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Symmetry and symmetry breaking in Modern Physics

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Abstract. In modern physics, the theory of symmetry, i.e. group theory, is a basic tool for understanding and formulating the fundamental principles of Physics, like Relativity, Quantum Mechanics and Particle Physics. In this work we focus on the relation between Mathematics, Physics and objective reality.

1. Introduction

Symmetry in ancient Greece and Rome became synonymous to harmony, beauty and unity. Plato's ideal world consisted of regular polyhedra: tetrahedron was representing the fire, cube - earth, octahedron - air, dodecahedron - spirit or ether and Icosahedron - water. The Aristotelean and Ptolomaic vision of the universe was based on spheres.

Symmetric structures attracted the interest of mankind from the start of civilization. Monuments presenting symmetry were built, like e.g. ancient temples and the pyramides in Egypt. Translational symmetry was the preferable one with the columns of the temples built at equal distances. Hexagonal, octagonal and other rotational symmetries were also used. The tetrahedral structures were of the favorite ones in pyramid structures. The practical advantage of symmetry in Architecture and Engineering was that one could use repetitive actions for construction. Thus, e.g. in the case of hexagonal structures one could use only a single unit of length, the radius of the circle and position all structural elements, e.g. columns, without any further measurements. As for the esthetic effect, we cannot say much, but from the optical point of view, once the eye recognized symmetry, one could form mentally the whole structure from a single structural element. This is a pleasing effect as one could visualize the whole object by storing in memory very "little information".

Beyond the symmetries observable by the eye or the ear, experimental evidence suggested the existence of symmetries in the microstructure of objects, like e.g. in crystals. In fact crystallography was initially developed by considering the permutation group of the crystallographic indices. This macroscopic symmetry incited René Just Haüy at about 1794 to conclude that crystal symmetry as originating from smaller symmetrical units (cubes, octahedra and tetrahedra) before the concept of algebraic group was formulated by Galois at the beginning of 1800. Thus, it was realized that a crystal was unaffected by certain symmetry operations. Lattices and their symmetries were studied for first time by M.L. Frankenheim in 1835, while Bravais derived the crystal classes by using pure geometrical theory. In 1890, the Russian crystallographer Fedorov and the German mathematician Schoenflies, working independently,

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demonstrated the role of group theory concepts in classifying crystal variety and for this purpose they made a list of 230 groups compatible with crystal symmetry, the so called crystallographic space groups. However, it was only after the discovery of X-rays and the Bragg reflections, that one could verify that crystal symmetries originated from the space group symmetries of the positions of atomic nuclei. Thus, finally it was realized that a solid is not a continuum, but it is built out of discrete subunits positioned in a regular and repetitive pattern.

2. From the Permutation groups to the Abstract Group Concept and Representation Theory

After the emergence of new geometries, (multidimensional Euclidean and non-Euclidean geometries) the need of their classification was realized by F. Klein, who in 1872, placed the concept of group and the notion of invariance at the heart of the Erlangen Programme. For F. Klein, geometry is the study of properties of space that are invariant under a given group of transformations. He showed that infinite continuous groups can be used to classify different geometries. In his view, both Euclidean and non-Euclidean geometries achieve the same status, because any geometry consists of a set (space) of points and a group of transformations that move geometrical objects in space, while preserving the properties appropriate to these geometries. In this way, the interest in group theory had shifted from permutations to the study of continuous transformation groups. Soon, it was realized that a symmetry of the Hamiltonian of a Physical system implied a conservation law (Noether's theorem).

The advent of Quantum Mechanics (QM) at the beginning of the 20th century rendered Group Theory sine qua non. The wide applications of group theory in QM relative to Classical Mechanics (CM) is due to its linearity. Thus in QM, by the symmetries present in a Hamiltonian, one can predict physical properties of the stationery states. The tool for this purpose is the theory of Group Representations. This theory is particularly efficient in QM because of the linearity of the energy eigenvalue equation. Using this theory, one can classify the solutions of the eigenvalue equation according to their transformation properties. This methodology started with Galois (1831), who was the first to conceive that the algebraic solution of an equation was related to the structure of a group of transformations and used the term "group" in its present technical sense. Galois realized that he was standing in front of a new algebra, appropriate for classifying the solutions of differential equations. Symmetry was linked to the properties of regularity, beauty and unity. In fact Galois called his theory "une simplification intellectuelle".

A turning point of the theory was the study of the algebraic representation of abstract groups: In 1854 Klein remarked that every finite abstract group can be represented by a permutation group and in 1896 Dedekind wrote a letter to Frobenius posing the problem to factorize a special kind of determinant associated with a finite group. The solution of this problems led Frobenius to the formulation of the representation theory of finite groups. This concept was later used in Quantum Mechanics for the classification of the eigenstates of Hamiltonians invariant under a group of transformations. But, while representation theory started as homomorphic mapping of a groups G into matrices D(g), in quantum mechanics the main interest was not the mapping but the invariant subspaces of group G. By invariant subspace we mean a subspace mapped into itself by the action of the group elements. In order to clarify the concept, we shall take the example of a finite group of order N. Starting from a vector $|\Psi\rangle$ belonging to a space V one finds N vectors $|\Psi_i\rangle = g_i|\Psi\rangle$, $g_i \in G$. Then, by using the group properties, one can show that the linear combinations $\sum_{i=1}^{N} c_i |\Psi_i\rangle$ of these vectors form an invariant subspace M of G. However, this invariant subspace may contain smaller subspaces which are invariant under the action of the group elements of G. If an invariant subspace does not contain invariant subspaces of smaller dimension, then the subspace is called an *Irreducible subspace* of G.

We shall now show that in searching for the eigenstates (eigenvectors) of a Hamiltonian H which is invariant under a group G, one may choose its search in a subspace of the whole space,

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whose basis vectors transform according to the Irreps of G. Thus, let us call S_i^{Γ} , the subspace of \mathcal{H} whose states can be labelled as $|\Phi_i^{\Gamma}\rangle$ and which have the transformation properties

$$g|\Phi_i^{\Gamma}\rangle = \sum_{j=1}^k D_{ji}^{\Gamma}(g)|\Phi_j^{\Gamma}\rangle$$
(1)

We shall show that if a Hamiltonian H is invariant under a group of transformations G, i.e. $gHg^{-1} = H$ for all $g \in G$, then the space S_i^{Γ} is a an invariant subspace of H. Thus let

 $|\Psi_i\rangle = H|\Phi_i^{\Gamma}\rangle$. Then

$$g|\Psi_i\rangle = gH|\Phi_i^{\Gamma}\rangle = gHg^{-1}g|\Phi_i^{\Gamma}\rangle = Hg|\Phi_i^{\Gamma}\rangle$$
(2)

and since $g|\Phi_i^{\Gamma}> = \sum_{j=1}^k D_{ji}^{\Gamma}(g)|\Phi_j>$ it follows that

$$g|\Psi_i\rangle = H\sum_{j=1}^k D_{ji}^{\Gamma}(g)|\Phi_j^{\Gamma}\rangle = \sum_{j=1}^k D_{ji}^{\Gamma}(g)H|\Phi_j^{\Gamma}\rangle$$
(3)

and since $H|\Phi_j^{\Gamma}>=|\Psi_j>$ it follows that

$$g|\Psi_i\rangle = \sum_{j=1}^k D_{ji}^{\Gamma}(g)|\Psi_j^{\Gamma}\rangle$$
(4)

Thus the states $|\Psi_i\rangle = H|\Phi_i^{\Gamma}\rangle$ have the same transformation properties as the $|\Phi_i^{\Gamma}\rangle$. Hence, they belong to the space S_i^{Γ} .

Since the geometric concept of eigenstate (eigenvector) of a Hamiltonian H is to find a onedimensional space which is mapped onto itself, i.e. one has to search for a vector $|\Psi\rangle$ which satisfies the equation

$$H|\Psi >= E|\Psi >$$

one can search separately in each $S_i^{\Gamma},$ which is an invariant subspace of G.

From the above it follows that only one class of solutions of the eigenvalue equation has the symmetry of the Hamiltonian, i.e. the $|\Psi\rangle$ of this class satisfy the relation $g|\Psi\rangle = |\Psi\rangle$. The corresponding Irrep is called the Identity Irrep. All other classes of solutions have symmetry breaking, i.e., they are less symmetric. However, we must emphasize that symmetry is not broken absolutely, since they have definite transformation properties.

The particular interest of the energy eigenstate problem in quantum mechanics is connected with the stable solutions of a physical system. Thus if we consider a collection of k protons and l neutrons interacting via nuclear and electromagnetic forces, described by a Hamiltonian H, we can search for the minima of the functional

$$\mathcal{E}(\Phi) = <\Phi|H|\Phi>, <\Phi|\Phi>=1 \tag{5}$$

in the space \mathcal{L}^2 of square integrable functions. Note that the definition of the space of minimization is necessary. By restricting the space to one of its subspaces, the minimum is raised, while by expanding the space, the minimizing $|\Psi\rangle$ may not exist. Let us suppose that such a $|\Psi\rangle$ exists. Then for 1st order variations of $|\Psi\rangle$, i.e. for

$$|\Psi_{\varepsilon}\rangle = |\Psi\rangle + \varepsilon |\Theta\rangle \quad \text{with} \quad <\Theta|\Psi\rangle = 0, <\Theta|\Theta\rangle = 1 \tag{6}$$

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the following relation must hold

$$\lim_{\varepsilon \to 0} \frac{\mathcal{E}(\Psi_{\varepsilon}) - \mathcal{E}(\Psi)}{\varepsilon} = 0$$
(7)

By taking limits we find

$$<\Theta|H|\Psi>=0\tag{8}$$

This means that the state $|\hat{\Psi}\rangle = H|\Psi\rangle$ is orthogonal to the space of the $|\Theta\rangle$ states. But, only the states $E |\Psi\rangle$ are orthogonal to $|\Theta\rangle$.

Hence $|\widehat{\Psi}\rangle = E |\Psi\rangle$ and thus $H|\Psi\rangle = E|\Psi\rangle$.

The above discussion is very useful in many particle physics, i.e. atoms, molecules, solid and in particular in elementary particles which, according to the present status of the theory, they are considered as composite particles, e.g. they consist of quarks.

3. Particle Physics

Although it looks strange, the groups of interest in particle physics, are isomorphic to groups of matrices. These groups are: U_n , SU_n , O_n , SO_n .

The classification of elementary particles in terms of symmetries did not follow a straight path. It started from an attempt to classify empirically the elementary particles and finally it culminated in the search of Lagrangians invariant under transformations of an abstract group.

Rutherford in 1920 and Heisenberg and Maiorana in 1933 made the proposal to consider p and n as bound states of the same particle, the nucleon. In this way they could explain the fact that the masses of p and n were almost the same and the experimental fact that nuclear forces did not depend on charge. In order to explain the behaviour of some measurements made on the n - p scattering and backscattering, a new symmetry was used for the Hamiltonian of the nucleons: The group of the isotopic spin SU_2 , which is isomorphic to the rotation group in the spin space. Later, the new symmetry contributed a lot to the interpretation of the properties of the atomic nuclei.

In 1949 the only known particles were: e_{-} , p, n, e_{+} , μ_{+} , μ_{-} , π_{+} , π_{-} , K_{+} , K_{-} . Fermi and Yang predicted that π was a bound state of n and anti - n. In the middle of the 50s more hadrons were discovered: π_0 , K_0 , Λ_0 , Σ_+ , Λ_0 , Ξ_- , etc. which had all masses around 938 MeV.

In 1953 Gell-Mann introduced the new quantum number S called *strangeness* to explain the fact that K and Λ were produced with the probability of the strong interactions, but were decaying like being subject to weak interactions. The name strangeness was used because of the deviation from the SU₂ predictions. In 1956 Sakata considered the 7 mesons $(3\pi, 4K)$ and 8 baryons $(2n, \Lambda, 3\Sigma, 2\Xi)$ known at that time, and postulated that 3 baryons (p, n, Λ) were more fundamental than the other 5 baryons and 7 mesons and demonstrated that these 12 particles could be composed only by p, n, Λ and anti- π , ant-n, anti- Λ .

In 1959 S. Okubo e.a. pointed out a symmetry between the 3 leptons(μ, e, ν) and the 3 baryons(p, n, Λ) in the Sakata model. The new symmetry was called the *Kiev symmetry*, i.e. it was named after the city in which a conference was taking place. On that basis, a new model was created by a generalization of the isotopic symmetry. It took into account that the strong interactions were involving particles having almost the same masses, same spin and intrinsic parity but a different electrical charge. The operator used to shift from one particle to another was the Isotopic spin which had the third component quantized and its different values were distinct particle groups in the same group (multiplet).

The Isotopic spin formalism introduced into the theory an abstract representation abandoning the previous link with a concrete materialist representation of matter through the elementary particles. In fact the theoreticians saw Isospin as rotation in an abstract 3dimensional space and tried to make a classification of the particles according to the value of the third component of the Isotopic spin and the hypercharge $Y = 2(Q - I_z)$. The classification obtained was similar to the periodicity of the magic numbers of the Periodic Table of atoms. In fact the particles were organized in groups of multiplets like: *baryonicoctet*, *pseudoscalar mesonic octet*, *octet meson decuplet*. This scheme was proposed by Gell-Mann and Ne'emann in 1962 and was called: the *Eigthfold way*. The discovery of Ω_{-} , according to the prediction, validated this model.

3.1. From the Kiev Symmetry to SU_3

The existence and algebra of unitary groups, was not known to Gell-Mann and his American and European colleagues, but was well known to the nuclear physics community. In fact SU₃ was used as the invariance group of the 3-dimensional harmonic oscillator. Its Irreducible representations and Glebsch-Gordan coefficients were always classified, using its subgroup of rotations in 3-dimensions. A group of Russian physicists (Levinson, Lipkin and Meshokov) knew this classification very well and applied it to the Sakata model to obtain the Clebsh-Gordan coefficients using the SU₂× U₁ sub-group. The cross multiplication among the groups was defined by the corresponding Lie algebra. SU₂ was already applied to systems of protons and neutrons and U₁ was the group of the spinor fields of QED. The term "sakaton" (p, n, Λ) was used as a general name for the fundamental triplet of SU₃ and Λ was considered as the constituent of hypernucleus.

3.2. SU_3 Group and the quark model

The introduction of a second quantum number S together with the Isospin, suggested the idea to extend the symmetry of SU_2 to a new group SU_3 . The octets constitute an eight-dimensional Irreducible representation (Irrep) of SU_3 , the decuplet a ten-dimensional Irrep and son on. But, unfortunately the particle multiplet that this group was representing, was showing a big difference among the masses of particles, for instance the baryons octet showed a difference in mass of 400 MeV over an average mass of 1100 Mev. The SU_3 symmetry was broken. This argument was taken as basis for the quark model.

In 1964 Gell-Mann and Zweig proposed independently a model in which all particles were made up of more elementary ones, called *quarks*. The quarks were 3: up, down and s, carried a fractional charge and followed the Fermi statistics. The u, d and s correspond to vectors which form a three-dimensional representation of SU₃. When symmetry breaks and reduced to the SU₂ subgroup, the space of states breaks into two invariant subspaces, a two-dimensional corresponding to iso - doublet (u, d) and isosinglet (s). In this way the whole spectrum of existing particles was organized in Meson and Baryon multiplets, according to the Irreps of SU₃, but a particle, named Δ_{++} , could not be classified because it resulted from 3 uuu quarks, violating the Pauli principle. In order to solve the problem one possibility was the hypothesis that each quark possesses another internal degree of freedom: color charge. According to this model p was composed of a red u quark, a blue d quark and a green u quark. A neutron had as constituents a green u quark, a red u quark, and a blue u quark . Δ_{++} was composed of a red, a blue and a green u quark.

In the following years SU₃ was expanded to SU(4), SU(5) and SU(6) introducing the *charm* quark c, the *bottom* quark b and the *top* quark t, respectively. A symmetry with the leptons: (e, ν_e , μ , ν_{μ} , τ , ν_{τ}) was established. Actually we have three families of quarks (u, d, s, c, b, t) and 3 of leptons. But the classification of the particle zoo was not enough to explain the interactions carried by the electromagnetic, weak and strong forces.

3.3. Gauge Theories

Quantum Field Theories (QFT) are described by Lagrangians invariant under a certain symmetry group of transformations. When they are invariant under a transformation identically performed at every space-time point, are said to have a global symmetry. Gauge theory extends this idea by requiring that the Lagrangians must posses local symmetries, i.e., it should be possible to perform these symmetry transformations in a particular region of space-time without affecting what happens in another region. An example from electrodynamics: The definition of zero voltage in an electric circuit is a case of a gauge theory, because, when the electric potential across all points is raised by the same amount, the circuit does not change the way it operates, since the potential differences in the circuit are unchanged. The ground voltage, taken as 0 is arbitrary, but after being chosen, then this definition must be followed globally. In contrast a local gauge symmetry is created when the symmetry is defined arbitrarily from one position to the next.

If in a Lagrangian (Hamiltonian) formulation there is a term which breaks symmetry, then we talk about an explicit symmetry breaking. Symmetry breaking terms are introduced by hands on the basis of theoretical or experimental results. As an example, we can recall that in the theory of weak interactions the mirror symmetry is violated (Parity violation), because of experimental evidence. Yang Mills theories are a particular examples of gauge theories with non-abelian symmetry groups specified by the Yang-Mills action.

In 1917 Emmy Noether published a theorem relating symmetries and conservation laws: Every symmetry in nature yields a conservation law and conversely every conservation law reveals an underlying symmetry. Thus, the invariance of electrodynamics under gauge transformations leads to the charge conservation. Since QFT are described by Lagrangians, their invariance under a specific group of transformations leads to the conservation of new quantum numbers, which are used to characterize a particle: J (angular momentum), B (baryonic number), S (strangeness), Y (hypercharge), I (isotopic spin), Q (charge) etc.

3.4. From SU_3 to the Standard Model $SU_2 \times U_1 \times SU_3$

The Standard Model (SM) consists of the electro-weak theory (which is a unified description of the electromagnetic and weak forces, described by $SU_2 \otimes U_1$ and the theory for the strong interactions known as QCD, described by SU_3 . According to this model, all matter consists of point-like particles which are either quarks or leptons (called fermions), whereas the forces between these particles are mediated by the exchange of intermediate bosons: the gluon, the photon, the Z and the W + /-. There are 3 families or "generations", but only the particles of the first family are believed to exist as stable particles in nature (the single quarks are not expected to exist as free particles but assumed to be bound within the protons). The leptons and the quarks of the second and third family are only present in extreme energy situations available at HEP accelerators or in cosmic rays. These energies were present, according to cosmological theory, right after the Big Bang. Each lepton and quark has an anti-particle partner and all quarks have 3 different "colors". Since there are 8 types of gluons (also associated with "color"), the Standad Model operates with 48 matter particles and 12 force mediators. All other particles are assumed to be combinations of these constituents. The Model contains 20 free parameters, the values of which are not derived by theory but are determined experimentally. The concept of Spontaneus Symmetry Breaking was transferred from condensed matter to QFT in analogy with the theory of superconductivity (BCS theory), the Goldstone bosons and the Higgs bosons are generated by symmetry breaking.

Both theories are needed to explain why particles acquire a mass. The Standard Model describes a world composed of matter and forces, but this is partially true because it is based on field theories rather on particle theories. S. Weinberg in his book: "The Search for Unity: Notes for a History of Quantum Field Theory" published in 1977 quotes: "The inhabitants of the

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universe were conceived to be a set of fields, an electron field, a proton field, an electromagnetic field and particles were reduced to mere epiphenomena. In its essentials, this point of view has survived to the present day and forms the central dogma of quantum field theory: the essential reality is a set of fields subject to the rules of special relativity and quantum mechanics."

3.5. Beyond the Standard Model: the Supersymmetry

The Standard Model, based on QFT is generated by merging QM and Relativity. According to this model, the Universe is filled with a condensate of Higgs Bosons, which disturbs matter particles and forces, not letting them go far and hence making them massive. For example, the W boson, carrier of the weak force, bumps on the Higgs condensate continuously and therefore becomes short-ranged, extending only over a thousandth of the size of nuclei. All masses of known elementary particles are supposed to have originated from the Higgs boson. But, the Higgs boson receives a large contribution from self-interaction, making impossible for us its study at smaller distances. Gravity is believed to be unified to the other forces at small distances of the order of the Planck length $(10^{-33}$ cm). At such distances the SM is in crisis. Supersymmetry solves the problems because for every particle, there is a superpartner whose spin differs by 1/2. In this way the number of particles doubles, there is a cancellation process with ordinary particles and the SM problems seem to disappear.

The supersymmetric particles, are considered good candidates as constituents of the so called dark matter, which according to more recent Cosmology theories, fills the Universe at about 20%. We hope that the forthcoming accelerator experiments at Tevatron collider in Fermilab, Illinois or the Large Hadron Collider at CERN, Geneva, will find them.

3.6. Philosophical Implications

Symmetry is a basic tool of scientific theory nowadays. Symmetry means simplicity as it gives as the way to formulate physical principles and understand the dynamic evolution of dynamical systems. Thus, Galilean invariance means space and time symmetry: The laws of nature are the same whether we are on the ground or on a boat moving with a constant speed. Then, in formulating a relation between cause and effect, one must take this symmetry into account. The translation or rotation of a system, provided that the external potential initial conditions are subject to the same transformations, must lead to the same evolution of its state. Thus e.g. the ground state $\Phi(\mathbf{r}_1, \mathbf{r}_2, ... \mathbf{r}_N)$ becomes $\Phi(\mathbf{r}_1 - \mathbf{R}, \mathbf{r}_2 - \mathbf{R}, ... \mathbf{r}_N - \mathbf{R})$ when its center of mass is shifted by **R**. Moreover, symmetry of the Hamiltonian under a group G, e.g. under O_3 , automatically gives the relation $\Phi_m^l(R_\omega \mathbf{r}_1, R_\omega \mathbf{r}_2, ..., R_\omega \mathbf{r}_N) = \sum_{m'} D_{m'}^l(R_\omega) \Phi_{m'}^l(\mathbf{r}_1, \mathbf{r}_2, ..., \mathbf{r}_N)$. Thus symmetry by itself, provides many properties of a system. This was a big step in our understanding of the symmetry effect: Symmetry of the external potential does not imply symmetry of the properties of the physical system. For the ignorant of the application of group representation theory to the eigenstate problem, this seemed strange and it was called spontaneous symmetry breaking. But, as stated earlier, if symmetry of the equations of motion implied symmetry of the solutions there would not be any physical phenomena. We must also stress the fact that systems with symmetry provide us with easy to understand and solve problems. The motion of a sphere on the floor is much simpler than that of a conic top which has less symmetry while that of an asymmetric stone is too complicated to bother a physicist. From the mathematical point of view it is easy to find the electric capacitance of a metallic sphere than that of a misshaped ball. Systems far from symmetry do not help our understanding, therefore they are not the object of a physicist. Thus, the electric capacitance of a misshaped ball is left to the engineer. The physicist will study systems with symmetry or not far from it.

As stated in the previous sections the road from the spatial symmetry of objects to the group theoretic formulation and the exploitation of symmetry for finding properties of physical systems was not straightforward. There were sharp turns and snakelike paths, but this is how science

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proceeds. The particle physics used initially permutation and spin symmetry. Next, the isospin SU_2 was used for the interpretation of approximate symmetries. But, more experimental facts from nuclear physics lead to the introduction of *strangeness* in order to "interpret" deviations from the SU_2 symmetry. Then SU_3 came to remedy the situation, and *strangeness* was not any more a strange property. $SU_2 \otimes U_1 \otimes SU_3$ followed after SU_3 was not sufficient to interpret the new experimental data. And lastly came supersymmetry.

Each of the above steps constitutes an epistemic cycle in the sense formulated by T. H. Brody. Before each new step, the whole frame of theoretical and experimental data had to be revised and a new theory was formulated. The formulation of each new theory did not have the interpretational strength and elegance of its final form. Thus, we have only approximations to physical reality. What is considered exact, turns out to be approximate seen from a higher epistemic cycle. But science cannot proceed without idealization, neither without abstraction. The surface of a metallic sphere is never a perfect spherical surface. There is always some roughness. On the microscopic level one discovers new discrepancy of the anisotropy, due to the crystal structure of metals. Thus, there is no homogeneity any more in the sphere. The next cycle is crystallography which takes into account the new symmetry.

Some remarks: Experiments in High Energy Physics (HEP) are conducted by accelerating beams of particles to very high energies and brought to collisions with the target particles. The products of the collision are signalled and counted by special detectors. Then, the reaction products of such collisions must be analyzed to determine the constituents of the original particles and the identity of new particles formed in the collision. From the collisions to "sensible data" there is a big step. Raw data are filtered for cutting off false events due to malfunctions of the detectors and the other experimental set up. Since theory dependent computer simulations play a central role in the data selection process, it follows that the final experimental results can be limited by the theory used in the simulations. Thus, the question posed here is: Does the technological set-up and the data handling processes guarantee that physicists extract facts of reality or the results are "constructed" by adjusting the apparatus and data selection criteria to fit a particular theoretical physical model? The Nobel Prize theoretical physicist S. Weinberg in his book "Dreams of a Final Theory" is in favor of scientific realism. Nevertheless he acknowledges that he has no proof of his realism. "the most dramatic abandonment of the principles of positivism has been in the development of our present theory of quarks". In fact the confinement hypothesis implies that quarks are never expected to be observed as individual particles, in contrast to a positivistic doctrine of only dealing with observables. A strong debate is framed in epistemological terms centered around the question of how the scientific product relates to the world. The whole spectrum can be summarized by the following thesis: Scientific theories are true descriptions of entities belonging to reality. The outcome is guaranteed by the scientific method of observing phenomena, formulating theories about these and testing and revising theories in the light of experiments until these agree. In this way scientists discover more and more truths about the world.

References

- Brody Th 1993 Philosophy behind Physics Ed de la Pena L and Hodgson P (Berlin, N. York, Heidelberg: Springer-Verlag)
- [2] Symmetry and Symmetry breaking by Standford Encyclopedia of Phylosophy; http://plato.stanford.edu
- [3] Bonolis L. 2004 From the Rise of the Group Concept to the Stormy Onset of Group Theory in New Quantum Mechanics. A saga of the invariant characterization of physical objects, events and theories *Rivista del Nuovo Cimento* Vol 27 N4-5
- [4] Okun L B 2007 The impact of the Sakata Model Preprint arXiv:hep-ph/0611298v2
- [5] Lipkin H J 2007 From Sakata Model to Goldberg-Ne'eman Quarks and Nambu QCD Phenomenology and "Right" and "Wrong" experiments *Preprint* rXiv:hep-ph/0701032v2
- [6] Zinkernagel H, 1998 High Energy Physics and Reality-Some Philosophical Aspects of a Science Ph. D. Thesis
- [7] Cetina K K 2003 Epistemic Cultures, How the Sciences Make Knowledge (Harvard University Press)