Fields By Peter Clark

I should emphasise that this is my take on the matters I am going to deal with. There is some debate about parts of it and a great deal of debate about others. Also, this is a fairly crude version of quantum theory I am offering, (as those scientists amongst us will soon realise), just to get the sense over.

The ontological question of just what the universe around us is really made of has been asked by the human race for millennia. From Thales, in ancient Greece, who thought water was the fundamental material of the world, through Anaximander, who thought it was apeiron, an indefinite substance from which all things are born and to which all things return, and Democritus, who imagined everything is composed of miniscule, inert, solid, geometrical objects, called atoms, existing in a void, with each substance, e.g. stone, having its own atoms, and all the way up to the 17th century, philosophers put forward various views as to what kind of substance material things were made of.

In the 17th century, influential versions of Greek atomism were formulated by a range of natural philosophers, in particular by Boyle, who regarded material things as being composed of insensibly small portions of matter of unchanging shape and size distinguished from the void. In 1803, Dalton developed the first modern atomic theory. Dalton and others pictured atoms as tiny billiard ball like particles, all atoms of a given element being identical; atoms of different elements having different properties.

The existence of atoms was, however, not universally accepted. But Einstein’s 1905 experiment on Brownian motion – fluctuating particles of an emulsion visible through a microscope - put Dalton’s atomic theory back in the driving seat.

Thomson had discovered the negatively charged electron in 1897, and this was the first indication there were things smaller than atoms. Rutherford discovered the nucleus, which he believed consisted of positively charged particles, which he termed protons, in 1911. The picture of the atom was then the nucleus surrounded by numbers of orbiting electrons. At this point, the prevailing view was that these were particles of substance, with attributes such as mass and size, and that the atom was a bit like a very miniature solar system.

(It wasn’t until 1932 that Chadwick discovered the neutron, an uncharged particle, which is also to be found in the nucleus of atoms).

So, there is a long history of thinking of the world around us as consisting of material substance or substances. Of course, there were many variants of this view and dissenting views, the most obvious one which springs to mind being ontological idealism, such as Berkeley’s immaterialism. This type of thinking was prevalent up to around 1900, and still current until 1924, when De Broglie suggested that matter itself could be described as waves. Then, in 1927, Dirac quantised the electromagnetic field. In 1928, Jordan and Pauli showed that quantum fields could be made to behave in the way predicted by special relativity.

In 1934, at the age of 16, Schwinger wrote an unpublished paper that attempted to extend to all fields what Dirac had done to the electromagnetic field. But it wasn’t until 1948 that he presented his paper on this topic. Then, between 1951 and 1954, he published five articles on ‘The Theory of Quantized Fields’. Schwinger’s field concept was not fully appreciated by the scientific community until much later, largely due to Feynman’s particle interpretation. Schwinger was one of the most brilliant and insightful physicists of the twentieth century. It is a great pity he is not better remembered.

What is a field? Well, there is a mathematical definition, but here I will be dealing with real fields. Actually, there is some question as to what sort of reality fields have. Basically, a field is a set of physical properties or conditions that exist at every point of space-time, mostly with numbers associated with each point. For example, the temperature in a room is a field; a scalar field in fact, as there is no direction involved. It is not a fundamental field, however, as it depends on the speed of the molecules in the air. The magnetic field round a magnet is an example of a vector field because, as you can see if you put iron filings around it, not only does it have a numerical strength value at each point, but also a direction. This is a fundamental field. There are also more complicated, many valued fields, such as tensor fields, which are used in Einstein’s theory of gravity. Quantum fields are more complex still (they are operator fields). Effects can ripple through a field, its parameters changing with time.

When Newton announced his theory of gravitation, there was a general reluctance to accept the concept of action at a distance, an invisible force. Descartes had argued that every physical interaction should be reducible to impulses between material objects. Newton himself was also worried by this but, nevertheless, persevered with the idea. Actually, what Newton had proposed was a gravitational field, but it wasn’t till much later that Laplace, born a century after Newton, specifically interpreted gravity as a field. And it was he who introduced fields as centrally important in physics.

The concept of a field was taken up by Faraday some years later, but he was no mathematician and it wasn’t until Maxwell that the electromagnetic field was described mathematically and became entrenched in physics. Faraday was not sure exactly what a field was. Either it was a state of a material medium (the aether) or modifications of space. He preferred the latter, as he believed forces themselves were the sole physical substance, filling all space, in which each point of the force field had a certain amount of force associated with it and interacted with its neighbours, allowing for vibrations of force and all kinds of patterns of force, including material bodies. Unfortunately, Maxwell opted for the aether. In an experiment in 1887, Michelson and Morley showed that the aether does not exist.

Newton’s force of gravity and the electromagnetic force remained the only two known natural forces until 1932, when Heisenberg proposed the strong nuclear force to explain why nucleons (neutrons and protons that make up the nuclei of atoms) stick together, although protons are positively charged and should repel each other. The following year Fermi proposed the weak nuclear force to explain beta decay. Certain nuclei do not have the optimum ratio of protons to neutrons to maximize their stability. To redress the balance neutrons or protons may be converted into each other, and an electron or positron (the antimatter partner to the electron) is created in the process to make sure that electric charge is conserved - and also another particle, called the neutrino, in fact, to make the energy sum work out. This idea that one particle can change into another is an essential aspect of quantum theory.

So, the field concept applies to these four forces. In the late 1960s Weinberg, Salam and Glashow unified the electromagnetic and weak forces. The unification of all four forces is one of physics’ greatest dreams. Einstein spent most of his life in America trying to discover a unified field theory. He never did.

In 1935, Yukawa came up with the idea that the strong nuclear force is carried by exchange particles; exchanged, that is, between matter particles. These pions, as they were later called, are virtual particles. They are created from nothing and go back to nothing. A simple way of looking at this process depends on two things; Heisenberg’s uncertainty principle and Einstein’s e=mc2. The first concerns our inability to assign precise values to complementary quantities such as, in this case, the shorter the time interval we consider, the wilder the fluctuations in energy that can occur. The second asserts that mass and energy are equivalent. So, for the sufficiently short time periods in which quantum events occur, enough energy can be borrowed to create a particle, provided the energy is paid back before the uncertainty principle is violated. It is a bit like that old stock market gamble when you place a buy order and then sell, all within the time allotted for payment. Provided the stock went up enough you need never pay anything and simply took your profit.

This idea was extended to the other forces, such as a virtual photon for the electromagnetic force. It is also proposed that there is an exchange particle for gravity, called the graviton. This has yet to be discovered, though, a few years ago, gravity waves were detected, which would indicate that it does exist. Einstein’s general relativity theory can be interpreted as saying that gravity is caused by distortions in space, but, as Einstein (1923) himself said: [There is] “a field of force, namely the gravitational field.”

Space-time itself is obviously linked in some way to the gravitational field, and so, as The Stanford Encyclopedia of Philosophy (SEP) entry for Quantum Field Theory (QFT), (2012) states: “Thus, quantising gravitation could amount to quantising space-time, and it is not at all clear what that could mean.” Personally, I think this means literally that space and time are discontinuous, i.e. there is a minimum time period and a minimum space distance.

As mentioned earlier, in 1924, de Broglie put forward the theory that, just as light, which had been thought of as waves, had been shown to be also a particle (the photon), so matter particles might also be waves. This was later experimentally shown to be the case, indeed, from experimental evidence, this concept was also extended to Buckyballs, a number of carbon atoms, generally 60, arranged in the form of a football.

In the Copenhagen interpretation of quantum mechanics, elementary particles exist as superpositions of waveforms, which means that they have no fixed properties, such as position in space or energy, until they are actually measured – an event often referred to as ‘the collapse of the wave function’. Until then, there are merely probabilities that such properties will have some given value until they actually react with something. So, they are seen as sometimes particles and sometimes waves.

QFT goes further. It postulates that these ‘particles’, whether matter or force ones, do not exist as proper particles, but merely as excitations of fields, called quanta. The picture of the world proposed by QFT is that of a multiplicity of fields, encompassing both the matter ‘particles’ (fermions) and the force ‘particles’ (bosons), with each of these treated differently, (to do with something called spin). Each fills the whole of space and has its own particular properties. There is nothing else except these fields; the whole of the material universe is built of them.

Each field manifests itself as quanta, matching one type of elementary particle, so, in many ways, it is convenient to talk of particles not quanta, and this is generally the case with physicists, even QFT ones. In the large hadron collider at CERN, ‘particles’ are smashed into one another. But, it seems to me, taking the quantum field view, that is a matter of bundles of energy crashing together to annihilate or create different types of quanta. So, I would say, no, quanta really can’t be thought of as particles, in the traditional sense.

I, too, will use the word particle, though, as it is so common in the literature, but I will really mean just some event resulting from certain processes of their field. The universe is made up of fields and nothing more. The so called ‘particles’ are really disturbances of these fields.

The number of particles of a given type is not fixed, for particles are constantly being created, annihilated or transmuted into one another. There are various kinds of interaction between fields. As Lincoln (2013) puts it: “These fields span all of space. Some fields can “see” other fields, while being blind to others. The photon field can interact with the fields of charged particles but cannot see … neutrino fields”.

The mathematician and theoretical physicist, Dyson (1995), states “It is not possible to explain in a non-technical language how particles arise mathematically out of the fluctuations of a field.” This remark is typical of many quantum theorists. The mathematics works; it gives solutions which match experimental results, so that is all that matters. This is the instrumentalist or ‘shut up and calculate’ approach to quantum theory. Dyson (1995), also wrote of QFT: “It describes how elementary particles behave; it does not attempt to explain why they behave so.”

It is interesting, here, to point to two quotes in Sheldrake (2011). The first is from de Broglie: “Quantum theory extends the Platonic approach into the very heart of matter, which Democritus and succeeding atomists had regarded as solid and homogeneous.” The second is from Heisenberg: “Modern physics has definitely decided for Plato. For the smallest units of matter are, in fact, not physical objects in the ordinary sense of the word; they are forms, structures or – in Plato’s sense – ideas, which can be unambiguously spoken of only in the language of mathematics”.

Regarding this, Davis and Hersch (1983), wrote: “The majority of writers on the subject seem to agree that most mathematicians, when doing mathematics, are convinced they are dealing with an objective reality, but then, if challenged to give a philosophical account of this reality, find it easiest to pretend they don’t believe in it after all. …. The typical mathematician is both Platonist and formalist - a secret Platonist with a formalist mask that he puts on when the occasion calls for it”.

As an extremely crude analogy of a quantum field, taken from ‘A Children’s Picture-book Introduction to Quantum Field Theory’, by Skinner (2015), imagine a ball bearing fixed on top of a spring. Then construct a field composed of an infinite, space-filling array of these. Constrain them to only move in the direction of the spring, extending or compressing it. But these would all be independent so we must add links between them. Let’s then add elastic bands, attaching each ball to its four nearest neighbours.

Of course, the actual fundamental fields of nature aren’t really made of physical things, (as far as we can tell). Physical things are made of them. But the idea of oscillations in this field is part of QFT. If you tap on this field at a particular location then it will set off a wave of ball-and-spring oscillations that propagate across the field. These waves are the quanta (‘particles’) of field theory. They have a number of properties usually attributed to particles. For example, they have a well-defined propagation velocity, which is related to the mass of each of the balls and the tightness of the springs and elastic bands. (These roughly correspond to the parameters of QFT).

The properties of the springs also define the way particles interact with each other. If two particle waves run into each other, they can scatter off each other in the same way that matter particles do, or simply pass each other without effect as some other particles do. Finally, the particles of this field clearly exhibit wave-particle duality.

To quantise this field, we must specify two additional conditions.

1) No ball can ever stop moving.

2) The extent (amplitude) of this motion can only take on certain discrete values.

The quantisation of the balls’ oscillation has two important consequences. Firstly, if you want to put energy into the field to create a quantum, you must put in at least one quantum of it. Once you tap the field hard enough, a particle is created, which can propagate stably through the field. This discrete amount of energy that the field can accept is called the rest mass energy (remember E=mc2). The faster the balls oscillate, the more energy they have. This matches the quantum theory fact that energy depends on frequency.

As result of 1). a feature of these fields is that they cannot be zero. I.e., in QFT there is no such thing as empty space. So, in a vacuum, elementary particles pop in and out of existence, just like the exchange particles. It also means that this happens outside of a vacuum too, of course. In particular, the Higgs field strongly permeates the whole of space, giving mass to those particles which do have it, including the Higgs particle itself.

In QFT it is not obvious how many different types of field there are, since fields can have components. For example, the electromagnetic field has as its components the electric and the magnetic fields. In the standard model, there are 18, corresponding to the number of different types of particle in that model. Personally, I think we should try to apply Occam’s razor here.

That’s all very well, but I still want to know what fields are made of and what it is exactly that is oscillating. You could, I suppose, say it is space-time itself. Rovelli (2017) has a slightly different take. He writes Quantum “fields do not live in space-time: they live, so to speak, one on top of the other fields.” Also, “Fields that live on themselves, without the need of a space-time to serve as a substratum, as a support, and which are capable by themselves of generating space-time are called ‘covariant quantum fields.” He links this idea to ancient Greek thought, saying that covariant quantum fields have become the best description we have of Anaximander’s apeiron.

Just as an aside, in March of this year, Vogel and Vogel (2017), published their ‘Chemical Model of Particles’, in which they claim to have shown that all the results of quantum theory can be reproduced – and much more besides, e.g. dark matter - by assuming only two particles, the electron and the anti-electron (the positron).

I can’t leave the topic of fields without discussing Sheldrake’s ideas. He talks about something he calls a morphic field. According to him, all material forms, living, e.g. rats, and non-living e.g. crystals, have their origin in this field. Shades of Plato and his ideal forms again. In the first few centuries of the Christian era, the Platonic forms were taken to be ideas in the mind of God. It strikes me that this theme could equally be applied to Sheldrake’s morphic fields.

One of Sheldrake’s motives to propose these morphic fields was to explain how a fertilized egg grows into, for example, a human baby. Why do the various bits of it appear where they do? He also refers to bodily regeneration as an example of these fields, e.g. flatworms can be cut up into much smaller pieces but still develop back into full flatworm form. He also believes they can influence behavior. For example, if rats in America are taught to run a particular maze, then if European rats of the same descent are taught the same maze in England, they will take less time to learn it.

There is a connection here to QFT. Durr, quoted in Sheldrake (2011), suggested that “processes of quantum physics might in principal contain a fruitful potential for an explanation of Sheldrake’s morphic fields”. And Sheldrake (2011) himself looks to the big bang, where there were no atoms, and writes; “As the universe evolved, one by one the possible kinds of atomic form took on material existence. It is as if the eternal forms of the atoms were awaiting their opportunities to be activated in time and space”. Back to Plato again.

But perhaps we should not bother too much about the realm of quantum theory. After all, we live in a world apparently made of solid matter. Physicists define matter as anything that has mass and occupies space. So, neither fields nor their quanta seem to qualify. Some physicists, called physical idealists by Lenin, quoted in Spirkin (1983), have declared that “Matter has disappeared and there is nothing left but equations.”

I’m going to give the last word to Engels, as reported in Spirkin (1983). He said: “Being indeed, is always an open question beyond the point where our sphere of observation ends”.

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