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B. K. Ridley
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Things

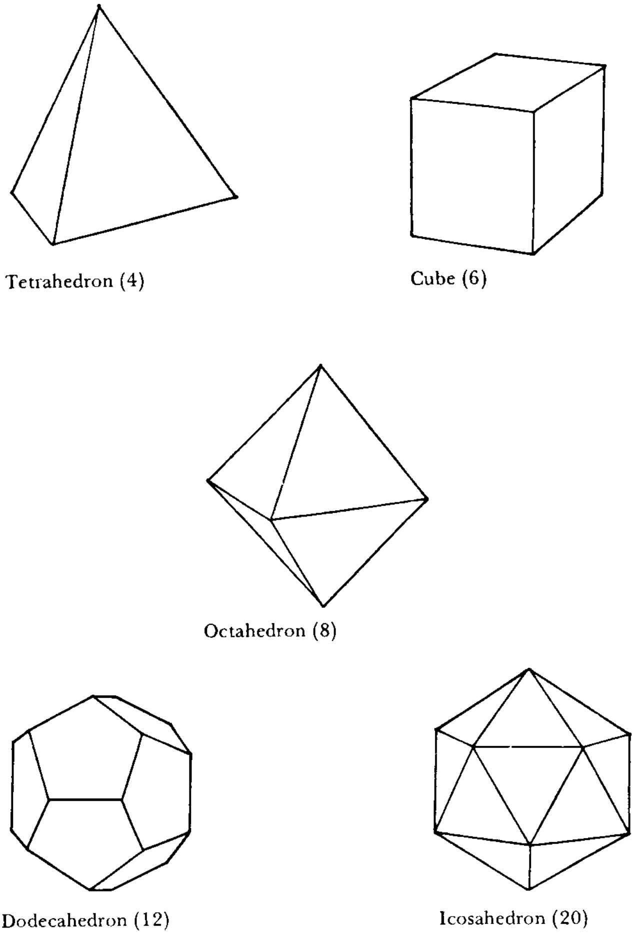
> The poet's eye, in a fine frenzy rolling,
> Doth glance from heaven to earth, from earth to heaven;
> And, as imagination bodies forth
> The forms of things unknown, the poet's pen
> Turns them to shapes, and gives to airy nothing
> A local habitation and a name.
>
> Shakespeare:
> *A Midsummer Night's Dream*

Physics is about the simple things of the Universe. It leaves the complication of life and living objects to biology, and is only too happy to yield to chemistry the exploration of the myriad ways atoms interact with one another. The living cell is clearly an impossibly complex system, and so, for example, is a surface – any surface. There may be the occasional flirtations with these topics, the one in biophysics, the other in chemical physics, but by and large they are terribly difficult to deal with. Cells and surfaces are not simple things.

It could be argued that simple things plainly do not exist. The Queen might boast to Alice that she could think of as many as six impossible things before breakfast, but she would be hard put to it to think of six *simple* things. But, to take a primitive example, what could be simpler than a chunk of rock, a stone that can be picked up in one hand and thrown? There is something very real and immediate about a thing that can be seen and felt and manipulated. And it is vital to have some understanding of how it can be moved around – a stone is the simplest missile, after all. A stone-age war department might have been keen to commission some customeroriented research on stone ballistics, but few physicists, unless heavily bribed, would touch it. A stone is too complicated. Its shape is horribly irregular, and think how intricate the flow of air would be over its rough surface. Far too messy to sort out what is general for all missiles from what is particular for this stone.

Then clearly one cuts the stone into a regular shape – say one of the five regular solids (Figure 1.1). An object

Figure 1.1. The five regular solids. In each case the number of faces is shown in brackets.



Tetrahedron (4)

Cube (6)

Octahedron (8)

Dodecahedron (12)

Icosahedron (20)

in the form of a tetrahedron, or a cube, looks a lot simpler to deal with because of the high symmetry. And how simple to have only five regular shapes to think about! Surely objects cut into such shapes must have an especially significant place in a subject professing to deal with simple things. The fact is they have not. The concept of the regular solids is a lovely one and important to apply given the slightest chance. Kepler tried very hard to construct a theory of the Solar System on this basis. The symmetry of the cube is particularly important in crystallography. Nevertheless, real objects in the form of one or another of the regular solids do not play any role in physics. The reason is that the regular solids suffer from corners and edges. Their regularity is only relative. They do not look the same from whatever point of view one cares to adopt. Some directions are 'more equal' than others.

Getting rid of the corners and edges leaves us with *the billiard ball.* To a physicist a billiard ball is a lovesome thing, God wot! It has an archetypal significance in the subject, unrivalled even by the weightless string. It looks the same from all directions and it can be handled, thrown, swung or rolled to investigate all the laws of mechanics. Our stone-age natural philosopher would have insisted on a grant especially ear-marked for the production of spherical stones. But, in spite of the undoubted glamour of our billiard ball, it is still not simple enough. Its flaw is that it has a surface and, as we mentioned at the beginning, a surface is not a simple thing. Yet any object, if it is to be distinguished from its surroundings, must necessarily possess a surface. That being so, we idealize the surface away by pure imagination – infinitely sharp, perfectly smooth, absolutely featureless. And while we are idealizing, let us make the billiard ball absolutely uniform, of infinitely hard and perfectly elastic material – shall we call it *utopium*? Now there is the first simple thing of physics – a billiard ball made of utopium.

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Yet nothing like it exists. The utopium ball is a product of, literally an ideology, and nobody, being dispassionate, believes entirely in the products of an ideology. That is, paradoxically, its strength. We know from the outset it is wrong, in the strict sense that it cannot possibly be exactly true, and so an assessment of how wrong it is in the particular case can begin straight away. Its conceptual simplicity is invaluable. At one end of the scale the utopium ball can double for a star swinging around a stellar cluster somewhere in a galaxy, or a planet orbiting a sun. At the other end it can be an atom – one of many, perhaps, arranged in the regular lattice of a crystal, or wandering about as the tiniest component of a liquid or gas. Given a positive electric charge it can attempt to pass as a proton; given a negative charge, an electron; or, given no charge at all, a neutron. The model of the atom described by Bohr consisted basically of charged utopium particles. Many properties of solids, liquids, gases and plasmas can be quite happily treated in terms of them. In short, the utopium billiard ball is the ideal elementary particle of classical mechanics. Though it is a failure as a useful concept to use in the quantum realm – electrons, protons and neutrons do not behave like billiard balls – its usefulness elsewhere makes it one of the archetypal models in physics.

But nevertheless it is a concept – a product of the imagination. It does not exist out there in the real world clamouring for attention. It is an idea. One day in the future perhaps there will be a subject called Erewhon Physics (to borrow from Samuel Butler), dealing entirely with possible but unreal universes, a subject which has come into being because the physics of the real universe has all been worked out and people still want to carry out the activity. A subject like that would consist purely of things of the imagination and some sort of self-consistent collection of rules. It would really be a branch of mathematics. Real physics deals with

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things which exist out there in the real world quite independently of our imagination. Yet it uses objects like our utopium ball which look as if they belong to an Erewhonian sort of physics rather than the real world. The reason is that such objects are more than ideas – they are ideals, chosen for their simplicity and used as model starting-points in the process of understanding the character and behaviour of real things. Physics is above all a model-making activity.

While we are on the subject of conceptual things, let us attempt a fine distinction between what we may call physical conceptual things and mathematical conceptual things. The utopium billiard ball is a physical concept. It can be obtained from the real billiard ball by extrapolating a few real properties to the ideal limit. The ideal behaviour differs from the real in degree only, but not in kind. Compare that with another archetypal thing of physics, *the point-particle*, much beloved by theoriticians. The point-particle is a mathematical concept because it is different in kind from a real particle – it has zero extension. It is therefore more unreal than our billiard ball, and we have to be careful not to push the concept too far. Theories of elementary particles are bedevilled by infinities which arise from the enthusiastic application of the point-particle concept. Nevertheless, whenever the extension or the internal structure of a particle is not an important factor, the simple concept of the point-particle is an invaluable tool.

But why concern ourselves with conceptual things when there are so many real identifiable things to be investigated and their natures understood? Unfortunately one cannot avoid a large degree of abstraction. There are just too many separate, unique, real objects in the world to appreciate them as individuals. All we can hope to do is classify into groups and study behaviour which we believe to be common to all members of the groups, and this means abstracting the general from the particular. All sciences function this way, but how suc-

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cessful such abstracting is depends a lot on what is studied. The budding science of sociology has the problem of coping with the effect of individual human beings. Although an amoeba with a strong personality has yet to be discovered, biology has always to keep a wary eye open for the effect of individual living things. Only in the study of inanimate matter can one be really successful at coping with the particular. But in doing so one has to invent ideals like the concepts we have been discussing, trusting that the psychology of the electron as a serious study is a long way off.

Even so, the forms taken by inanimate matter are fantastically varied. How to cope with such complexity?

One attempt is to see all the matter within our immediate experience as just one huge body, the Earth. The *Earth* is then our first real thing of physics. The structure and composition of this vast object is incredibly complex but it can behave, nevertheless, in simple ways, almost like a large version of our utopium ball. The *Moon*, the *Sun*, and the individual *planets* also follow as identifiable objects in the same realm. Though each is unique, demanding a field of study all to itself, each is also an example of a general thing. This emerges with the concept of the *Solar System*. The Earth becomes one of the planets, and the Sun becomes the local *star*, one of 10^{11} stars inhabiting our *Galaxy*, which itself is part of a cluster of galaxies, one of many inhabiting the *Universe*.

Here are all the large-scale real things of physics – the Universe, containing all matter, and the only truly unique thing to be studied in physics; the star, atom of the galaxy; the planet, satellite of the star. Universe, galaxy, star and planet all lend themselves to the modelling powers of the chi medium (chi medium is explained on page 9), the endlessly versatile utopium ball, and sometimes even to the blandishments of the point-particle. They represent matter on the grandest scale and, when the scale is so large, one can often afford to overlook the details; but not all the time. In fact the

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study of stars positively demands a detailed understanding of the structure of matter. So we are directed back to the study of the forms which inanimate matter can take.

In this we are vastly helped by the discovery in chemistry of the *atom*. The simple thing of matter is the atom. And there are only about a hundred different sorts. All the intricate varieties of substance which are presented to us are collections of atoms, of one type, or mixed, or chemically combined with others. The atom is too small to see directly (unless one regards the images displayed by an instrument like the ion microscope as direct viewing) but their existence, supported by overwhelming evidence in chemistry, and in the last hundred years in physics, is not in doubt.

Many of the properties of the matter surrounding us, particularly the mechanical and thermal properties, are understandable in terms of hosts of microscopic billiard balls posing as atoms. Sparsely scattered, they represent a *gas*. Densely packed, with some short-range ordering, they look like a *liquid* or an *amorphous solid* like glass. Impose a long-range ordering and we get *crystals*, liquid crystals as well as solid ones. Put them in chains like a necklace and they become *polymers*. They can hunt around singly, as elements, or in packs, as molecules.

Nature has provided an immense simplification in allowing us the atom, but it is not enough for physics. Physics craves simplicity, and coping with the detailed properties of each individual atom, from the simplest – hydrogen – to the most complex, presents itself as a mammoth task, thankfully left to the fortitude of chemists. Of course, physics cannot escape from this entirely, nor would it wish to. It must appreciate certain characteristics peculiar to each atom, but the fewer idiosyncrasies the better. Thus the physicist is delighted to find that all gases, whatever atoms or molecules they consist of, behave in a roughly similar way; so much so that he invents an *ideal gas* as a

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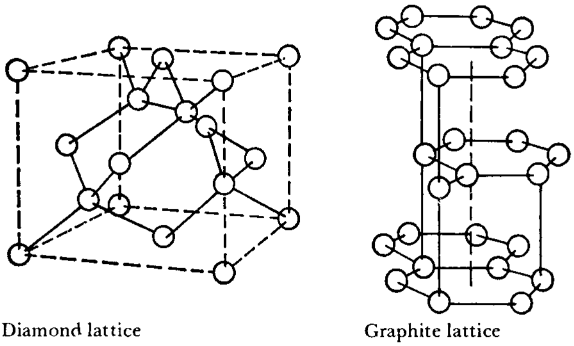
paradigm. He finds that fluids tend to flow in certain ways which are quite independent of their chemical (atomic) properties. He invents the concept of the *perfect crystal*, a vision of rows upon rows of atoms, in exemplary order, yielding properties which depend as much on the symmetry of the arrangement of atoms as on the chemical nature of them. Rather than be grateful that the number of different sorts of atom is only a hundred or so, the physicist makes it known he would have preferred just one – utopium. One is quite enough to give idealized body to the three states of atomic matter – gases, liquids, solids.

More accurately, the idealized atom is a beginning of the attempt to understand the behaviour of matter. However attractive it may be to evolve general pictures with simple concepts like utopium billiard balls, one must eventually appreciate the peculiarities of individual atoms in a real system. How else can one understand why oxygen melts at −219 °C and ice at 0 °C? Although one may point to the enormous importance of the arrangement rather than the chemical nature of atoms in a crystal with regard to its properties, and quote with glee the case of carbon atoms which form the hardest substance known when ordered in a diamond lattice, and one of the softest, as its use in pencils testifies, when ordered in a graphite lattice (Figure 1.2), it

Figure 1.2. Carbon atoms in diamond and graphite.



Diamond lattice

Graphite lattice

is obviously essential that individual atomic characteristics be ultimately built into whatever model is developed. A theory of some crystal may begin with a point-lattice, to explore the role of its special symmetry, and the points then expanded into utopium balls in order to investigate its mechanical and thermal properties, but, for increasingly sophisticated understanding, balls have to become real atoms and individual atomic eccentricities have to be taken into account.

That may be so, but it does not stop the physicist, in his quest for simplicity, applying successfully even more unrealistic concepts than the utopium ball or the point-particle. What could be more appalling than to ignore the existence of atoms entirely? Regard this solid or that liquid as a *continuum*, a substance filling all the space occupied by the object. Such a model, in spite of its apparent crudity, works extremely well on a scale much larger than an atom.

The concept of the continuum is, in a sense, the complement of the point. It is just as unphysical, but within its own scope extremely valuable. One of the famous conceptual things of physics is the continuum which is both homogeneous and isotropic. A homogeneous substance has the same properties throughout its extent, independent of position. An isotropic material has the additional simplicity of possessing properties which are totally independent of direction – a material without a grain. Such a medium is so popular in physics that it really ought to have a name – perhaps *chi*, formed from the initial letters (of 'continuum', 'homogeneous' and 'isotropic'), with the Greek letter χ its symbol. Chi appears everywhere – as a model of the Universe itself, as the stuff we have called utopium in the archetypal billiard ball. It makes a splendid gas, a perfect fluid, and, given basic elastic properties, a beautifully simple solid. And, as a tremendous mathematical bonus, one can use the differential and integral calculus to describe its behaviour.

But the important advantage of the concept of the continuum over the atom picture is that it emphasizes properties which are to do with the whole of whatever is under scrutiny. Bulk, rather than atomic properties, the holistic, rather than the microscopic, are picked out and given prominence. The detail is deliberately obscured so that the manifestations of the whole stand out clearly. One such manifestation of vital significance in physics is the *wave*.

First appreciated as an up-and-down motion travelling along the surface of water, capable of being reflected, refracted, diffracted and suffering interference, the wave is undoubtedly a thing. In a continuum it arises out of the elastic interaction of one infinitesimal element with its neighbour in a jelly-like way. In an atomic model it arises out of the interactions between atoms, and is therefore a form of collective motion of all the atoms in the material. The important point is that waves, though nothing more than motions of atoms, are as much entities inhabiting matter as atoms themselves are. They are called *elastic*, or *mechanical waves*. They may be *surface waves*, or *bulk waves*. In either, their essential feature is the to-and-fro displacement of matter. Three types can be picked out. One sort is the *longitudinal wave*, familiar to us as the sound wave, in which the to-and-fro displacement is along the direction of propagation (Figure 1.3(*a*)). Then there are two *transverse waves*, in which the displacement is at right-angles to the direction of propagation, either up-and-down or side-to-side (Figure 1.3(*b*)). The longitudinal, or compression-rarefaction, wave, can travel through anything except a vacuum. The transverse, or shear waves, can travel through solids only.

An excellent example of mechanical waves is to be found in the study of earthquakes. An earthquake produces vibrations in the surrounding rocks which travel round and through the Earth, and these so-called seismic waves can be detected in laboratories all over the