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SYMMETRY IN PHYSICS FROM THE FOUNDATIONS

Peter Rowlands

Physicist, (b. Warrington, U.K., 1949).

Address: Physics Department, University of Liverpool, Oliver Lodge Laboratory, Oxford St, Liverpool, L69 7ZE, UK

Fields of interest: foundations of physics, quantum mechanics, particle physics, genetics

Awards: Best paper awards at CASYS, Liège, 2005, 2007, 2009.

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Abstract: *Nature has only become comprehensible to human investigators because similar patterns repeat themselves at different levels of complexity. At the most fundamental level in physics, two particular features seem to be manifest, duality and anticommutativity, and we recognise them by the respective appearances of the numerical factors 2 and 3. The most fundamental level in physics seems to require a group symmetry of order 4 between space, time, mass and charge, based on a combination of 3 dualities. The group suggests that symmetry, and, in particular, duality is an indication that Nature is constructed on a totality zero principle. Broken symmetries are a sign of emergence and complexity and their signature at the fundamental level is associated with the number 5.*

Keywords: fundamental parameters, zero totality, broken symmetry, duality, anticommutativity.

1. THE FUNDAMENTAL PARAMETERS

Nature tends to go for the simplest possible options, but physics, as presently understood, is far from simple. There are two competing theories, quantum mechanics and general relativity, which seem to contradict each other, and neither is simple. A brilliantly successful Standard Model of particle physics has now been in place for forty years, with no fundamental explanation. Is there any route to finding the supposed simplicity in the chaos of present-day physics? At present there are:

Four interactions or primary forces
Twelve primary states of matter and twelve antistates
Numerous measurement parameters, such as space, time, mass
Many seemingly arbitrary laws connecting these
A universe which is intrinsically inexplicable

How do we make sense of all this? Certainly not by imagining something even more complicated. We are not going to find the answer overnight, but we might find a key, a ‘Rosetta Stone’, to decipher the hieroglyphics of physics. Is there perhaps a hidden structure which will show that all the apparent complications ultimately result from something much simpler?

We have to avoid treating our sophisticated ‘high level’ theories as the fundamental language, rather than looking at the more basic elements from which they are constructed. If Nature is simple, why does it look complex? What trick does Nature perform to make the intrinsically simple end up building complication on complication? What clue have we got that might lead us back from the complex to the simple? There is only one that has ever been found to work. It is based on the one talent that we have developed along with our evolution – pattern recognition. We use the conjuror’s trick of doing it by mirrors – we look for symmetries.

Everywhere in Nature, and especially in physics, there are hints that symmetry is the key to deeper understanding. And physics has shown that the symmetries are often ‘broken’, that is disguised or hidden. A classic example is that between space and time, which are combined in relativity, but which remain obstinately different. In fact, broken symmetries may well be the clue, as our instincts must tell us that Nature should not break symmetries at the most fundamental level. They must be a sign of complexity, of ‘emergence’, of combining or ‘compactifying’ different things into a ‘package’. Broken symmetries may well give us clues about the original, possibly simpler, symmetries from which they emerged.

So, the probability is that there is a hidden structure, which somehow appears to us in a broken way. And it has to be simple, in fact at the simplest level we can imagine – that of the parameters, the only ways we have ever devised of understanding the world about us. And we have to go for those ideas which seem to be present at every level of complexity in our investigations of Nature. So space and time are fundamental, but not solidity. Concepts like force, acceleration, angular momentum, temperature, and so on, are very important in physics, but they are not fundamental. They are composites or can be expressed in composite way using dimensional analysis.

If we are looking for the simplest parameters, the most elementary, then clearly space is fundamental. No physicist or philosopher has ever thought otherwise. The 3-dimensional aspect has to be especially significant, because it indicates structure in itself. It is also difficult to imagine physics without time. After this there are only the sources of the four physical interactions: gravity, and the strong, weak and electromagnetic forces. These forces are a spectacular example of a broken symmetry, alike in some respects, but strikingly different in others. The source of gravity is mass, by which we mean mass-energy, not rest mass (which is, of course, never observed in any case). The others appear to form a broken symmetry which under ideal conditions would be perfect. Here, we will assume the ideal conditions and call the source charge, as it is in the electromagnetic interaction. Charge will become a generic term for the sources of the electric, strong and weak interactions, and we will assume that, in its unbroken symmetry state, it behaves as a kind of 3-dimensional parameter, like space.

The discovery of a broken symmetry is the clue we need to finding a hidden structure. We have to answer the question why these forces which seemingly should be similar are so very different. Ultimately, we will answer this question, and show how the symmetry-breaking occurs. First, though, we need to project back to what would have been there 'before' the symmetry was broken, and, to attempt this, we will subject these seemingly most 'elementary' parameters to a searching analysis. We imagine that the perfect symmetry between the electric, strong and weak charges is broken at normal energies, but that, under ideal conditions (grand unification), all 3 charge terms would be exactly alike.

Now, of the four fundamental parameters, space has a unique property. It is the only parameter that can be measured. Every other so-called measurement becomes a matter of observing a pointer moving over a scale or equivalent. Any object whatsoever sets up a measurement of space. Time 'measurement', on the other hand, requires special conditions in which we count repetitions of the same interval. Measurability, it would seem, is not a universal aspect of nature; nor, in fact, is anything else – nature resists any specific characterization. That is why we also need time, mass and charge.

We will now assume that enough iterations have been done to establish that this is the correct starting point, and that the assumptions will ultimately be justified by the results; also, that our sophisticated 'high level' theories will emerge as constructed from 'packages' composed from such elements; and, finally, that symmetry-breaking is an aspect of the packaging and not of the fundamental nature of the constituents.

2. CONSERVATION AND NONCONSERVATION

When we examine the four fundamental parameters in relation to each other, we find that they consist of three dual pairs, determined in each case by a single property / antiproperty. The first is conservation / nonconservation, which pairs mass and charge against space and time. Now, some of the most fundamental laws are about conservation, and we have a fairly good understanding of what it means. Nonconservation is less well understand, but, if we examine it closely, we will find that it is not simply the absence of conservation but a property with equally definite characteristics. Nonconserved quantities have no *identity*. One unit of the quantity is as good as any other. So, we have

the translation symmetry of time
the translation symmetry of space
the rotation symmetry of space

Conserved quantities, by contrast, are translation and rotation asymmetric. Each unit is unique. One cannot be replaced by another. So, we have

the translation *a*symmetry of mass
the translation *a*symmetry of charge
the rotation *a*symmetry of charge

The last is especially important. The three types of charge do not rotate into each other. They are separately conserved. This is the origin of baryon and lepton conservation. The first says that strong charges are separately conserved; baryons can only decay into other baryons. The second says that weak charges are separately conserved, so fermions, or the sum of baryons and leptons, must be conserved

Another key property of nonconserved quantities is gauge invariance. Field terms remain unchanged if we arbitrarily change potentials, due to translations (or rotations) in the space and time coordinates. In effect, we can arbitrary changes in the coordinates which do not produce changes in the values of conserved quantities such as charge, energy, momentum and angular momentum. In general, physics structures itself in terms of differential equations which ensure that the conserved quantities – mass and charge, and others derived from them, such as energy, momentum and angular momentum – remain unchanged while the nonconserved or variable quantities vary absolutely. This means that the nonconserved or variable quantities are expressed in physics equations as differentials, *dx*, *dt*, directly expressing this variation.

The idea that 'God plays dice' in the quantum state will no longer trouble us if we accept the logic of defining space and time as nonconserved quantities. This means that they are not fixed and should be subject to absolute variation. It is only the fact that conservation principles should hold at the same time, that restricts the range of variation when systems interact with each other. When the interactions are on a massive scale, we can even make a classical 'measurement'!

Noether's theorem is a natural consequence of defining conservation and nonconservation properties symmetrically. According to this theorem, to every variational property there is a conserved quantity. So

translation symmetry of time ≡ conservation of energy
translation symmetry of space ≡ conservation of momentum
rotation symmetry of space ≡ conservation of angular momentum

So nonconservation of time ≡ conservation of mass (energy), and so on. We can extend the theorem, purely by symmetry, to the following equivalences:

conservation of	**conservation of**	**symmetry of**
energy	mass	time translation
momentum	magnitude of charge	space translation
angular momentum	type of charge	space rotation

The first result is a consequence of $E = mc^2$, the second seems to be related to the gauge invariance already discussed, but the third is totally unexpected. There is, however, a remarkable explanation. Angular momentum conservation is, in fact, three separate conservation laws – of magnitude; of direction; and of handedness – and these are precisely those involved in the $U(1)$, $SU(3)$ and $SU(2)$ symmetries involved with the electric, strong and weak charges. In principle, the conservation laws of magnitude, of direction, and of handedness, say, respectively, that the spherical symmetry of 3-dimensional space is preserved by a rotating system

whatever the length of the radius vector;
whatever system of axes we choose; and
whether we choose to rotate the system left- or right-handed

and these considerations are totally independent of each other.

3. REAL AND IMAGINARY

The second major duality is between real and imaginary quantities. This time we pair space and mass against time and charge. By 'real' we mean norm 1, the units square to positive numbers; by 'imaginary' we mean norm –1, the units square to negative numbers. Now, special relativity combines space and time in a 4-vector, with 3 real parts (space) and one imaginary part (time). We extend Pythagoras' theorem to four dimensions, so that

$$r^2 = x^2 + y^2 + z^2 - c^2t^2 = x^2 + y^2 + z^2 + i^2\, c^2t^2$$

and write the square root in terms of a 4-vector:

$$\mathrm{r} = \mathbf{i}x + \mathbf{j}y + \mathbf{k}z + ict$$

The fact that identical masses attract while identical charges (of any kind) repel has long been considered rather mysterious, but, if masses are real, while charges imaginary, it has a very simple explanation. If we take, for instance, the law of attraction between two identical masses

$$F = - \text{ constant} \times \frac{m_1 m_2}{r^2}$$

and compare it with the law of repulsion between two identical electrical charges,

$$F = + \text{ constant} \times \frac{e_1 e_2}{r^2},$$

we see that the two laws would be identical in form if the charges were represented by imaginary numbers:

$$F = - \text{ constant} \times \frac{ie_1 ie_2}{r^2},$$

But there are, of course, three charges, electric, strong and weak, and these are alike in being exhibiting mutual repulsion for identical particles, while we have the perfect way of describing a 3-D imaginary quantity in the quaternion system, whose units combine 3 imaginary parts ***i***, ***j***, ***k*** with one real, the scalar value 1. The quaternions are anticommutative, following the multiplication rules:

$$\boldsymbol{i}^2 = \boldsymbol{j}^2 = \boldsymbol{k}^2 = \boldsymbol{ijk} = -1$$
$$\boldsymbol{ij} = -\boldsymbol{ji} = \boldsymbol{k}$$
$$\boldsymbol{jk} = -\boldsymbol{kj} = \boldsymbol{i}$$
$$\boldsymbol{ki} = -\boldsymbol{ik} = \boldsymbol{j}$$

Significantly, also, their dimensionality is restricted to exactly 3. There are no algebras with more than 3 imaginary dimensions, with the single exception of the *antiassociative* octonions, with 7 imaginary dimensions. In a sense, anticommutativity explains 3-dimensionality, for it cannot be made to work with any other dimensionality.

If the quaternion units 1, ***i***, ***j***, ***k*** are multiplied by the pseudoscalar *i*, they become a 4-vector system, with units *i*, ***i***, ***j***, ***k***. This accommodates the space-time connection in relativity, but there is also a significant additional result. If we apply quaternionic multiplication rules to the space vector, as we require for absolute symmetry, we also automatically incorporate the otherwise strange property of spin. The multivariate vector algebra, as Hestenes described it (1966), is, in fact, a Clifford or geometrical algebra, with a full product between two algebraic units **a** and **b** of the form

$$\mathbf{ab} = \mathbf{a.b} + i\mathbf{a} \times \mathbf{b}.$$

It is the extra $i\mathbf{a} \times \mathbf{b}$ term which generates spin when applied in the equations of quantum mechanics.

But there are also other advantages in the real / imaginary description, for the imaginary description of time explains why only quantities in which the time is squared, such as acceleration and force, are significant in physics, and why time 'measurement' always requires force and acceleration. In the case of charge we use the fact that imaginary quantities are algebraically dual (unlike real ones), with + solutions only existing if there are also – ones, to indicate why all charges have to have solutions for both signs and why we have to have antiparticles or antistates to all particles, include those such as neutrons and neutrinos with weak and / or strong, but no electric charges. Again, we have two ways of detecting real mass, directly, though inertia, and via the squared quantity (gravity), but only one way of detecting imaginary charge, via the squared quantity (electric force, etc.).

4. COMMUTATIVE AND ANTICOMMUTATIVE

Mass, in the sense of mass-energy, is a continuum. It is present at all points in space. There is the Higgs field (246 GeV) or vacuum, zero-point energy, even ordinary fields. The continuity of mass is the precise reason why it can never be negative (or, more strictly, change sign). There is no zero or crossover point. Charge, however, has always been recognized as being discrete and being delivered in precise units.

Space and time are also fundamentally different, and not just mathematically (real and imaginary), because time is continuous and space is not. Time's continuity has many consequences. It means that time is irreversible. To reverse time, we would have to create a discontinuity, a zero-point, and it would no longer be continuous. Time is not an observable in quantum mechanics. And it is always treated as the independent variable, dx / dt, not dt / dx. Then there is Zeno's ancient paradox, in which Achilles races a tortoise but never catches it, however fast he is, if he gives it a start, because in each interval of time in which Achilles makes up the distance separating them, the tortoise travels slightly further. Essentially, this is because time, unlike space, cannot be divided into finite measurable units.

Also, although all normal physical equations time-reversible, time is not, as we know from the second law of thermodynamics. Physical equations are time-reversible mathematically, because time is an imaginary parameter with equal + and – solutions; and, of course, the action of physical forces always involves time squared, so + or – makes no difference. However, time itself, as a continuum can never be reversed. There is thus no paradox.

Space has to be discrete, because it could not otherwise be observed. However, its discreteness is different from that of charge because it is a nonconserved quantity and so has no fixed units. This means that its discreteness must be endlessly reconstructed. In other words, it is infinitely divisible. It is the absolute continuity of time which denies it this property. Infinite divisibility is the absolute opposite of continuity.

Even though space is represented mathematically as a real number line (because of nonconservation), real numbers are not necessarily absolutely continuous. There are two systems of algebra, two of geometry and two of calculus, which depend on two different, equally valid definitions of the real numbers. They are called Standard and Nonstandard Analysis, and there is a perfect duality between them. There were two ways of differentiating, known from the seventeenth century, based respectively on the properties of time and space. Only the time-based one (limits) solves Zeno. There are also two ways of defining real (transcendental) numbers. If they are 'out there' they are uncountable, leading to standard analysis. If they have to be 'constructed', then they are countable, leading to nonstandard analysis.

The duality we have seen at the foundational level in mathematics applies in exactly the same way in physics. When we combine space and time in a 4-vector, we are really doing something that is physically impossible. So we either make time spacelike, the discrete solution, or space timelike the continuous solution. This is the origin of wave-particle duality, and the opposite viewpoints of Heisenberg and Schrödinger.

Remarkably, discrete quantities appear to be always 3-dimensional while continuous quantities are non-dimensional. It is easy to see why continuous quantities cannot have dimensions – dimensionality requires an origin, a zero or crossover point, which is incompatible with continuity. We can also see why are discrete quantities are 3-D in a roundabout way, by noticing that a quantity with only 1-D couldn't be measured, because the crossover points to another dimension are needed to do the scaling. So, a line is not actually a 1-D structure, but a 1-D structure that can only exist in a 2-D world. Then the 3-D extension is required for symmetry with quaternions. However, there is a direct argument which is much more profound and takes us to the very deepest foundations of both mathematics and physics. The seemingly difficult-to-explain connection between discreteness and 3-dimensionality turns out to be the key to the whole problem of getting something from nothing.

The only discreteness that exists in the whole of Nature (including numbers) comes from anticommutativity. Ultimately, anticommutativity allows us to have a dual pairing between, say, ***ij*** and ***ji***, whose total is zero. Nature generates something from nothing by producing an infinite series of closed quaternion triplets (like ***i***, ***j***, ***k***) which can represent discrete numbers or objects.

5. A GROUP OF ORDER 4

The parameters can be arranged as a nonclyclic group of order 4 (D_2), with the 3 pairings of property and antiproperty forming 3 C_2 supgroups:

mass	conserved	real	continuous (1-D) commutative
time	nonconserved	imaginary	continuous (1-D) commutative
charge	conserved	imaginary	discrete (3-D) anticommutative
space	nonconserved	real	discrete (3-D) anticommutative

We could represent this algebraically in the form:

mass	x	y	z
time	$-x$	$-y$	z
charge	x	$-y$	$-z$
space	$-x$	y	$-z$

In algebraic terms, this is a conceptual zero. The symmetry may be assumed to be absolutely exact; no exception to this rule has ever been found. And this condition can be used to put constraints on physics to derive laws and states of matter. We can also develop a number of representations, which not only show the absoluteness of the symmetry, but also the centrality to the whole concept of the idea of 3-dimensionality. A perfect symmetry between 4 parameters means that only the properties of one parameter need be assumed. The others then emerge automatically like kaleidoscopic images. It is, in principle, arbitrary which parameter we assume to begin with, as the following visual representations will show. The representations also suggest that 3-dimensionality is a fundamental component of the symmetry.

What is striking about the parameters and their properties is that they are purely abstract. They can be reduced, in effect, to pure algebra. The real / imaginary and commutative / anticommutative are obviously so, but the conserved / nonconserved can also be shown to be purely algebraic. They also each have their own algebra, which serves to define them. Their 'physical' properties come solely from this algebra.

Mass	1	scalar
Time	i	pseudoscalar
Charge	***i j k***	quaternion
Space	**i j k**	vector

The first three are subalgebras of the last, and combine to produce a version of it, say **I**, **J**, **K** (constructed from *i**i***, *i**j***, *i**k***), assuming that the charge units are commutative to those of space, and come from a different vector algebra. In other words they are equivalent to a 'vector space', an 'antispace' to counter **i**, **j**, **k**. We see why space appears to have a privileged status. The four algebras also have the appearance of an evolutionary sequence, and it has been shown that this can be generated using a computational process, which is a universal rewrite system (Diaz and Rowlands, 2002, Rowlands, 2007, 2010a).

6. THE FUNDAMENTAL PHYSICAL STATE

Working out every possible combination of the four requires 64 units. This turns out to be the algebra of the Dirac equation. We started with eight basic units, but, by the time that we have worked out all the possible combinations of vectors, scalars, pseudoscalars and quaternions, we find that the Dirac algebra has 32 possible units or 64 if you have + and – signs. However, the most efficient way of generating the 2 × 32 is to start with five composites, rather than eight primitives.

(±1, ± i)	4	units
(±1, ± i) × (**i**, **j**, **k**)	12	units
(±1, ± i) × (**i**, **j**, **k**)	12	units
(±1, ± i) × (**i**, **j**, **k**) × (**i**, **j**, **k**)	36	units

This is a group of order 64 which requires only 5 generators. There are many ways of selecting these, but all such pentad sets have the same overall structure.

Time	Space	Mass	Charge
i	**i j k**	1	***i j k***

We take one of each of the charge units ***i***, ***j***, ***k*** on to each of the units of the other three parameters, for example:

*i**k***	***i*i** ***i*j** ***i*k**	1***j***

Here, we have to break the symmetry of one space **i**, **j**, **k** or the other ***i***, ***j***, ***k*** (equivalent to **I**, **J**, **K**). Distributing the charge units onto the other parameters also creates new ‘compound’ (and ‘quantized’) physical quantities:

Energy	Momentum	Rest mass
E	p_x p_y p_z	m
*i**k***	***i*i** ***i*j** ***i*k**	1***j***

Simultaneously, it breaks the symmetry between the three charge units and we then have

weak charge	strong charge	electric charge
*i**k***	***i*i** ***i*j** ***i*k**	1***j***

Ultimately, this is responsible for the different symmetries responsible for the weak, strong and electric interactions. The $SU(2)$ symmetry comes from the pseudoscalar operator i attached to the weak charge $\boldsymbol{k}$, the $SU(3)$ symmetry comes from the three vector units $\mathbf{i}$, $\mathbf{j}$, $\mathbf{k}$ attached to the strong charge $\boldsymbol{i}$, and the $U(1)$ symmetry from the scalar unit 1 attached to the electric charge $\boldsymbol{j}$.

The symmetry-breaking comes when we reduce the eight basic units (i, $\mathbf{i}$, $\mathbf{j}$, $\mathbf{k}$, 1, $\boldsymbol{i}$, $\boldsymbol{j}$, $\boldsymbol{k}$) of time, space, mass and charge, or the six basic units ($\mathbf{i}$, $\mathbf{j}$, $\mathbf{k}$, $\mathbf{I}$, $\mathbf{J}$, $\mathbf{K}$) of the two equivalent vector spaces down to the five composite ones ($i\boldsymbol{k}$, $\boldsymbol{i}\mathbf{i}$, $\boldsymbol{i}\mathbf{j}$, $\boldsymbol{i}\mathbf{k}$, $1\boldsymbol{j}$), which form the minimum generators for the group. Five, as we know from such examples as quantic equations and Penrose tilings is always a symmetry-breaking number. It can never be associated with a perfect symmetry.

The combined object is nilpotent, squaring to zero, because

$$(i\boldsymbol{k}E + \boldsymbol{i}\mathbf{i}p_x + \boldsymbol{i}\mathbf{j}p_y + \boldsymbol{i}\mathbf{k}p_y + \boldsymbol{j}m)\ (i\boldsymbol{k}E + \boldsymbol{i}\mathbf{i}p_x + \boldsymbol{i}\mathbf{j}p_y + \boldsymbol{i}\mathbf{k}p_y + \boldsymbol{j}m) = 0$$

and we can identify this as Einstein's relativistic energy equation:

$$E^2 - p^2 - m^2 = 0.$$

The Dirac equation simply quantizes the nilpotent equation, using differentials in time and space for E and $\mathbf{p}$, where the momentum components have been collected into a single term. Allowing for all possible sign variations of E and $\mathbf{p}$,

$$(\pm\, i\boldsymbol{k}E \pm \boldsymbol{i}\mathbf{p} + \boldsymbol{j}m)\ (\pm\, i\boldsymbol{k}E \pm \boldsymbol{i}\mathbf{p} + \boldsymbol{j}m) = 0$$

becomes

$$\left(\mp\, \boldsymbol{k}\partial / \partial t \mp i\boldsymbol{i}\nabla + \boldsymbol{j}m\right)\left(\pm\, i\boldsymbol{k}E \pm ip + \boldsymbol{j}m\right)e^{-i(Et - \mathbf{p.r})} = 0$$

for the free particle, simultaneously giving us relativity and quantum mechanics.

In quantum mechanics we take the first bracket as an operator acting on a phase factor. The E and $\mathbf{p}$ terms can include any number of potentials or interactions with other particles. In these cases, when the particle is not free, we convert the differential terms to covariant derivatives and choose the single phase factor which will produce a nilpotent amplitude (Rowlands, 2007). Squaring to 0 gives us the Pauli exclusion principle, because if any 2 particles are the same, their combination state is 0. Another way of looking at Pauli exclusion is to say that Nature represents a totality of zero, and if you imagine creating a particle (with all the potentials representing its interactions) in the form

$$(\pm\, i\boldsymbol{k}E \pm \boldsymbol{i}\mathbf{p} + \boldsymbol{j}m)$$

then you must structure the rest of the universe, so that it can be represented by

$$-\,(\pm\, i\boldsymbol{k}E \pm \boldsymbol{i}\mathbf{p} + \boldsymbol{j}m)$$

The 'hole' left by creating the particle from nothing is the rest of the universe needed to maintain it in that state. We give it the name vacuum. So the vacuum for one particle cannot be the vacuum for any other.

We have now reached a position where we can show that the hidden structure of physics is a symmetry between space, time, mass and charge. The packaging of these into a single structure as a fundamental particle creates quantum mechanics and relativity and breaks the symmetry between the 3 units of charge. The structure is an expression of zero totality. If the symmetry between space, time, mass and charge is true, and it has now been tested to destruction over many years, we may have our 'Rosetta Stone' (Rowlands, 1983, 2001a, 2007, 2008). To take it to the next level of application, we assume that the symmetry is absolute (unbreakable) and exclusive, i.e. there is no other source of information in physics. This becomes a powerful constraint on all possible theories and the results of its application can be seen in Zero to Infinity.

7. ZERO TOTALITY

We can now propose that the most significant symmetries in physics originate in a universal zero totality. At the most fundamental level symmetries emerge to maintain this totality in two specific forms, duality and anticommutativity, which are respectively associated with the numbers 2 and 3. In our group structure, there is duality between every pair of parameters, and there are 3 such dualities. In principle, duality is the way we create 'something from nothing'. We only ever really create dual pairs, in which each thing is opposed by another thing which negates it.

The three dualities lead directly to factors of 2 or ½ appearing everywhere in physics

(Rowlands, 2001b, 2007). The conserved / nonconserved duality leads to this factor where we have, for example, action and reaction, absorption and emission, radiation plus reaction, potential versus. kinetic energy, relativistic versus rest mass, uniform versus uniformly accelerated motion, or when conjugate variables are paired in defining a system, in either classical or quantum physics. The real / imaginary duality produces this factor, when we compare bosons with fermions, or when we consider electric and magnetic fields in Maxwell's equations, and space-like versus time-like systems. It is the one which we find in relativistic contexts, and allows transformations to be made between space and time representations. The commutative / anticommutative duality creates the factor of 2 or ½ when we investigate a fermion in an 'environment', as in the Aharonov-Bohm, Jahn-Teller, or other Berry phase type effects. It is characteristically observed when we compare space-like and time-like systems, particles and waves, Heisenberg and Schrödinger versions of quantum mechanics, 4π and 2π rotation, and all examples in which physical dimensionality or noncommutativity is involved.

The factor 3 in fundamental physics is usually a sign of anticommutativity, and stems from one or other of the two spaces that create the entire algebra of the parameter group. So we have 3 dimensions of space, 3 nongravitational interactions, 3 fundamental symmetries (*C*, *P* and *T*), 3 conserved dynamical quantities (momentum, angular momentum and energy), 3 quarks in a baryon, 3 generations of fermions (which can be attributed to *C*, *P* and *T*), and even 3 fundamental dualities.

Wherever the numbers 2 and 3 appear in physics in a fundamental context, they are nearly always traceable to the symmetries as manifested in the parameter group. In addition, the building up of higher order, or more advanced, structures from more basic or primitive ones is based on duality and anticommutativity, and, to some degree, on a competition between them. This is manifested in both algebraic and geometric formulations. It encompasses such things as fundamental particles and the group symmetries that describe their interactions, but there are manifestations throughout the laws of physics in both classical and quantum forms.

8. BROKEN SYMMETRIES

An area of particular significance is the emergence of broken symmetries and chirality. These are not manifested at the most primitive level, but emerge at higher levels of complexity and their emergence can be traced to the way that the more 'primitive' concepts are ‘packaged’. It would seem that the characteristic level at which broken symmetries first emerge is associated with the combination of duality and anticommutativity, and its most basic level is connected with the number 5 (Hill and Rowlands, 2010a). In the case of fundamental particles or fermions it arises from a duality of two spaces constructed from anticommuting elements (Rowlands, 2007, 2010b). The chirality, which is also characteristic of the fermionic state, can also be seen as another consequence of the way that the symmetry between the algebraic units is broken.

Examples are not only seen in many areas of physics, but also in mathematics, chemistry and biology (Rowlands, 2007, Hill and Rowlands, 2010a,b). Ultimately, the only reason why we seem to be able to make any sense of a world which is structured at many orders of magnitude below our immediate perceptions is because we have evolved to be capable of recognising recurring patterns, and such patterns seem to repeat themselves in nature at different levels of complexity. Symmetry is certainly the key to understanding physics as well as many other aspects of the natural world.

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