K&E Series on Knots and Everything — Vol. 42

# THE ORIGIN OF DISCRETE PARTICLES

T. Bastin • C. W. Kilmister

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T. Bastin • C. W. Kilmister

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# Foreword

During the twentieth century the concept of particle underwent a profound change. An electron differs from the particle of Newton in having discrete properties. All electrons have identical mass, charge and spin. The charge and spin of the electron and other elementary particles are logical properties which the particles either have or not. There are a number of other such logical properties. Mass is a more obscure matter but is logical none the less. This book attempts to show why such a change has come about. As a historical matter these investigations did not start from this problem. They began from trying to give physical interpretation to a curious algebraic construction of A.F.Parker-Rhodes. This construction gave rise to a graded algebra having exactly four levels with which were associated the numbers 3, 10, 137 and $10^{38}$. The rough correspondence of the last two with the inverses of the electromagnetic and gravitational coupling constants and the restriction to four levels suggested a physical connection. It transpired that a very abstract account of the discrete process by which knowledge of the universe is gained provides a reason for an algebraic structure more general than Parker-Rhodes' but having his as a special case. The fact that the more general structure then modifies 137 to a value agreeing with the measured value of the inverse fine-structure constant to better than one part in ten million confirms its correctness. The discrete nature of elementary particles follows from the essentially discrete nature of the process. This explanation is logically prior to one invoking Planck's constant, since assuming the existence of Planck's constant is equivalent to assuming the discreteness. The fact that the algebraic structure contains a substructure agreeing with that of the quarks is a further confirmation of its correctness. Much more work is needed to evaluate all the implications for physics but it is hoped that this book will serve to inspire it.

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# Contents

*Foreword* v

*Acknowledgments* vii

1. Introduction 1

2. Combinatorial space 5

3. The story of the particle concept 17

4. Dimensionality 25

5. The simple bit-string picture 31

6. The fine-structure constant calculated 35

7. Process and iteration 83

8. Pre-space: High-energy particles: Non-locality 95

9. Space, relativity and classical space 115

10. Perception 135

11. Current quantum physics, state/observer philosophy: complementarity 141



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12. Just six numbers 163

13. Quantum or Gravity? 169

*References* 173

*Index* 175

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# Chapter 1

# Introduction

The method for physics put forward in this book is *constructive*. One may alternatively say that it is a *process* theory. In it one does not imagine the space and time continua as existing outside the theory and giving us a universe of objects already distributed in these continua to start from. All this has to be constructed.

Any construction of this kind must necessarily start from discrete quantities — numbers in fact. However remote that may seem from the classical basis of physics, we argue in this book that it is the place at which the physicists concerned with the high energy physics of the particles in fact have to start. The book constitutes a discussion from the process point of view of the evolution of the concept of *particle*. In high energy physics, new knowledge about particles has to be expressed in terms of properties like those familiar from classical physics even though they are not classical particles.

To make this clearer we begin by specifying what is meant by a classical particle. That concept has changed over time but by, say, the mid-eighteenth century a particle had one *primary* property, its mass, and two *secondary* properties, its position and its momentum. Change in position as time elapsed then produced a path. The other primary properties quoted by Newton (Opticks) of roundness and hardness were no longer necessary. As electromagnetism developed a second primary property, charge, was added. It would have been possible to introduce another secondary property, intrinsic spin, which could have been useful in the analysis of ball games, for example billiards, but as a matter of history, the notion of a rigid sphere was used instead to carry spin. The advent of relativity pro-



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duced no great conceptual change by itself. It is true that relativity allowed a convenient description of the spinning particle but the stimulus for this came from quantum mechanics.

Quantum mechanics called for major changes in the concept of particle. The two secondary properties, position and momentum, were restricted by the uncertainty principle. In practice, the momentum became more important and the position increasingly disregarded so that the path became uncertain. The two primary properties, charge and mass, and the secondary one, spin, were taken over though only with important modification. The charge could have only three possible values including zero, a fundamental unit or its negative. A given particle has always the same charge. The mass could have a range of values, but again all particles of one kind had always the same mass. Finally, the spin became a third primary property whose value was some multiple of a fundamental unit.

The new knowledge that was coming in about particles in high energy physics has to be expressed by new primary properties. These are represented by descriptors which are called 'quantum numbers'. Descriptors are things that either exist or do not exist in any particular case. (For example some particles have charge though the neutron does not.) Conventionally they are given the values 0, 1 or digits reducible to 0, 1. The rules for assigning these quantum numbers capture their conservation laws in particle interactions. The first step from these descriptors toward the notion of a particle is the interaction strength. This is no longer an all-or-none property but has one definite value which characterizes a given particle process. An important investigation is always necessary to relate this value with the value of the mass, since mass will have a range of values even though it is not continuously variable.

The interaction strength is moreover a *number* that comes from counting of processes and only at a further remove should it be thought of as a field strength. The classical notion of a field is, in any case, inappropriate when the position of the particle is uncertain. Underlying the interaction strengths is a set of coupling constants that are dimensionless.

In our theory we find the origins of the coupling constants in a study of the building up of structures from interactions with an unknown background rather similar to the vacuum of high-energy particle physics. Construction does not go on into ever-increasing complexity but can be reversed or started all over again, so that there is a dynamic process at work.

This book is therefore an essay in the conceptual foundations of physics. Its purpose is to introduce what we shall call a *combinatorial* approach.

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A process approach is necessarily combinatorial but the opposite is not the case. To clarify this consider a combinatorial approach in quite a different sphere, that of plane geometry. The fundamental entity there is the *point*. A pair of points is *defined* as a line. Two such pairs then define a fifth point. In normal parlance this would be the intersection of the two lines. Appropriate rules governing the derived entities then lead to the construction of projective geometry. (Euclidean geometry would be another matter.) In contrast the usual view would be of a continuum containing all the points of the plane and all their joins. These would all be on an equal footing so that it can only be an accident in what order they appear.

In physics our method will be to view physical theory under the aspect of a particular point of view which is combinatorial in character. In the course of the book questions will be asked and discussed which may have a long history, but which are not seen as live issues at the present because of the special philosophical stance of present-day physicists. However for combinatorial physics they are very much alive.

The idea which underlies combinatorial physics is that of *process*. The most fundamental knowledge that we can have is of step-by-step unfolding of things; so in a sequence. This is the kind of knowledge we have of quantum processes, and that fact becomes specially evident in the experimental techniques of high-energy physics. Such a process is necessarily combinatorial but not conversely. The example of plane geometry above exhibits a combinatorial theory which is not a process one.

The contrasting view, which has been the main guide of physics in the past, is of a background of physical things whose spatial relationships are on an equal footing in the sense that it can only be an accident in what order we happen across them. To put it another way, when the sequence or process is fundamental then we have to specify the steps by which we get to a particular point, whereas in the conventional picture we imagine we are free to move about in the space in which phenomena occur, without its being necessary to be explicit about it.

Suggestions for fundamental revision of the conceptual framework of physics are unlikely to engage the attention of physicists unless they bring about major improvements in the technical understanding of physics — particularly in new explanations and calculations of experimental results. The strong position of the combinatorial theory is that it has been used to deduce some experimental quantities that have not been deduced from more conventional theory. The closeness to the experimental values of these deductions makes it very unlikely that their success is fortuitous. Moreover

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it would be agreed on all sides that the experimental quantities in question play a sufficiently important part in physics to warrant attention being paid to any theory that claims to calculate them.

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# Chapter 2

# Combinatorial space

*Contents*

*A hierachical theory presented in Chapters 6 and 7 is prefigured. In it, contact with the experimental world is through elementary interactions which appear as the strengths of elementary particles. Space is combinatorial and not absolute — or existing beforehand. Leibniz was the pioneer of this combinatorial approach. Computing models provide the connectivity of this relational space (this term for it used by Leibniz).*

In this book we work with a space that is built up of elementary interactions. The first point of contact with the experimental world is the set of interaction strengths of fundamental particles and which give rise to their fields. We therefore postulate a combinatorial space; not a continuous or absolute space that exists independently. We have to be more explicit about what we mean by a combinatorial physical theory. Combinatorial physics is physics in which the mathematical relations are combinatorial, and combinatorial mathematics is mathematics in which we study the ways in which symbols are combined. The term 'combinatorial' is often defined ostensively by giving examples. Ryser[1] gives the following examples: interest in magic squares, study of permutations and (indeed) of combinations, finite projective geometry and problems connected with covering of spaces with arrangements of shapes in circumstances in which the space is divided into a finite number of sections and there is a convention which enables us to decide unambiguously whether or not a given section is covered. Such conventions exist, for example, for the use of chess boards and most other gaming boards, and the conventions enable us to decide all questions of the



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relation of combinatorial structures to physically defined spaces. Ryser[1] sums up his exemplification thus: 'Combinatorial mathematics cuts across the many subdivisions of mathematics, and this makes a formal definition difficult. But by and large it is concerned with the study of the arrangements of elements into sets.'

The first person to have seen a very profound difference between the combinatorial method and traditional thinking was Leibniz. The term 'combinatorial', used in this context, originates with Leibniz's "Dissertate de arte combinatoria", and according to Polya[2] the originator saw that difference in a very striking form. ... "Leibniz planned more and more applications of his combinatorial art or 'combinatorics': to coding and decoding, to games, to mortality tables, to the combination of observations. Also he widened more and more the scope of the subject. He sometimes regards combinatorics as one half of a general Art of Invention; this half should deal with synthesis, whereas the other half should deal with analysis. Combinatorics should deal, he says in another passage, with the same and the different, the similar and the dissimilar, the absolute and the relative, whereas ordinary mathematics deals with the one and the many, the great and the small, the whole and the part."

The general connexion between combinatorial mathematics and the impulse behind computing science has been widely remarked. Computer programmes are constructed in formal steps with information stored in (binary) patterns. It is the *connectivity* of the computer programme which is its vital characteristic, and we need to see this as an aspect of the 'ars combinatoria'. Weyl[3] says, "Modern computing machines translate our insight into the combinatorial structure of mathematics into practice by mechanical and electronic devices." When one is subjecting oneself to the discipline of the computer programming, which in its essentials is arranging the mathematical operations in sequential order so that each brings the next appropriate one in its train without intervention on the part of the mathematician, then (Weyl is saying) one has, through exercise of that discipline, displayed that insight.

Arguing this way, one comes to feel that in spite of all the modern sophistication about the impact of computing on the foundations of mathematics, not enough attention has been paid to the vast difference between the classical idea of the mathematician and that required by the computer revolution. This difference shows up clearly when it comes to making mathematical models. The mathematician makes up his mind about how to get

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from point to point in a mathematical structure on the basis of some purpose that he imagines to be directing his efforts, whereas, by contrast a computer person insists on having these instructions incorporated in the program.

What we abandon in making this change is the automatic freedom to consider a problem from several points of view and involving several mathematical techniques which have no coherence but which we take as simultaneously relevant. At this point the idea of space has changed in an important way. We expect a kind of coherence to these points of view and mathematical techniques because we associate them all to the same point of space. The combinatorial approach, by contrast, has to construct a *process* that plays the part of the composite picture of what is happening at a point of space. If we let a computing model stand for the combinatorial process, then we have to view every process from a preferred viewpoint which is conveyed by whatever is at the moment in the central processor. The possibility of parallel or concurrent computing does not change this argument and arises at a less fundamental stage: If there are several computers going, then insofar as we can speak of them as one model they are one computing system, even though the connexions between them may be randomized.

Can Leibniz' view of space fit his combinatorial method? In the first place Leibniz' space is essentially *relational*. So is time. There are *things*, and each pair of these things has a relationship together that we speak of as spatial and he does not suppose that there is a really existing scheme of all these relationships that exists independently of, and before the consideration of, the things. If it is possible to attach a number to characterize each relationship then we may call that the *distance* between those two things, though Leibniz does not tell us how that is to be done.

What are the things? The only answer given by Leibniz requires us to look into his all-embracing theory of the monads. The worldview of Leibniz — seen in relation to the Newtonian legacy of modern atomism — is well described by Whitehead[4]. "He" (Newton) "held the most simple-minded version of the Lucretian doctrine of the void, the most simple-minded version of the Lucretian doctrine of material atoms, and the most simple-minded version of Law imposed by Divine decree. His only approach to any metaphysical penetration arises from his way of connecting the Void with the sensorium of the Divine Nature. ... The monads of Leibniz constitute another version of the atomic doctrine of the Universe. Leibniz was acutely conscious of ... the problem of the criticism of knowledge. Thus he approached the problem of cosmology from the subjective side, whereas

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Lucretius and Newton approach it from the objective point of view. They implicitly ask the question, What does the world of atoms look like to an intellect surveying it? ... But Leibniz answered another question. He explained what it must be like to be an atom. Lucretius tells us what an atom looks like to others, and Leibniz tells us how an atom is feeling about itself. Leibniz wrestles with a difficulty which infects modern cosmologies, a difficulty which Plato, Aristotle, Lucretius, and Newton entirely ignore. "The modern outlook arises from the slow influence of Aristotle's logic, during a period of two thousand years. Keeping to the point of view derived from Aristotle's logic, if we ask for a complete account of a real particular thing in the physical world, the adequate answer is expressed in terms of a set of abstract characteristics, which are united into an individual togetherness which is the real thing in question."

For Leibniz, this way of handling the particle concept is the only one possible. There never is a case where (as in the modern correspondence principle) it gradually becomes legitimate to go over into a classical mode of thought with its absolute space. Whitehead is drawing attention to Leibniz' doctrine on matter: an object is defined by the bundle of attributes that it has. Such a definition should be congenial to particle physics. But it does raise a problem — that of continuing identity — which is neatly dodged in the Newtonian synthesis by appealing to a continuity in temporal and spatial positions. No such appeal is open to Leibniz, (nor, incidentally to us) and this leads him on to the doctrine of monads.

Whitehead goes on to say of Leibniz's position that it "is beautifully simple. But it entirely leaves out of account the interconnexions between real things. Each substantial thing is thus conceived as complete in itself, without reference to any other substantial thing. Such an account of the ultimate atoms or of the ultimate monads, or of the ultimate objects enjoying experience, renders an interconnected world of real individuals unintelligible. The universe is shivered into a multitude of disconnected substantial things, each thing in its own way exemplifying its private bundle of abstract characters which have found a common home in its own substantial individuality. But substantial thing cannot call unto substantial thing."

This is the famous problem of the windowless monads. The system itself is necessarily incomplete, and Leibniz recognized this by breaking the system to the extent of allowing one supreme monad to have windows toward the rest. As far as his writing for the world of his contemporaries was concerned he could make a virtue of this necessity by identifying the supreme monad with the agglomeration of ideas that made up the then cur-

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rent perception of God. Whitehead comments "such has been the long slow influence of Aristotelian logic upon cosmological theory. Leibniz was the first, and by far the greatest philosopher who both accepted the modern" (outlook) "and frankly faced its difficulty".

Leibniz' writings on combinatorics only became available at the beginning of the nineteenth century. It appears that Leibniz found his Ars Combinatoria difficult to get across to his contemporaries and so did not publicise it. Russell argues that in doing this Leibniz was disingenuous because he liked the approbation that he got from the theism that his monadology permitted in spite of the fact that the combinatorics made the monadology unnecessary if not fallacious. Russell's view is wrong whatever he may have thought about Leibniz' morality. If we come only to the matters that are of direct concern to this book we find that the rather thin logical positivism embraced by Russell would never have presented the deep problems of modern physics satisfactorily, and Leibniz' combinatorics would not help anyway. That criticism would apply too to other writers of a positivistic orientation such as Popper (who concerned himself more directly with quantum theory than did Russell). Of course this is not to say that the monadology could solve these problems.

Russell[5] concludes: "What I, for my part, think best in his theory of monads is his two kinds of space, one subjective, in the perceptions of each monad, and one objective, consisting of the points of view of the various monads."

Though we reject Russell's sharp separation of combinatorics from the monadology, with the combinatorics as the way forward, that separation does seem to reappear in our approach. The process theory that we develop is thoroughly combinatorial, and our use of it as a basis for physical theory was not contemplated by Leibniz at all. By itself the Ars Combinatoria seems to be a bit thin. True, it prefigured much of modern computing science, but Leibniz would have demanded much more physical contact than that. Why could he not have that? The answer must be that Leibniz was born in the wrong century, whereas Newton was born in the right one. Celestial mechanics played into Newton's hands. If we may imagine Leibniz having been aware of the facts of quantum theory things might have been very different. We can play with the idea of Leibniz being offered the relational space of relativity and the combinatorial aspect of the world exhibited by the quantum theory, and wonder just how far he would not have gone with such a marvellous springboard.

Russell quotes Couturat[6] with great approval as saying "Leibniz's

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metaphysics rests solely upon the principles of his Logic, and proceeds entirely from them. Perhaps the most revolutionary conclusion in the whole book" (Couturat's) "is, that the principle of reason for all its trappings of teleology and Divine goodness, means no more than that, in every true proposition, the predicate is contained in the subject, i.e., that all truths are analytic." It is hard now, in the light of the criticism of Wittgenstein, to put oneself in Russell's position in which subjects and predicates and so on were completely commonsense and self-explanatory ideas, rather than having all the difficulties of metaphysical concepts. One cannot imagine Leibniz falling into this trap of logicist absolutism. He knew that time was not ripe for his ars combinatoria because such a metaphysics needs a subject matter which the physics of his day did not provide.

We turn from this account of Leibniz' thought to the way in which the authors began to put into effect the combinatorial ideas.

In current physics every question that may be raised about spatial relationships is referred to measurements of lengths expressed by numbers. Those numbers will provide the experimental meaning. If, now, we wish to replace absolute space by sequential construction, then we have to start afresh. To explain how we could still significantly speak about the physical world without the metrical provision of numerical relations we spoke of a *theory-language*. In the simplest theory-language dimension numbers were found in algebraic considerations separate from, and more basic than the metrical relationships.

Classical physics uses a continuum background of space within which things have positions, and the changes in those positions give rise to a second continuum of time. These continua are imagined as perfectly smooth, perfectly homogeneous, infinitely divisible. They are modelled mathematically by the continuum of all real numbers as that was formalized by Dedekind and Cantor between 1870 and 1880. The irreducibly simplest entities in these continua of space and time are particles — idealized as single points whose position in space changes continuously with time — and fields. Fields are spread through space and have at each spatial point a magnitude which again varies smoothly both with time and with changes of the point at which the field is specified. Upon this basis, a scheme of dynamical concepts was elaborated which seemed to provide a complete description of the motion of things in the space continuum. The work of Newton was the cornerstone of this edifice. With its subsequent extension to electromagnetism, it compelled a feeling of universality: one felt one was in possession of the means to describe reality direct. Indeed this scheme

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became for the physicist the mathematical elaboration of commonsense and the automatic vehicle for his thought. It was reality.

The set of concepts that makes up the scheme have an interlocking and closed character that makes it unique in the history of thought. Other disciplines have aspired to this cohesion, but have only very partially been able to achieve it. Through its long elaboration classical mechanics has become like a language that we learn to use rather than like an exploration that may turn out right or may turn out wrong, though of course it started off like that. When we learned classical mechanics we found to our surprise that the definitions of the concepts chase themselves round in circles. The mass of a body is given a numerical value through the behaviour of that body under a given applied force. The force is specified numerically by the acceleration of the body, but only if we already know the mass, and so on. At the time of Newton, there was no such unanimity on the use of the concepts, and if one were asked to give a definition of one of them, one would refer to some experimental situation which made the use one was proposing plausible: one would have to argue for it. Now things are interestingly different, for the set of interlocking concepts defines its own appropriate application, and cannot conflict with experiment without some major revolution having taken place. This set of interlocking concepts, with its dimensional structure that we find independently of metrical space, is our 'theory-language'.

For the great majority of physicists there is no problem in understanding the success of the theory-language of classical physics: they do not have to worry how it comes about that the theory-language describes the world so automatically because there is no distinction between it and reality. In a way we are suffering from the enormous success of classical physics. Over three centuries its concepts have penetrated our common language about the world almost completely, and the resulting amalgam of theory and experience seen under the aspect of that theory has become commonsense; it is identified with reality; and has the corresponding incorrigibility.

It is a strange fact that this immunity of the deductive language of classical physics to experimental check has received little or no attention in contemporary writing on the philosophy of physics. The term 'theory-language' refers to a theory which has reached this stage of development. The authors tried early on to use the 'logic of facts' of Wittgenstein's Tractatus Logico-philosophicus, to describe it : "... a physical theory consists of propositions which may be thoughts, sentences written or spoken, or manipulations with bits of the physical world ... the experimental thing has

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meaning only as part of a theory. The theory may have different degrees of complexity, and there will be experimental procedures corresponding to each degree. Thus the theory is a kind of language, but experiments in the theory are the same language. One cannot use experiments in a complex language to criticise a simpler theoretical language."

The simplest theory-languages, which play an important part in this book, are algebraic structures with a single binary operation. The first of these will be shown below to be the quadratic group $S$ of 3 elements $a$, $b$, $c$ together with an identity $e$. In this group $a^2 = b^2 = c^2 = e$ and $ab = ba = c$. The hierarchy of such structures consists of levels which are direct products of $S$ with itself.

Let us suppose that the non-metrical basis of theory can be expressed as a theory-language and ask how metrical relations appear. The answer arises from the prevalence of the dynamics of the particle. The history of physics from Galileo onwards has been the progressive displacement by the dynamics of the particle of all other forms of explanation. Descartes' vortices failed because it proved not to be possible to calculate with them, and 'to calculate' increasingly came to mean 'calculate using the dynamics of the particle'. It is true that the great nineteenth century inventions of electromagnetism and fluid mechanics, which depend upon the theory of fluid rotation, could be seen as a vindication of Descartes' vortices, but really this would be to stretch a point, for the mode of action which Descartes imagined was not through particles. That came in the nineteenth century theory when all fields came to be specified in terms of the behaviour of ideal 'test-particles'. We don't understand the mechanics of rigid bodies and such things as gyroscopic motion until we have satisfied ourselves that the special concepts which they introduce can be made explicable in terms of particle dynamics. In fluid mechanics one must start with the 'experience' of the particle moving with the fluid.

Whatever the usefulness of the idea of the theory-language may be in general, it is an important part of our story because it was our attempt to formalize the idea that led to study of levels of interaction strengths and from that to the finding of the numerical values of them.

In an absolute space interpreted metrically, it is impossible to ask the question 'what happens when the metrical description fails to work?' The theory-language idea could provide independence of metrical application. It could, as it were, be carried around to see where it would fit; where it would not fit; and why. With no such recourse there is an obvious logical difficulty, if not actually an absurdity, in asking for a theory that accounts for, or even

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describes, the limits of applicability of itself. You must have something like a grid on which it is mapped to do that, and classical mechanics does not envisage anything of that sort. Both the great innovatory theories of this century — the quantum theory and relativity — found themselves up against this difficulty, and for that reason early forms of both theories took the form of arbitrarily imposed restrictions or alterations to the existing theory which came into effect at certain scales. This made the failure to fit of the theory look like an additional piece of mechanics of the type that the theory dealt in, when the true origins of the limits in each case were really quite different. The incorporation of the constant $h$ into the mathematics of the quantum theory, and the Lorentz contraction, respectively, were the points of application of this method in the two theories. In these ways it was possible to put off the recognition that familiar metrically based dynamical concepts no longer applied universally.

Subsequently the theories became more sophisticated. In particular the inevitability of non-locality is recognized. However current ways of speaking about non-locality still show a backward-looking stance. One expects normal locality and takes to special devices when it fails, instead of seeing a more general form of connectivity as the norm. Very similar remarks apply to the quantum limits. Discussion of how one can have a dynamics without a classical background space and time when one adopts a combinatorial point of view will occupy a large part of this book, and we can stay at the level of general comment here. At that level it may be worth pointing out one principle that makes limits to the applicability of familiar dynamics easier to understand. One is accustomed to have a description of the world that is derived from our everyday laboratory-scale experience and to extrapolate it to different magnitudes. The technique and its very language suggest nothing that is not scale-invariant, and therefore we are puzzled to find it failing to work at particular scales, and have no way of describing that failure. How are we to understand limits to extrapolation? One piece of the puzzle arises from the way we take it for granted that there are an indefinite number of quite distinct ways of making the observations upon which our physical descriptions are based, and that these give consistent information. However, as we extrapolate further in both the small and the large scales, this presumption gets further and further from being valid. In the cosmological case, so far from having an indefinite number of cross-referencing methods of observing, we are reduced to very few, and ultimately to one. Notoriously, all our information about the universe on the largest scale depends on an interpretation of the red

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shift of spectra, while at the quantum end we are using the very particles we are investigating to do the investigating.

A quite insightful way of looking at what is happening is to say that theory and observation are losing their separability. By 'separability' we mean the situation, usually taken for granted, of a body of experimental results which is then rationalized or simplified to a greater or lesser extent by one of a number of possible theories. The choice of theory is influenced by, amongst other things, the extent of the rationalization produced. Here by contrast one gets towards a state where one would not know how to present the results without presupposing one particular theory. None of this discussion is in any way to impugn the validity of the observational work for what it is, nor to cast doubt on the care and sophistication with which deductions from it are made. It is only that current thinking allows for only one category of experimental knowledge, whereas we are confronted with something like a sliding scale from a situation where consistency is assured to one where it has no meaning. The very notion of observation has undergone a change in logical character. If we recognize that the experimental evidence and the theory can no longer be separated it is easier to understand the limit to extrapolation. It is usually true that adequate critical standards are applied to interpretations of experimental evidence near the extrapolation limits, yet the absence of a way of speaking that gives the experimental evidence its proper status cannot but cause confusion and possibly misdirection of effort. Thus in speaking of the big bang, talk of "the first three minutes" will certainly mislead people into taking the time language literally, and it is by no means certain that none of them will be professionals. There is no language that contains within itself a 'health warning' that there is trouble if you move back and forth over time while assuming the usual meaning for all the physical concepts.

The small pieces of matter that we usually associate with the mechanics of Galileo and Newton are always presupposed. However they have never been made a true part of that picture in the sense that their stability and impenetrability could be explained within the picture. The distribution of matter in the particles is never explained in a way consistent with the representation of the spatial distributions of those particles. Perhaps that is not surprising for it would seem to involve a circular argument. The clash of continuum and discrete which will occupy us centrally, becomes evident.

With the coming of field theories, and particularly of classical electromagnetism, this explanatory limitation became harder to overlook. The profound perplexities that arose in the continuum theories with the

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Michelson-Morley experiment, and then with the ultra-violet catastrophe were given answers that had the effect of overlooking the problem about explanatory limitation for the time being. Discreteness was given an exact mathematical form by Planck, which seemed to be forced by experiment even though no one could justify it: it looked as though things were on the move. During the ensuing half-century the mathematical imposition of discreteness was progressively elaborated. It is probably assumed by a majority of physicists today that the right tools for any discussion of the explanatory limitation are already to hand in the modern formulations of quantum physics. We shall show at length that this is not the case and that therefore the fundamental problem of atomicity remains. The physical elements of the constructive scheme will need to have a simple mathematical representation that will specify their interactions with one another. One scheme like this has dominated our approach and will be developed in detail. We give it a central place because it provides a theory of the coupling constants and gives the interaction strengths of the fundamental fields; an understanding of the distribution of their numerical values; and in the electromagnetic case a very accurate calculation of its experimental value.

These numbers are dimensionless and therefore there is no contradiction in taking them as the required basis for a discrete scheme for all measurements, so that their primacy is assured. To calculate the numbers it is necessary to postulate a statistical background out of which a hierarchy of nested structures or *levels* develops during the interaction process. The construction of elements of these levels is a two-way process that can be reversed so that it can keep on starting all over again. What dictates what happens in the construction is the interaction with the statistical background, so that the background is the reality whose empirical shape is emerging. However this is the only access we have to the background and it would be wrong to think that discoveries are being made about the distribution of things in a space. The notion of things being "out there" at different distances and in different directions has not yet emerged.

In the 'platonic receptacle' view of space, space is what holds whatever we care to put into it. The idea, particularly of the Timaeus, is that there has to be a 'seat' that things can enter into or disappear from. The 'receptacle' is then the spatial location for them.

In physics a method that we use all the time is to have a variety of arguments of pieces of mathematical analysis each of which is supposed to contribute to our understanding of what is going on at a particular place and yet which are all different and may even be incompatible with each

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other. All that holds them together is their referring to that point in space. This use of the absolute space seems best put in terms of the platonic receptacle, and in this way the receptacle view is deep in our thinking. As an example suppose we are considering the dynamics of the spiral nebula. It is as though we transport ourselves in the imagination to that place and think what would happen to us in order to formulate the theoretical description. It is now known that the spiral nebulae rotate like solid bodies, so that parts of the nebula at different distances out on a radius stay on that radius. Not merely that, but there may be no simple relation between the rotation and the swept back look: in certain cases the arms may advance point first. After those shocks one is almost disappointed to find that the thing does rotate in the plane in which its arms lie, like a catherine-wheel. Yet, one would have sworn, if ever there were an object whose rough dynamics was plain for all to see, it would have been the spiral nebula – a loose aggregate of matter having some angular momentum, and with some radial motion shown by distribution of material along the arms, but with the arms appearing swept back because of greater angular velocities near the centre.

We are using the fascinating subject of galactic dynamics only to make a methodological point. Our habit is to assume that the universe out there would seem as it does to us here, and exhibit the same mechanics, if we could be transported there. We know we have to give up that presumption as we approach the atomic scale. It is more difficult to give up in the face of possible contrary evidence at the increasingly large scale. It is something between a guiding principle and a prejudice and it should be scrutinized in the light of the information we actually have each time we use it.

Our combinatorial approach makes this scrutiny of the platonic receptacle the more necessary and will figure in later discussions of particle physics.

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## Chapter 3

# The story of the particle concept

*Contents*

*History of the particle concept, Democritus, Aristotle, Epicurus. Reality or hypothetical view? Is there a limit to cutting things up ever smaller? Newton represented the unphilosophical mechanical view that dominated classical mechanics. Dalton confirmed the realism. Planck imposed the discreteness mathematically. Logical incompatibility of discreteness and this classical picture led to the quantum theory of 1926 based on the state/observer principle. Schroedinger's and Dirac's views of this principle. An entirely new attribute of the particle appears with 'exchange'.*

The physical world has through modern times been imagined by the physicist as a compendium of moving parts, and these parts move in ways that have a regularity and close similarity that tells him what the world is like and what it can do. This knowledge is enshrined in the laws of classical dynamics. Classical dynamics was formulated from experience of laboratory-scale bodies, in terms of a set of interlinked concepts — most notably mass, distance, momentum, and dimensionality. This set of generative concepts and its use as a universally applicable descriptive language, was the work of a set of thinkers among whom Galileo was the great innovator. Galileo also has something like the modern notion of 'force' but that was not quite the clear modern notion because it had extraneous elements and it waited to be tidied up by Newton. The set of concepts forming this descriptive language constitutes probably the most amazing and powerful achievement of the human mind.

One striking aspect of the set of generative concepts is their evident closed character:- the way that each is linked to others, with the linkages



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reproducing the same set. For example force requires for its specification mass and acceleration: mass has to be measured through the force it exerts under acceleration: and so on.

So successful was classical dynamics that changes to it and limitations to its applicability seemed unthinkable and this had consequences for the development of the quantum theory that we well know. To this scheme was added the idea of a smallest bit: together with the idea that there were a small number of different kinds of bit: and that the bits of any one kind were identical. These last ideas were assumed in the classical theory though possibly as a hypothesis. After Planck and Thomson and the others, it became accepted experimental knowledge. People would have said that if there were particles they would naturally obey the laws of classical dynamics since all went on in one world.

We arrive in this book at a view of the particle that is a far cry from the view just outlined of it as just a small bit of matter. The new view needs careful statement and in this chapter we first look in general terms at its main features. We start by placing it in its historical context.

Democritus (460–370 B.C.), is the most important figure in the early history of atomicity. He evidently owed much to his teacher Leucippus. Democritus separated space, or the void, from "Being" or the phenomena that went on in the void. The void, for him, was an infinite space in which there moved an infinite number of atoms ("atoma" means *indivisible*). His atoms are eternal and indivisible, and so small that their size cannot be diminished. The idea appears at this stage, therefore, that in cutting things up smaller one reaches a limit. This idea of course appears extensively in later physics, and whether or not Democritus is really the origin of it he does not seem to have analysed it or said more about where it came from. The different qualities of the atoms were meant by Democritus to be explained as different combinations or configuration of the atoms though he seems not to have elaborated on this vital idea but rather to have returned in a circular manner to giving the different kinds special properties in their own right (roughness or smoothness, for example).

Aristotle was critical of Democritus for introducing the idea of 'minima' or entities of the smallest conceivable size. He supported the 4-element theory (earth, air, fire and water) and discussed the transformations of one into another but does not seem to have exploited the analysis of nature into 'atoma' and is therefore hardly a part of the development of the particle concept.

The generality of principles from which Democritus begins is helpful for

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us and tends to be lost in the subsequent specialization of the principles as the particle began to take its modern forms. We find this narrowing down beginning with Epicurus. Epicurus (*c.* 310 B.C.) believed that everything in the world had a natural explanation, which meant an explanation in materialist terms. The idea seems to have crept in at that stage that explanations in terms of psychically induced, or caused, effects were not to be considered as proper explanations. Evidently 'explanation' was to be material explanation. For Epicurus the universe is finite and eternal and everything in the universe is made up of atoms. Further; even living things are made up of atoms, and it should be possible to explain the mind and its senses through the interaction of these.

In support of Epicurus' development from Democritus, one could see by carefully observing nature, that there were in fact a far larger number of different elements, and by 400 B.C. it was commonly believed that these diverse elements existed as individual particles or *atoms*. A further step would have been to say that the diversity of elements provided a number of different sorts, but that there would be many of any given sort. These would be all the same, or identical. The universe consists of bodies and the void. The bodies may be compound in which case they are composed of elements (atoma) that are indivisible and unchangeable. The elements are not all of the same size, but there is no suggestion that they fall into classes whose members are of the same size.

What can be said in general terms about the views of the ancients that led to the concept of the particle? The most important step in the path toward the modern particle that became current with them was the idea of different classes, each class having a unique type of member but with members of that type all the same. This idea was assumed in the whole of later practice. It derived its force from the view that the process of cutting up the world ever smaller must have a limit. Given that whole point of view, the term 'particle' had become appropriate.

Did the early thinkers believe that particles were real, or might they be hypothetical? We are familiar with one argument in the physics of modern times that holds that the real world is a continuum with fields pre-eminent, and that atomicity is a theoretical imposition that may well be wrong, and we know that that view had a lot of force in the last century. More recently the emphasis has swung back to realism over the particle. Both views were embraced by various of the early thinkers and the tension between the views was always there.

On this matter of the particle, history seems to take a leap to the six-

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teenth or seventeenth century. Almost everything in mechanics can be traced to the monumental work of Galileo, but Galileo wrote about bodies without bothering very much about limits to their size, and therefore whether they were particles. For that concern we move to his close successor Newton.

With Newton we plunge into the crudest possible material picture of the particle. His very well-known opinion that in the beginning God formed matter in solid, massy, hard, impenetrable moveable particles (see Chapter 4 for full quotation) used the God-language to circumvent any discussion of the deep questions about the particle concept that have occupied us. Particles were little balls with gravitational and inertial mass. His laws demanded matter cut up into bits (as had the mechanics of Galileo) and the space in which the bits were spread out is usually referred to as 'absolute space'. This term is probably best taken to mean that no consideration needed to be provided of the relations between bodies or particles that may be needed to fit them into space. Newton's position was in contrast to that of Leibniz for whom space was relational (see Chapter 2). Newton and Leibniz were contemporaries and engaged in close exchanges of view over the space question as is very well known, but there seems to have been little exchange between the two over particles. Whereas Spinoza saw the world as simple comprehensive substance, and Descartes had extended matter, Leibniz postulated many discrete particles — each being simple, active and independent of every other. These were examples of his monads. The wide sweep of the monadology made no impact on Newton who was content to leave the particle concept unanalysed. Evidently the excitement and exhilarating sweep of the new mechanics (perhaps the most remarkable achievement of human thought) was allowed to carry the conviction that here one had the description of reality direct, so that no one bothered with the doubt that it might not apply universally and on all scales of magnitude — down indeed to the particles.

The contemporary of Newton, Boscovich (1711–1787) took an important step in the history of the particle concept. In contrast with Newton who did not analyse the actual impact of particles on one another, Boscovich, in his "Theory of Natural Philosophy" (1763), thought about the forces that must accompany the impacts in a way that was so modern as to mark a real change. It is exactly as though Boscovich were describing electromagnetic forces, though of course the concepts of electromagnetism did not then exist. He inferred that there must be forces of attraction and repulsion at work between particles of different kinds that had to be specified in detail, and

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was explicit about the changes from attraction to repulsion that would have to be precisely associated with the varying distances between the particles at each moment, if the particles were to have their mechanical stability as the centres of fields of force.

The centuries following Newton are a history of how sophistication over the particle concept was forced by experimental facts that fell outside the Newtonian picture. The steps are so well known as not to need much comment here, but our (not so hidden) agenda will be to show, emerging outside and beyond the accepted picture, the need for the view of the particle that appears in the rest of the book (starting with the process theory of Chapter 6).

The studies in chemistry by Dalton showed that the atoms had indeed the material reality demanded by Newton, but revitalized older conjectures that we described earlier that matter was constructed out of different species of particle — all the members of one species being the same. It was common for people who held Newton's views nevertheless to hold that atoms were fictional structures in continuum physics, but Dalton's step — taking matter to be constructed out of different species of particle, refuted that position.

Now we take another step. The discovery of the electron made the lingering idea that atoms were a convenient fiction in spite of Dalton, out of the question. Later, Millikan's observation of discrete charges on oil drops, where their motion advanced in jumps would force the idea that they were being impelled by one, or by two, or by more units of charge (later seen to be electrons) reacting to a field. First, however, the guiding spirit was that of Planck. His was the simple approach of forcing on the experimental world a *mathematically* specified discreteness in response to an experimental need and the precision of the agreement of his numbers with experiment forced it to be taken seriously against vigorously expressed objections that no explanation of the mathematics had been provided (*Meine Herren: dass ist kein Physik!*). The difficulty in jumping from any numerical scheme to physics was discussed in the last chapter.

The problems posed by Planck's work persisted up to the Bohr atom: Bohr put some classical dynamics into the behaviour of the particles composing the atoms. The theory was by then so successful that it had in some way to be right in spite of its incomprehensibility. To get rid of this incomprehensibility was the task of the quantum theory. The success or failure of the quantum theory in this task will be assessed in Chapter 11 where we address what we call the state/observer philosophy — taking that to be

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its central argument. We shall find this philosophy to fail — at any rate so far as the understanding of the discreteness of the elementary particle is concerned.

Our present purpose is only to pick out from current thinking on quantum physics those changes that it has made in the concept of the particle itself. There are some such changes whose evident importance is not acknowledged. Thus in quantum mechanics the Schrödinger equation is usually taught as describing the behaviour of *one* particle. However when the theory is "made relativistic" in the form of Dirac's equation, it turns out to be impossible to look at it that way (notwithstanding that it is usually called "Dirac's equation for the electron").

The most important change follows from the appearance of "exchange". Exchange will be discussed in Chapter 8 in the rôle it plays in the theory of fundamental particles and in particular in the quantum theory. For example the concept of exchange provides a background into which one can fit the modern discovery of the mesons — the scope of the concept being expanded as more mesons were found.

That is the conventional view of exchange. However we wish to show that the very appearance of exchange altered the idea of the particle itself, and did this in a way that our theory made comprehensible. We started with the identification of our basic level multiplicities as the origin of the coupling constants. The fine-structure constant is the most prominent of the coupling constants. It is usually presented as a dimensionless ratio of atomic constants that are individually measures of particle properties. We calculate for it a very exact value, but that calculation is quite independent of those particle measures, and they are only associated with it later on. That constant does indeed come from a stage in the developing construction of every particle but the existence of each such particle depends on there being more than one of them in combination. We could therefore say that the exchange concept is built in. It marks the point at which the particle idea swings in the direction of the process theory. With exchange, particles cease to be the unanalysable individuals that are reached at the end of a variety of experimental investigations, and take on properties that derive from the mere existence of two at the same time. These properties are thus mutual. As described in Chapter 8, a mutual force is explained away by postulating a third particle that has the new rôle of travelling back and forth between the original two. An energy goes along with this motion and since there is energy there will be force. No details are given of the mechanics of this travelling back and forth motion, and this is because it is

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all just a *façon de parler*. It is much clearer to explain the exchange idea as something quite new.

The fact is that the particle concept as it existed during the reign of quantum theory is not adequate to handle exchange, and we ask whether our particle picture can do any better. Our answer is 'yes' because the essentials of the exchange concept exist through the hierarchical structure. In that, the quadratic group representing the primary dimensional structure is repeated at a second level. Then the combined group structure can be used as a unit, or else we can persist in using both separately. The process view requires us to combine both views — switching between them. There lies the exchange notion: you need both, but simultaneously have to treat them singly. Indeed this picture does not provide the particle buzzing back and forth, but as we have argued something would be wrong if it did.

The appearance of recondite kinds of particle properties brings to mind the quark. This is indeed needed to complete the current picture of atomic constitution but the quark cannot be said to be a part of the *spatial* particle picture. One may insist that with quarks the particle picture has had to change, but since they cannot be isolated they are something different and we leave discussion of them and their conceptual place to later chapters.

Let us anticipate the conclusions of this book to see where its argument takes the particle concept. A fundamental construction process generates levels of increasing size. The evidence is strong that the ordinal numbers that give the magnitudes of these levels correspond with the characteristic numbers (coupling constants) of fields or particles. Could it be right to say that the elements of the levels are themselves particles? The answer has to be NO if by 'particle' we mean a free-standing entity capable of moving about among others. The generative interactions are mathematical entities that have only some of the properties implied by the word 'particle'. In particular there is no space at the stage where the experimental connections with physics are derived. How this limited account is extended to provide for ordinary dynamics will be explained in Chapter 9. It is important to realize however that the first incomplete stage is inevitable in the provision of the particles, and that some of their essential properties have already appeared at that stage.

The discovery of the constants and the great part played by Parker-Rhodes was indeed prompted by physical theory rather than through the development of the process theory as we have portrayed the history in this chapter. That appears in Chapters 4 and 5.

The elementary interactions in the 'process' thus have to have a sort

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of physical reality even though we deny them the status of fully-fledged particles precisely because there is no way of getting to fully-fledged particles except by passing through that intermediate stage. This progression in stages to the particle is without parallel in current physics and it is the conclusion to our story of the particle concept.

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# Chapter 4

# Dimensionality

*Contents*

*Eddington's program of finding values for dimensionless constants. Symmetry of spatial dimensions invoked in answer. The quadratic group S fundamental. Complexity had to be introduced by putting together a multiplicity of groups. Association of two, gave enough complexity to define electromagnetism. No metric used. Multiple feedback models constructed (Gordon Pask) to provide a metric. Parker-Rhodes formalized these principles and discovered the algebraic hierarchy with its striking progression of numbers.*

The last chapter was a historical survey of the development of the particle concept. The present, by contrast, concentrates on the way the authors have developed the combinatorial ideas, and will be expanded later.

The thinking of Eddington played an important part in the discussions from which this book arose, but the theory expounded here is totally different from Eddington's. Apart from his important work in introducing and explaining Einstein, Eddington was well-known for his view that much that was accepted as theoretical analysis of experiment was really imposed by the way we thought about it. In contrast with us, Eddington defined 'particle' as "a conceptual carrier of a set of variates". The word 'variates' probably is just a hangover from Eddington's use of statistical methods to analyse astronomical observation. 'Conceptual' probably is his way of saying that he is introducing his philosophical position. Eddington called his position "selective subjectivism". This position was supported, in Eddington's view, by the possibility of obtaining certain important constants prior to experiment. Not surprisingly, this view drew upon itself criticism



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amounting to scorn for seeming to replace proper empirical method with what was labelled "a priori" thinking. In fact 'a priori' became a convenient word to dismiss Eddington. We shall find, in this chapter, reasons to reconsider Eddington's arguments: the basic numbers that we find generating particles are reminiscent of his position.

In the period soon after Eddington's death, the authors were persuaded of the correctness of his policy of obtaining numbers characteristic of foundational physical theory from algebraic considerations. His efforts in "The Relativity Theory of Protons and Electrons" and later in "Fundamental Theory" could not be sustained. Nevertheless we thought his motivation was well-based — and we tried to find out where the thinking had gone wrong. Eddington's calculations had started from the 3 and the $3 + 1$ of space and space-time as necessitated by the structure of a Clifford algebra. Accordingly he saw them as existing in their own right beyond their geometrical setting. This procedure seemed to us to require an investigation of what dimensionality itself really was.

Somehow some vital numbers are introduced into physics at the inception of efforts to explain any properties of particles. Famously, Newton[7] said "All these things being consider'd, it seems probable to me, that God in the Beginning form'd matter in solid, massy, hard, impenetrable, moveable Particles, of such Sizes and Figures, and with such other Properties, and in such Proportion to space, as most conduced to the End for which he (sic) formed them; and that these primitive Particles being Solids, are incomparably harder than any porous Bodies compounded of them; even so very hard, as never to wear or break in pieces; no ordinary Power being able to divide what God himself made one in the first Creation". Modern physicists would look for the continuing identity of particles of a given sort to be understood within the ambit of quantum theory, but they follow Newton in accepting the sorts of particles as a given fact of Nature (or God).

Our seminal idea came as follows. We said that when we described the world as spatially three-dimensional we were simply drawing attention to a very strong symmetry. If we say that there are a number, $j$, of dimensions then we assert that if we build a set of relationships from these, then each such relationship remains true in whatever order we take the $j$ dimensions. This symmetry was best shown at its simplest in an algebraic structure with a single binary operation. The significance of this binary operation was not yet apparent. The symmetry then requires that any equation $pq = r$ which holds in the structure will imply that $qp = r$ so that the operation is commutative. But from $pq = qp$ it will follow that $p^2 = q^2$ so that all

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the elements have the same square; call it $e$. Moreover $p^2 = e$ implies that $pe = ep = p$, so that $e$ is a (two-sided) identity. Finally, if $p(qr) = s$, then $r(qp) = s$ and commutativity leads to associativity, $p(qr) = (pq)r$. We are therefore dealing with an Abelian group in which every element is of order two. It is well-known that such a group is a direct product of cyclic groups of order two: $C_2 \times C_2 \times \ldots \times C_2$. $C_2$ is itself a trivial example of the symmetry so that the simplest non-trivial structure is $C_2 \times C_2$ which is the quadratic group (Klein's 'Viergruppe') $S$.

However the three elements $a$, $b$, $c$ also possess a stronger symmetry. If any equation $pq = r$ holds in $S$, it remains true if any of $a$, $b$, $c$ in the equation are replaced by other elements (as long as different elements are replaced by different elements). Thus $a^2 = e$ implies $b^2 = e$. $S$ is unique in having this symmetry. Here, then, are the primary numbers 3 and 4.

The question that then confronted us was how 'could such a view of dimensionality replace the usual way of representing the results of measurements as ordered sets — namely by coordinates?' Such sets could not be based upon the $a$, $b$, $c$ and $e$ of the group $S$. It appeared that the only way forward in increasing the range of numbers available to represent measurement was to associate two $S$-structures to form a product algebraic language, so that one could, as it were, change gear and go up a stage of complexity. The idea of hierarchical structure was born.

What was still missing in our thinking at this stage was how exactly to relate two structures at different levels. We simply supposed that the complexification process (attaining greater descriptive power by combining as many of the structures already created) could be continued. The treatment of a coordinate space remained for future thinking.

The relationship between mechanics and electromagnetism can satisfactorily be understood in terms of this progression of stages of complexity, as will be shown in Chapter 7. We called this primary representation abstracted from any coordinate space a *theory-language*, as we have described in Chapter 2. Eddington could be said to have used the level idea in his calculation of the fine-structure constant since he used the numerical dimensions of space-time in juxtaposition with the 16-term energy-momentum tensor. He did not use the two as stages in a build-up process as we find essential however. Not only did he not see how to relate the levels (and at this point neither did we) but neither could he explain how the hierarchical process of going from 16 to 256 elements, and in one calculation to $256^2 = 65536$, would ever terminate. He was reduced to the rather weak statement that physics does not seem to need a greater level of complex-

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ity. We refer to this as 'Eddington's difficulty' and return to it in the next chapter. To our way of thinking it was essential that each new level should be constructed out of the operations or operators that described what was going on in the previous level, so that nothing new and inevitably arbitrary should be brought in, though we could not then see how to do that.

The next question was how we should incorporate the empirical input to the structure. How could the numbers that gave the results of measurements find a place? There were evidently 4 interacting elements at the first level and 16 at the next, and we knew absolutely nothing about their structure except that three of those at the first level were equivalent. We thought a model might be constructed that would represent the way the elements of the levels continuously interacted with each other, while rigorously preserving the basic symmetries. Then we might impose constraints on the activity of the model to introduce a 3-and-one asymmetry artificially. Then we might find that that restraint was in some way responsible for the values of the dimensionless coupling constants that we had in our sights, and that the results of other measurements that had not the total fixity of being dimensionless might follow a similar pattern.

Gordon Pask was interested in the idea. He thought that one could build a machine in which (a) every element was exactly the same as every other, and (b) each could be connected with every other in such a way as to run through all the possibilities of connexion. Pask provided $4 + 16$ units which were high-grade amplifying switching units that had been sold off as unneeded wartime equipment. The feedback loops connected the 16 units with each other in pairs *via* the 4 units, and the connections were discrete — being controlled by switches that brought in the discreteness. The choice of connections that existed at any given time was controlled by the state of the units being connected. Pask thought that if you connected everything with everything else while observing their total symmetry you were representing everything that could happen and therefore introducing nothing arbitrary.

These units, using thermionic valves of course, were quite large, and the whole lot together with the ancillary switching units sat on benches occupying a large room. They used quite a lot of power — several kilowatts. This wondrous machine continually changed its configuration and the activity could be heard going from place to place in it. This technique appeared in most of Pask's actual learning and teaching machines. Input to the 16-level was randomised to compensate for having to cut off the construction somewhere.

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It was intended to use the machine by imposing a constraint on its working corresponding to the physical requirement that one of the 4 units differed from the others — distinguishing space from time. One would then see if this imposition produced numerical effects that might be interpreted as the coupling constants, and perhaps exhibit these in a larger class of numbers that were more like continuous variables.

Bastin had been offered the use of the PACE analogue computing equipment in Brussells in the hope that that would make our investigation more precise. At this stage Frederick Parker-Rhodes came on the scene and Parker-Rhodes accompanied Bastin on one trip. He was to come again but was prevented by flu. He had already maintained that we seemed to be doing what binary algebra was designed for. He used strings of binary units, written 1, and 0, and used them to express the ideas of a hierarchy of levels and of the construction of each given level out of elements of the preceding one that was advocated by the authors.

When Bastin got back Parker-Rhodes had worked out the essentials of the bit-string hierarchy which is described in the next chapter. It was noticed at once (including by Parker-Rhodes) that the numbers that characterized each stage in the generation of levels were very suggestive of coupling constants of particles with their fields. The story has got about that Bastin asked Parker-Rhodes to produce numbers like these and that he succeeded in doing that by fiddling about with algebra. This tale does not do justice — particularly to Parker-Rhodes. In fact he was explicitly trying to represent in binary algebra the two principles:- (1) hierarchy construction in levels of increasing complexity, and (2) the construction of each new level using as elements the operations at the previous level.

Another story is entirely accurate. A few days after this denoument Parker-Rhodes came, deflated and actually apologetic, because he had come upon the fact that his hierarchy progression stopped. We commented that he had discovered why gravitation is the weakest force and was seeing that as failure!

No more was done with the mechanical model since all energies were turned for some time to exploring the consequences of Parker-Rhodes' algebra.

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# Chapter 5

# The simple bit-string picture

*Contents*

*A hierarchy of levels used the idea of any one level being constructed out of the operations at the preceding level. Parker-Rhodes gave this idea digital or combinatorial form. The unit for such physics was the discriminately closed subset. Characteristic numbers emerged. These provided the setting for particles.*

This chapter describes the early history of the idea of the *levels* that came to assume such importance in the process theory that principally occupies this book. One would have to say that current physics is a *one-level* theory. Of course if there is only one level then the idea of level hardly comes into play. One might perhaps imagine that electromagnetism had been thought of as a new and different kind of thing altogether from classical mechanics. Then the 'forces' between charges might have had to be built up quite differently from the forces between masses. One word 'force' would no longer suffice. Physicists do not think this way since the unification of these forces is regarded as a great success.

A quite different way of thinking would appear if one had always to construct a piece of theory of limited application as a first stage, and only then to build upon and use what one had done in order to encompass a wider range of experimental knowledge. One would then have more than one level and the resulting system could be described as *hierarchical*. This different way of thinking has been employed in the process approach of this book, and we look now at the way it had already appeared before a concerted process view had been formulated which later came to incorporate it. The writers did have such a theoretical nucleus given by their studies of the



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symmetry properties of $S$, the quadratic group, and it seemed to them that the only way to combine such structures was by appealing to a system of levels.

At this point Frederick Parker-Rhodes, in the context explained in the last chapter, took up the idea of basing physical description on a hierarchy of levels in which a new level could be constructed using operators at the existing level to form new elements of greater complexity at a new level. (This construction was to be the way increasingly large numbers representing physical quantities could come to exist. Later, it became clear that these levels should be interpreted as the set of particle interaction strengths, or of the fundamental fields.) Parker-Rhodes formalised the ideas. He introduced for the first time a completely discrete or combinatorial calculus in which things in the world were represented by strings or vectors of symbols 0, 1 (bit-strings). Any two vectors of a given length could be brought together to produce a new one by operating with the two elements in a given place using the symmetric difference operation, that is, addition over the field $Z_2$ with only two elements. A new vector would arise if the starting vectors were different; otherwise a string of zeroes would be produced indicating that they were the same. This process later came to be called *discrimination*.

Physical importance would attach to any set of vectors that was closed under the discrimination operation applied to any two different vectors. This was called a *discriminately closed set*. Every set of vectors will generate its *discriminate closure* by repeated application of discrimination to every two different vectors. In the world this will happen given enough time.

So far, Parker-Rhodes' structure is just an isomorphic copy of the $C_2 \times C_2 \times \ldots \times C_2$ groups found by the authors. He represents the (Abelian) group representation by addition over $Z_2$ and accordingly $e$ becomes the zero, the identity element in addition. What was important in Parker-Rhodes' formulation was that it provided the precise relationship between levels. Moreover it turned out to have solved Eddington's difficulty over indefinite continuation because Parker-Rhodes' sequence terminated.

Operations upon the vectors were defined as square matrices over the binary field — thus introducing a second operation written as multiplication. A discriminately closed subset generated by a subset of the generators of a level was represented by a square matrix leaving every element of the subset unchanged. These matrices were therefore the generators of the new level and for that purpose they were rewritten as column or row vectors

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of squared order. Elements of the new level thus have to be mapped onto a space of order of the square of the preceding level. Since the number of significant entities increases faster than the size of the vector space the process comes to an end.

Because physical importance will be attached to any set of vectors that is closed under the discrimination operation there must be a limit to the number of discriminately closed sets at any given level, and this limit is the characteristic number of that level. Parker-Rhodes drew our attention to this sequence of these numbers, which has the value 3 in the simplest case and thereafter follows the rule $2^r - 1$, where $r$ is the number computed for the previous level. If we take cumulative sums of the numbers at the levels to give the total available numbers then these come out 3, 10, 137, and $\approx 10^{39}$. Parker-Rhodes could not justify the formation of these cumulative sums, but as we shall see it was an intimation of our fundamental principle of *process*.

The approximate correspondence of these numbers with the reciprocals of the coupling constants of the fundamental fields, including the astonishing gap between the electromagnetic and the gravitational numbers, and with the fact that the sequence cannot be continued, has been sufficiently persuasive to promote further work over a long period.

Parker-Rhodes originally saw the discriminate closure of the sets by analogy with the eigenvectors of quantum theory, but we have preferred the terminology that was to come later. In particular the idea of the vectors being physical things that reacted to others in an unknown statistical background was foreign to Parker-Rhodes' thinking. Parker-Rhodes had succeeded in constructing a system with levels and solved the level-change principle that was necessary to incorporate the basic principles used by the authors in a way that placed it within conventional theory. Of course it raised as many problems as it answered. There were no clear physical answers to the obvious queries:- why bit strings? Why start with just two bit strings? Why square matrices for level change? Why eigenvectors? Why form cumulative sums of 3, 7, 127?

It will be shown in the next chapter that the process theory yields a more complex algebraic structure. This structure contains the Parker-Rhodes algebra in a peculiar way. By exhibiting the Parker-Rhodes algebra in this way we answer the questions above. We present it here in spite of its crudity so that readers whose interest is primarily in the physics will be able to see what the whole argument is about.

The setting in physical theory of the numbers is given in Chapter 12,

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while the full calculations of the most important and familiar of the numbers appear in Chapter 6. It may seem strange that so much can be said about the precise values of the constants before their place in current physical theory is described. This apparent presentational confusion is actually what is demanded by our general approach. We do in fact start from algebraically generated numbers which will provide our mode of construction of the physical world through their progressive development, and that development is the world of physical theory.

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## Chapter 6

# The fine-structure constant calculated

*Contents*

*The inverse fine-structure constant is calculated as* 137.036011393..., *agreeing to better than one part in* $10^7$ *with the latest experimental value,* 137.035999710.... *The statistics that generates the base number* 137 *from the process theory is progressiviely refined in a long calculation, the details of which are set out at length in two notes at the end.*

In earlier chapters we described the historical path that led us to a progressive construction that had stages in which we found the numerical characteristics of fundamental particles. This constructive picture is unfamiliar in physical theory and if we wish to maintain the numerical successes obtained this way we have to explain the constructive picture. The present chapter represents a change of gear. In it we ignore the historical development in order to provide a formal basis for the construction.

The chapter falls into two closely related parts. The first part fulfills the promise of the last chapter by exhibiting the Parker-Rhodes algebra as determined in a particular way by the more general algebraic structure derived from the notion of process. The second part then calculates a close approximation to the fine-structure constant. In this calculation an important part is played by the two related algebras, that derived from process, and Parker-Rhodes' original one.

We postulate a universe that is constructed progressively, and so we speak of process. We expect physical principles to emerge from our formulation of the process. These principles will be valid for all experimental procedures and will guide them. In the process elements are constructed in a sequence. It is convenient to speak of 'elements coming into play'. To



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start with, we do not know what meaning to give them: any meaning that they will eventually acquire is solely as a consequence of the construction process and the formalism develops with the construction. This approach is reminiscent of Brouwer, and Brouwer has been an influence on the authors though this theory is not intuitionistic. To be a sequence implies that the process determines whether a new element is the same as one already in play or not. This determination is of paramount importance in our theory. Such an emphasis is by no means novel. One finds it already in the nineteenth century with Sir William Hamilton. John Stuart Mill summarises Hamilton's view with approval: "We only know anything by knowing it as distinguished from something else; all consciousness is of difference; two objects are the smallest number required to constitute consciousness; a thing is only seen to be what it is by contrast with what it is not." (in his *Examination of Sir William Hamilton's Philosophy*). The difference from our process theory is that we have abstracted from the epistemic character of Hamilton's statement.

However the determination is done, finding that $b$ is the same or different from $a$ is a new element, $c$ say, in play. The binary operation $a\,b = c$ is called *discrimination*, and a primary object of our investigation is to determine what this operation is. It will turn out that it has to have different forms at different stages in the theory. When discrimination has been formalised it cannot be restricted to apply to discriminating between new and old elements only (since to do this would require the process to determine whether or not one of the two elements was indeed new or not and so an infinite regress would result). The discrimination must go on all the time so the process must be iterative. In the course of the construction elements may be deleted as well as coming into play.

The process continues without limit so there is a sense in which one might say it was potentially infinite, although we shall find that this continual development is restricted in a particular way. This is the Parker-Rhodes limit (see below). Here, a nod in the direction of Brouwer again since the finiteness is such that for each element to come into play the determination of its place in the sequence takes only a finite number of steps in the process.

A binary operation suggests a group in which the binary operation is the discrimination operation. But this will be an example only if the group satisfies the condition that the set of group elements that can arise as products of 2 different elements is disjoint from the set of products of equal elements (i.e. squares). Now think of the Cayley table (multiplication table)

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of the group. The restriction is that the diagonal elements can never occur in the rest of the table. But since each line of the table has all the group elements in it this means that there can be only one element occurring in the diagonal which must therefore be the identity. Hence every element is of order 2 and it is well known that the group is a direct product of cyclic groups of order 2. The identity is a signal that the product is of equal elements.

Another way of writing such a group is as a set of bit-strings (vectors over the field $Z_2$). The signal for equality is now the zero string. It is not necessary for the system to be a group. Another example would be to begin with the quaternion group in the abbreviated form familiar from quaternion algebra. This has three elements and an identity with their four negatives. Now modify the Cayley table by writing the identity in all diagonal places. Then $a\,(-a) = 1$ in the original table becomes $a\,(-a) = -a^2 = -1$ in the new one. The identity would then be the signal for equality, and this fulfils the condition above because the identity never appears elsewhere in the Cayley table. Just as the group had an isomorphic copy made of bit-strings so here there is a bit-string version with strings of length 3. One way of doing this is to number off the bit strings like this:

$$\begin{array}{ccccccc} 100 & 010 & 110 & 001 & 101 & 011 & 111 \\ 1 & 2 & 3 & 4 & 5 & 6 & 7 \end{array}$$

that is, in binary, though in the reverse order from the more usual one, and then to define $a \cdot b = a + b + H(a, b)$ where $H$ is called the *complexion* of the pair $(a, b)$ and is defined by

$$H(1,2) = H(2,3) = H(3,1) = H(u,u) = 0$$
$$H(u,v) + H(v,u) = 7, \qquad \text{and} \quad H(u+7,v) = H(u,v)$$

The system is not a group because it is not associative. It is a loop. We call it $Q^*$.

Because the argument leading to the complete determination of the discrimination operation is lengthy we begin with a summary of it, with the main conclusions. This will also introduce some technical terms. In the flux of discriminations a set of elements will usually be augmented or diminished. Physical importance attaches to sets that are not increased by random discriminations between the elements :

A *discriminately closed subset* (dcs) is a set of elements closed under discrimination of any two different elements of the set. This definition needs further qualification when the subset has one or two elements only. Details

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must be deferred to the full discussion.

The *discriminate closure* of any set of elements is the smallest dcs containing them.

A set of *generators* of a dcs is any set for which it is the discriminate closure.

A level of type $r$, $L_r$ say, is a set $G$ of $r$ elements, called *generators* of the level; together with the members of the level which are

(a) the elements of the discriminate closure of $G$,

(b) all those dcss which are discriminate closures of subsets of $G$ (including $G$ itself).

The *multiplicity* of $L_r$ is the number of different dcss which are members of $L_r$.

When all members of $L_r$ have come into play the process has *filled* $L_r$.

If further elements come into play the level is inadequate to describe the further ranges of experiment and an increase in structure is required. Such an increase is provided by :

The *superior* level to $L_r$ is that defined by a set of generators, one for each of the dcss of $L_r$.

For this increase of structure the process *goes up a level* to the superior level to $L_r$. The elements of this superior level are the dcss of the original level (together with their dcss of course).

The general picture will now be clear. The process starts with some level, which becomes filled eventually. It then goes up a level and repeats the filling up with the new elements (the dcss of the original ones). The detailed investigation shows that the construction of new levels stops quite soon for technical reasons that are of great physical importance. In one case only, when the initial level is one with two generators, a four-fold hierarchy is built up. In Parker-Rhodes' original construction the successive multiplicities of the whole system were 3, 10, 137, and $10^{38\cdot2}$. The approximate relation of at least the last two to the reciprocals of the interaction strengths is important for the connection to physics. We shall find analogous results in the exact theory.

In the case of a group a dcs is simply a subgroup with the identity omitted. If the group is, for example, of order 8 — $C_2 \times C_2 \times C_2$ — a typical dcs is $C_2 \times C_2$ of order 4 except that the identity is to be omitted. That is, it is the non-identity part of the quadratic group $[a, b, c]$ where $a\,b = c$ and so on.

In the bit-string expression with strings of length $n$ a typical dcs is the set of bit-strings of length $m < n$. Notice however that in each example the

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dcs may not be presented in the way just described. For example if $n = 3$ one dcs would be 010, 101, 111 which does not appear as a bit-string of length 2. But it is equivalent to it since the first and third bits are the same, so that one could be omitted. Similar qualifications apply to the group.

The dcss in the loop case are left to the detailed development as are details of what form the superior level has in each case. Suffice it to say here that the elements of the superior level in the bit-string case will be square matrices over $Z_2$.

We begin the investigation of the form of the discrimination operation by asking first how the process determines whether two elements at the same level are the same or not. If $a$, $b$ are in fact the same element then no new element can arise in the discrimination. Hence either $a \cdot a = a$ or $a \cdot a$ is not an element. The first alternative cannot achieve discrimination because the next step would have to be to check that the element on the right-hand side was or was not $a$: that is, exactly the same problem again. The second alternative is the only possible one and $a \cdot a$ is then a non-element, $z$ say, which must be unique so that its appearance removes the need for any further discrimination. We shall prefer the term *signal* to 'non-element' for $z$.

In order that $z$ may signal equality the binary operation must be such that when $a$, $b$ are different then $a \cdot b \neq z$. A structure with such a signal is a *discrimination system*. When $a$, $b$ are different elements their discrimination is then a third element: call it $c$. Then $c = a \cdot b$ is the discrimination of a putative new element $b$ against one already in play, $a$. This is different from the discrimination of a putative new element $a$ against $b$ already in play; so $b \cdot a = d \neq c$. However for obvious physical reasons $c$ and $d$ are closely related. We call this relation *duality*; say $c$, $d$ are *duals*; and write $d = c^*$, $c = d^*$. The notion of duality plays an important part in determining the form of the discrimination operation. It leads to the following further notions: two elements may be (i) the *same* or *identical*, (ii) *duals*, (iii) *essentially different*. Duality has been defined for $c$ and $c^*$ which come from two related discriminations, but the structure of the system is such that every element can be expressed (in many ways) as a discrimination, so that $a^*$ and $b^*$ also exist.

To determine when two elements are duals will require a signal for exactly the same reasons as for when they are identical, and this signal must be different from that indicating identity. We call it $y$, so that $a \cdot a^* = y$.

The second signal necessitates a change in the definition of a dcs. A dcs is a set of elements, so signals are excluded. The definition should therefore

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