity differs from Newton's gravitational theory in practice only in some minor observational matters... there are basically two such circumstances: (1) when the gravitational potential energy is large [compared to the rest energy mc^2]... (2) When fast motions are involved [because the interaction is not instantaneous, the interaction speed is presumed to be the same as the speed of electromagnetic interaction]. [7]

So Einstein's theory basically agrees with what I have put forward. The fact that the speed of gravitational interaction is assumed to be the same as electric interaction follows immediately in the shadow theory. The difference between Newton and Einstein with large gravitational potential has to do with the failure of the principle of superposition for gravity. Feynman says this:

> Although the principle of superposition applies exactly for electrical forces, it is not exact for gravity if the field is too strong, and Newton's equation is only approximate, according to Einstein's gravitational theory. [8]

I do not agree that the principle of superposition holds for electromagnetic interaction—to me gravity is the evidence that it does not. It is no surprise if it does not hold for the shadowing. There is no reason for it to be strictly additive if objects shadow each other.

Presumably we could compute the gravitational constant if we knew about the charge distribution in the universe. Bondi says:

> In as far as we can give any real meaning to the constant of gravitation, it does express the relation between the gravitational and the inertial properties of matter. The gravitational ones, we have every reason to believe, are directly connected with the local sources... on any theory of Mach's principle, the inertial properties are connected with the distant sources. If we have an evolving universe—which of course, we might not have—then the structure and layout of the distant sources will be changing in time. One must then contemplate, to say the least, that the constant of gravitation itself will change in the course of time. [9]

In this chapter, I have drawn several very important inferences. Because certain physical laws are mathematically simple, I must seek an explanation. This has led me to adopt as an appropriate explanation of electromagnetic interaction the "bullet" theory introduced by Page and elaborated by Lowry. These bullets are not particles of matter. Neither are they photons. Photons are associated with a particular frequency of radiation. For me, all electromagnetic waves are just patterns travelling out as the bullets travel out. They are like information travelling on a carrier—the carrier is a stream of bullets. Photons are part of a model that I cannot accept and for me, can be forgotten about.

Because the gravitational mass and the inertial mass of an object are identical there is a strong suggestion that gravity is of the same nature as what gives rise to inertial mass. Bondi argues quite convincingly that inertia must be the result of the electromagnetic influence of the rest of the universe. Inertia is not a gravitational effect. So if inertia is not gravitational then, if inertial and gravitational mass are identical, gravity must be an electromagnetic effect of some sort. I cannot stand coincidences—they seem too much like design. So this all leads me to adopt the shadow theory of gravity and identify the gravitational effect as evidence of the failure of the principle of superposition for electromagnetic effects. The shadow theory also neatly explains the inverse-square character of gravity. It was about gravity that Newton said, "Hypotheses non fingo." Perhaps it is time to "fingo" an hypothesis. The shadow theory, I believe, is generally consistent with Einstein's theory of gravity, his general relativity. It is somewhat simpler too.

Bondi says that we cannot think about laws for the cosmos because there is only one:

> But in the case of [the] universe we have got precisely this one example. It is bound to affect our whole outlook enormously... We have got to take the motion of the universe, and not its law of motion. It is boring to describe separately the motion of the apple and of the moon and so on. But, if there is nothing but one apple falling, then you would be silly if you did anything but describe that motion. So the best that we can hope to provide about the motion of the universe is a description, not a law of motion. [10]

My whole thesis is that there are no laws, only descriptions of the behavior of specific objects and their behavior in the presence of each other. It just happens that there are many natural recurrences of some few fundamental objects. An apple and the moon can be described by the same laws because they are both made of these fundamental objects and both in the same environment, of the rest of the universe.

Summary

1. The simplicity of the mathematical formula for the interaction between two charged particles must, for me, be explained in the same kind of way as the law of illumination is explained. This leads me to an interest in the "bullet" model of electromagnetic interaction proposed by Page.

2. The inertial effect of the rest of the universe on any particle must be an electromagnetic effect.

3. Because of the equivalence of gravitational and inertial mass I believe that gravity is an electromagnetic effect.

4. The shadow theory of gravity explains the inverse-square law and the connection with electromagnetism.

5. If a nearby object shadows other objects from the effect of the rest of the universe, the principle of superposition cannot be precisely true for electromagnetic interaction.

6. Gravity is the result of the fact that the principle of superposition is only approximately true for electromagnetic interaction. Gravity is not a separate kind of force.

CHAPTER 14

The Nature of Things

In this book, I have been trying to outline my view of the universe. Sometimes this idea of a world view is called a Weltanschauung, after the German. Most scientists would not admit to having a world view, but I believe that they really do. And, what is more, I believe that the world view of many scientists is largely influenced by famous scientists like Newton, Bohr, and Einstein. These men were very vocal in expressing their philosophical positions. Newton clearly built a system. His most famous work is called *Principia*. Einstein longed to discover—or invent—a unified field theory. I suppose when you build a world view you are building a system. At the beginning of this book there are two quotations, the first by Ernst Mach:

> It is the object of science to replace, or save, experiences,
> by the reproduction and anticipation of facts in thought.
> Memory is handier than experience. [1]

The second is a remark made to me over lunch one day by Professor Robert Finch:

> When you build a system it is either a ragbag or a bed of
> Procrustes.

My son Stephen was not familiar with the story of Procrustes so I told him that he was a legendary ancient Greek robber who forced victims to sleep in his bed. If they were too short, he stretched them to fit—if too tall, he chopped them off. Finch was saying that attempts to devise a system in order to "save experience" could result in one of two extremes: no system at all, where things were just collected randomly like rags in a bag, or a far too rigid system where everything was forced to fit.

As long as we are aware of the perils of the activity of organizing our experiences so as to form a world view—a systematization—we can perhaps steer clear of the pitfalls. I am afraid that the systems of Newton and Einstein are, to me, examples of a "bed of Procrustes."

Bohr on the other hand doubted that there was a system into which all our information about the physical world could be fitted. He was influenced by the philosopher Hoffding who said:

> An absolute systemization of our knowledge is not possible...[great systems are only useful as] projection, search-lights, with whose help we try to explore the dark... [but] no verification is possible. [2]

Nevertheless, the Copenhagen interpretation of quantum mechanics fostered by Bohr has many of the aspects of a system that is a "bed of Procrustes."

Reichenbach says of the kinds of systems that Newton and Einstein held:

> The ideal of the complete mathematization of knowledge, of a physics which is of the same type as geometry and arithmetic, springs from the desire to find absolute certainty for the laws of nature. [3]

Bohr was convinced, I think, that a more mysterious system existed and that our knowledge of it would consist of complementarities and probabilities rather than certainties. Einstein rejected this point of view—"God does not play dice." Here he speaks in *Out of My Later Years*:

> Rather, it [research activity] is similar to that of a man engaged in solving a well-designed word puzzle. He may, it is true, propose any word as the solution; but there is only one word which really solves the puzzle in all its forms. It is an outcome of faith that nature—as she is perceptible to our five senses—takes the character of such a well formulated puzzle. The successes reaped up to now by science do, it is true, give a certain encouragement for this faith. [4]

Einstein assumes that nature is like "a well formulated puzzle." He, like Newton, believed that a system exists and that man may be able to discover the system.

Whether you accept the Newton-Einstein view of a mathematical system or the Bohr view of a somewhat mystical system, you are still stuck with trying to fit everything into a system. And that system becomes a "bed of Procrustes" even though you originally saw it only as a searchlight "to explore the dark." But what is the alternative? Is it a ragbag? What if it were—this is not a disaster. Even a ragbag can be organized—but the organization is up to you, and is arbitrary. For instance, you could separate your rags into ones that are patterned and ones that are plain, then you could divide them further into different color ranges. This is a system, but it is your system, and you know it can be changed if you want. You could instead sort your ragbag out into categories by fiber content of the rags: cotton in one pile, silk in another, and wool in a third.

One of the things that started me on this book is that I had a ragbag of my own. Over the years I had collected quotations from books and articles, quotations that were especially meaningful to me. I decided that my ragbag needed organizing, so I sorted the quotations into various categories. The categories were based on the fact that there was a similarity of theme in certain quotations. All the quotations together in some sense represented my view of the world, some because they agreed with it, some because they were diametrically opposed.

My idea was to write a book so that I would be forced to think through a lot of disorganized notions that I had. The key to my systematization came to me one day when I realized that if there were a real system behind the universe—a design—that it should not be accessible by scientific investigation. If we could discern a system by scientific investigation there would be a firm basis for natural theology. And somehow I reject natural theology.

In Computer Science, there are many applications of computers in the area of artificial intelligence where there is no direct method of solving a problem. Many such problems involve searching for a particular solution among many, many possible solutions. It is like looking for a needle in a haystack. We can never reach a solution by a direct method that exhaustively looks at every possibility. For these problems we use a heuristic method where some guiding principle is used to guess where to look, rather than looking everywhere. These heuristic principles are devised by computer scientists to help them discover solutions. The heuristic principle I devised is that "whether or not there is a design in the physical universe is an undecidable question." This has given me a different viewpoint, the one from which I started to organize my own system. As an information scientist my purpose in looking critically at the body of physical theory is to see whether all of the notions we now use to describe our collected knowledge of the physical universe are really essential. As I expressed it in my textbook on Physics:

> The object of scientific activity is to gather information about the physical world and to try to summarize it as clearly and succinctly as possible. In that way we think we understand. By understanding electromagnetic interaction we do not mean that we know what causes it, merely that we can describe exactly how two charged particles behave when they interact. We know the nature of charged particles. [5]

As a computer scientist I have become concerned with the enormous problem of information retrieval. Vast quantities of facts can be stored in a computer memory and, if properly indexed and filed, can be rapidly retrieved. But, the more facts we have in our information banks the more complex the retrieval problem becomes. It is important that we keep housecleaning our files, to eliminate duplicate information and to discard detailed information in favor of summaries when summaries are all we ever refer to. In most cases, the details are forever lost unless it is possible to regenerate the details from the summaries. This, in fact, is the case with summaries of physical information which we often call laws or principles. It is, in many cases, possible from a summary to retrieve the details of individual instances. By keeping these summaries and transmitting them from one generation to the next, scientists are able to build on the work of the past. Computers have been very helpful in the business of data reduction—vast quantities of experimental measurements have been reduced to summary form. Computers are also very useful in working out the results in particular cases, described, in general, by our physical laws. This is constantly necessary in the design of structures such as molecules or bridges.

Another reason for wanting to summarize our information about the physical universe as succinctly as possible is so that it can be looked at all at one time. What we have now is an accumulation from the past and our hope is to add to this in the future. When we add a new piece to our science, it must be consistent with everything we now have, or we must discard some of what we have in order to add some new information. The parts we discard must not be necessary to the total picture or important information would be lost.

At any time, the body of fundamental law tends to be regarded as scientific truth although as scientists we are all prepared to recognize the tentative character of our approximations to scientific truth. Many believe that as scientific investigation goes on we approach closer and closer to the absolute scientific truth. This is why it is very difficult at any stage to abandon a particular formulation of the laws for something quite different. But, it has happened in the past, when Newton's laws were replaced by Einstein's relativity theory, and deterministic Newtonian or Einsteinian mechanics by quantum—or probabilistic—mechanics. We have made these radical changes, and we will without doubt make radical changes again.

The business of accumulating information about the universe has been the work of scientists for generations. But, the heroes of the story seem to be people who make startling discoveries. Sometimes we hear that a scientist has found a new "secret of nature." But, not every scientist sees himself as looking for the secrets of nature. Here is a statement from a text written by Gamow and Cleveland in 1960:

> Such relations, based on direct measurements, are known as the *empirical laws of nature*, and the progress of observational and experimental science leads to the accumulations of ever larger and larger numbers of such empirical laws. The role of theoretical science is to find the hidden interrelations between the empirical laws and to interpret them in terms of certain hypothetical assumptions concerning the internal structure of matter and various material objects which are not subject to direct observation. [6]

In this book I have been examining the idea that the "secrets of nature" are really facts about specific things like electrons, protons, and neutrons. And I have speculated that there may be things —like messenger bullets— that are not subject to direct observation but which may explain the way that the fundamental objects behave. This explanation is in contrast to one which says that there are general laws which govern—or describe—the behavior of all things. I believe that the idea of the existence of "general laws" is widely held by scientists and is for them a "bed of Procrustes."

Scientists like Newton who really started the general law idea thought they were finding the nature of nature. I believe that all we can do is to find out about the nature of things—things like electrons, protons, and neutrons.

I found in physics many discrepancies that to me are intolerable. One of these was the assumption that a system of particles could be isolated from the rest of the universe. Mach says:

> But, we must not forget that all things in the world are connected with one another and depend on one another. [7]

Another discrepancy was involved with all the double talk about wave-particle duality and the fact that atoms were not producing radiation in their ground states.

In examining the various discrepancies I have come up, I think, with a logically consistent view of the world which does not contain them. This view is a pastiche, made up of pieces from here and there — pieces I had saved in my ragbag. Most of the ideas that are unconventional were suggested by other scientists. As an example, the idea of explaining the electromagnetic interaction in terms of messenger bullets started with Page and was explored by Lowry. Mach originated most of the environment ideas, attributing inertia of a body to the rest of the universe. Many people have examined the stochastic atom idea. The shadow theory of gravity is very old.

But, I have made some suggestions that, as far as I know, are my own. I have not seen it suggested before that gravity is a result of the failure of the principle of superposition for electromagnetic interaction. Nor has anyone said that the only stationary state that an atom can be in is the ground state and that atoms in the ground state radiate a continuous spectrum. Or that the second law of thermodynamics is really a statement that microscopic conservation of energy cannot be valid. A few of the pieces are indeed my own. They are of course speculations but, I hope, worthy of some consideration.

There is no doubt that reading Darwin's work inspired a lot of my thinking. His theory of evolution seemed to point to the fact that we could not tell from the animate world whether or not it happened by chance or by design. Darwin's work also emphasized that the nature of animate things depended on their environment—and the environment for living things is provided by other living things as well as the inanimate world. Might not the nature of inanimate things, I said to myself, have evolved in a similar way.

Obviously, I have a different point of view but I certainly do not expect a massive realignment of committed scientists to my way of thinking. As Kuhn says:

> The transfer of allegiance from paradigm to paradigm is a conversion experience that cannot be forced. [8]

My writings contain speculations on the nature of things. I have gone counter to Newton's advice of "hypotheses non fingo." But so did Newton. Listen to him as he writes in his *Second Paper on Light and Colours* in 1675:

> Perhaps the whole frame of nature may be nothing but various contextures of some certain aethereal spirits, or vapours, condensed as it were by precipitation. Much after the manner that vapours are condensed into water, or exhalations into grosser substances, though not so easily condensible; and after condensation wrought into various forms; at first by the immediate hand of the Creator; and ever since by the power of nature; which, by virtue of the command, increase and multiply, became a complete imitator of the copies set her by the protoplast. Thus, perhaps may all things be originated from aether. [9]

Sounds somewhat like evolution!

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