THE NATURE OF SUBSTANCE

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Modern physics has cast doubt on Newton's idea of particles with definite properties. Do we have to go back to Aristotle for a new understanding of the ultimate nature of substance?

If we ask, 'what are substances?', we may be told that this substance is salt, that one is copper, or that all atomic nuclei are mixtures of protons and neutrons. But what do all these have in common which makes them substances? They have shapes and numbers in common, but we don't seem to think that such things as colours, numbers, or shapes are by themselves 'substantial enough' to be substances in their own right. We therefore change our question to 'what is it to be a substance?', or to 'what is the ultimate nature of the simplest substances?'. We might first turn to scientists for an answer, to physicists in particular.

A physicist will explain how all kinds of ordinary matter are composed of small atoms, and these are composed of electrons, protons, and neutrons. Protons and neutrons are again composed of quarks, he says he believes, but when pressed as to what really *are* electrons and quarks, he says that he can tell you how they *behave*, but that he doesn't really know what they *are*. If he is feeling unkind, he may say 'we asked a meaningless question'; otherwise he will say that the electrons and quarks seem to be some kind of 'ultimate particles' whose existence you just have to take on trust. 'You have to start somewhere', he might add.

But when we asked the question, 'what is it to be a substance?', in a sense we were going straight to the question of these 'ultimate particles.' We wanted to know what the world is really made of, and what are the ultimate individuals in the physical world. We have a feeling that we can't go on looking for smaller and smaller constituents *ad infinitum*. The process of subdivision should ultimately come to a stop with the 'real individuals' that are the real *substances* of the world. We don't know for certain if physics has yet reached the stage of looking at these ultimate substances. Of course, physicists almost always *believe* they have come to that stage, but that may just be because they haven't yet done the right kind of experiment.

This suggests that if we want to know what these ultimate substances might be like, we have to turn to philosophy rather than to physics. We will then have to be satisfied with general principles rather than particular knowledge, because philosophers can only argue from general considerations about what is possible, and do not provide detailed knowledge about what actually occurs in particular circumstances. You may think that consideration of 'mere possibilities' will not be fruitful, but you would be forgetting that every scientific theory *presupposes* some general framework about what is possible. Different scientific theories go along with different philosophical frameworks about what our ultimate substances might be like. The physical theories of the Greeks, of Newton and of modern quantum physics assume *different* philosophical ideas about substances, and these ideas are not compatible with each other. They cannot all be correct! My purpose in this article is to illuminate these different basic ideas, and to see whether we can choose between them.

Newton's Corpuscles

The idea most people have of ultimate substances is one that derives from Democritus (c. 460 - 370 BC), and was systematised in the seventeenth century by Boyle (1627 - 1691) and Newton (1642 - 1727). This is that the world is ultimately made up of small solid 'atoms' or 'corpuscles.' These corpuscles have a definite position and size, and within their volume are solid and impenetrable. They are the ultimate atoms, since they cannot be broken up. They can fly around in space, and bounce off each other perfectly elastically. It was claimed that *all* phenomena in nature could be explained in terms of the movements and collisions of the corpuscles. It would have been nice if nature had been so simple.

Newton soon realised that his gravitational attraction could *not* be explained purely in terms of movements and collisions. In fact, when you think about it, the attractive forces that hold *any* object together cannot be explained in such terms (unless, as the Greeks did, you imagined that atoms had little hooks to hold on to each other). Later scientists soon realised that the electric and magnetic effects they discovered had no simple explanation in terms of movements and collisions. Boscovich (1711 - 1787) and Faraday (1791 - 1867) found that their best explanation was in terms of electric and magnetic fields. But what is a field? Are fields some kind of substance? If so, are they or are they not composed of the same kind of ultimate substances as ordinary matter?

In the corpuscular theory there are in general severe problems when it comes to seeing the exact relation of the corpuscles to their forces of interaction (whether gravitational, electric, magnetic, or other). This is because the corpuscles were assumed to be *purely actual and definite* in every respect, and hence could never have any such thing as a *potential field* or a *force* for interactions. For potentials and forces are features (technically called *dispositions*) which may or may not operate. Remember from your physics that a field potential at a place describes how a test charge *would* react *if* placed there. According to the basic ideas of corpuscular theory, this uncertainty means that potentials are like 'occult powers' in that they are not directly observable, and are not as accurately describable as the corpuscles themselves. In other words, they are not sufficiently actual and definite to be given to corpuscles.

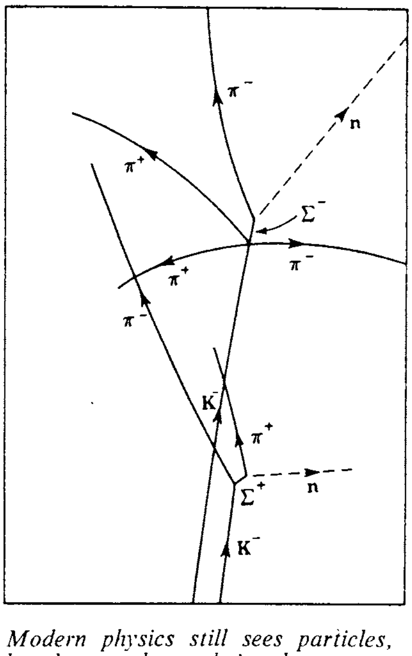
The gravitational, electric and magnetic forces are, however, just those properties we want science to explain for us. The problems with them show that we have to go back to philosophical considerations about what kinds of substances there may *possibly* be. We ought to reconsider those general principles on which we based our very idea of atomic corpuscles. Let us look at the alternatives that were considered in Newton's time.

Descartes and Leibniz

The other most popular approaches were those of Descartes (1596 - 1650), and those of Leibniz (1646 - 1712). Descartes had imagined that the natural world is made out of *res extensae*, or *extended bodies*. That is, the ultimate individuals are those whose nature is just to be extended, and to occupy volumes in space. For Descartes, in fact, there is no *empty* space, as (according to his definition) 'to be extended' and 'to be a body' were synonymous descriptions.

The trouble with this alternative is that the problem of substance is *further* from solution, not nearer. According to Descartes, it is mysterious why the ultimate individuals should have mass or inertia, or should proceed through space at constant velocity (unless disturbed). It is even not clear what is stopping the individuals from penetrating each other, and hence from passing through each other unchanged. We can easily imagine' extended bodies (such as two geometric spheres) doing this. What would stop inter-penetration would be some solidity or filling of the space that has an ability to repel other individuals, but to say this is to say rather more than that the individuals are 'extended bodies'.

Leibniz, on the other hand, had imagined that the world is made of *monads*, or 'simple substances' that are all independent of each other. He writes, furthermore, that all natural changes of the monad come from within, as 'an external cause can have no influence upon its inner being' (Leibniz, *Monadology*, ¶ 11). But the trouble is that it is now mysterious how the monads, his simple substances, can *interact* with each other at all. Although Leibniz was a strong advocate of the importance of dynamics and forces in physical explanations, in the end he cannot explain how these are real features of his ultimate monads, because the monads only *appear* to interact with each other, and, as just stated, do not *really* do so.



Modern physics still sees particles, but does not know their substance.

Descartes, Newton and Leibniz all shared the assumption that the ultimate substances had to be *purely actual and definite* in their inner form. In particular, they could never be internally changed by interactions with other substances. They assumed, as a general principle, that the ultimate substances had nothing in them like a *potentiality* for changing or being changed during interactions. It is, of course, possible to have some account of forces or potentials grafted onto the account of Newtonian corpuscles, and simply *assert* the 'scientific law' that all matter, for example, attracts all other matter in certain ways. However, Newton realised that that is hardly a satisfying explanation in the long run.

Back to Aristotle

The earliest view of substances which gave a consistent account of potentialities is that of Aristotle (384 - 322 BC). We now know that some of the details of Aristotle's physics are wrong: bodies do not *all* tend to move to the centre of the earth, for example. But, as we explained earlier in the article, there is a philosophical approach that discusses general principles rather than specific knowledge of what actually happens. Although Aristotle's specific claims turned out to be incorrect, on a number of points his general principles are more satisfactory. We may summarise his general principles as follows (following Gotthelf, *Review of Metaphysics*, Vol. 30, pp. 226 - 254).

Nature, according to Aristotle, consists of individual entities, each of a specific kind, possessing various properties, moving and changing in various ways. They are all composed of simple bodies, the 'elements', which are themselves analyzable into combinations of prime qualities and some sort of underlying matter. To describe how they behave, we must first say how they act if not impeded, and then how they interact with other bodies. According to Aristotle, all natural things move and/or change in ways characteristic of themselves if not impeded. That is to say, each has a *nature*, having 'within themselves a source of motion-or-change and rest' (Aristotle, *Physics* II.I 192b, 13-14). A thing's nature explains these different characteristic changes, as it contains the source or principle of the changes.

Other kinds of changes are caused by *interactions*, in which things act on other things. Thus, in addition to having a nature, each natural thing has *potentials* to change (and be changed by) certain other things in certain ways. Aristotle has no separate concept of 'physical laws'. For him, explanations of particular changes are always in terms of the particular natures and/or potentials of the things involved. No appeal is made to some universal law, for each thing has *within itself* its nature and potentials, which are the source of changes to itself and others.

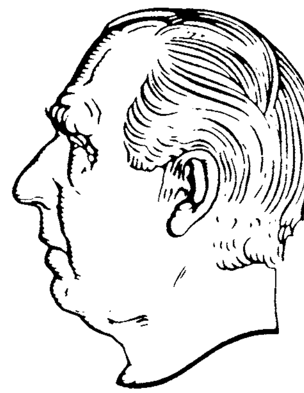
Aristotle thought that there are only four elements, and that these are earth, air, fire, and water. These four are the different pair-wise combinations of the 'prime qualities' dry/moist with hot/cold, so earth is dry and cold, water is cold and moist, air is moist and hot, and fire is hot and dry. It is not necessary, however, for us to accept this detailed identification even if his general principles seem sound. (We will see later what may be more realistic identifications today.) What is relevant to our problem of substance, is his idea of natures and potentials, which are those features of substances which lead them to behave as they do.

The problem with Newton's concept of substance, we can now see, is that the nature of his corpuscles (as purely actual and definite atoms) does *not* lead to their gravitational attractions. If we described the nature of his corpuscles, we would know their position, velocity, size and mass. Because those are all their properties, they *ought* to tell us everything about how they can act and interact, but we still would not know about the existence or the strength of any gravitational attraction. Still less would we know about the electric, magnetic and nuclear attractions that have been discovered subsequently.

John Locke (1632 - 1704) was one philosopher in Newton's time who tried to explain the internal constitution of the corpuscles which the scientists were postulating. He imagined that to describe the constitution of the corporeal substances was to give their 'real essences', from which all their qualities and effects could be derived. These constitutions were thought to be comprised of the 'primary qualities' of solidity, extension, shape and motion. It was clear to him that the scientists of his day had not discovered these details. Science, however, has advanced in many directions since then.

Modern Approaches

With the progress of physics we hope that we discover ultimate constituents which have many definite properties (e.g. mass, shape, position, velocity, energy etc.), and only a few of those



Niels Bohr

peculiar dispositional properties (e.g. perfect elasticity, gravitational attraction, electric charge, etc.). In that way there might be a minimum number of these peculiar dispositions or potentialities, which seem like 'occult powers', and are to be avoided where possible. Such would be the case if Newtonian physics were true. Quantum physics shows, however, that this hope is not satisfied.

In the quantum world there are in fact *more* kinds of dispositions than in Newtonian physics. For the properties of position and velocity, previously thought quite definite, now may or may not have definite values. Position and velocity seem to behave more like dispositional properties, in that they may or may not have definite values according to experimental circumstances. In the quantum world, it turns out, there are very few *non*-dispositional properties, i.e. very few properties that always have perfectly definite values. In particular, there is no such thing as a corpuscle with a definite size and shape: quantum particles can be spread out over a whole crystal, or compressed into a volume smaller than an atomic nucleus, depending on which experiments we choose to perform. For this reason, physicists such as de Broglie and Schrödinger have proposed that particles are really *patterns of waves* like the electro-magnetic fields mentioned earlier. We know that waves can be spread out and be focused again. In fact, some experiments support the idea of particles, and others the idea of waves!

There are four main ways of describing the nature of substances as revealed by quantum physics (assuming, as we did at the beginning, that the question of their nature is not a meaningless one).

1. We could follow A. N. Whitehead, or Bertrand Russell, and declare that there are *no* continuing substances, and that the only things in nature that definitely exist are *events* or *processes*. The world is not composed of definite material substances, we could then say, but consists only of 'patterns of activity', or 'energy in certain forms'.
2. Another approach is to take some of Aristotle's ideas more seriously, and build potentialities and/or dispositions into the very nature of substance itself.
3. A third view is to hold that substances are still really Newtonian corpuscles, but that they behave in rather peculiar ways which we just have to accept as 'facts of nature'.
4. The final way is similar to the third, but holds that substances are really *waves*, albeit rather peculiar waves.

Let us look at these ways in turn.

According to the first option, the only things in nature are events, such as collisions, particle decays, and even the interaction of the scientist with his apparatus when he observes it. These events are at particular places and times, or else take place in some definite volume of space for some stretch of time. This gets around the problem of the nature of substances by not having any! It may seem a far-fetched solution to the problem of substance, but this option is at least consistent. It *does* explain all the measurements and observations we may make, because *they* are all *events* of some kind. Where we might normally look for substances to which the events are changes, this option says that events just occur, without being changes in anything.

The second choice has it that the ultimate substances are really *forms of potentiality*, or 'forms of propensity' to give a more commonly used description. This is an extension of Aristotle's approach, if we take 'propensity' to be his 'underlying matter'. His general principle about elements is that they are the underlying matter in forms of combinations of prime qualities. The elements are thus the underlying propensity in forms described by combinations of prime qualities, and these basic qualities could be electric charge, spin, 'quark colour', etc.. The elements, therefore, could reasonably be the different kinds of electrons and quarks. Aristotle's natures and potentialities of the elements could be explained as the different operations of their particular forms of propensity.

With this second choice it is then not surprising that in the quantum world there are very few properties that always have perfectly definite values, and that there is no such thing as a definite corpuscle. Instead of a corpuscle we have a 'packet of propensity', or 'propensiton' (following Nicholas Maxwell, one of the modern advocates of this interpretation, in his *Foundations of Physics* article, Vol. 12, p. 607).

The third way of dealing with the problem is that taken by many scientists today. As the modern physicist Richard Feynman puts it (in *Q.E.D*, p. 37), 'quantum [theory] "resolves" this [problem] by saying that light is made of particles (as Newton originally thought), but the price of this great advancement of science is a retreat by physics to the position of being able to calculate only the *probability* that a photon will hit a detector, without offering a good model of how it actually happens'. (A photon is a particle of light.)

The fourth approach, which takes *waves* to be the ultimate substance, is also followed by a number of physicists. They like the idea of a 'universal field' of which all particles are simply localised concentrations. This universal field could be the wave function Ψ of Schrodinger's form of quantum physics, or it could be some new kind of 'unified field' which some modern physicists have proposed. It is not clear, however, what exactly is 'waving' when a wave or a field goes by, and this is our old problem of substance all over again!

There are troubles with both the third and fourth approaches, as it turns out that nature does not behave as we would expect if it were only particles, or as it would if it were only waves. Niels Bohr therefore proposed his idea of 'wave-particle complementarity', which is that nature alternates between being like particles and being like waves, according to what the experimentalist chooses to measure.

Both particles and waves are definite things that Newton knew about, but neither of these concepts by itself is adequate to describe the nature of quantum substances. We may be forced to take a strange and unpalatable mixture of the two concepts, or we may have to swallow our pride that we are more advanced than the Greeks, and go back to Aristotle for some general principles which may lead to a new understanding of the nature of ultimate substance.

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