

A Quantum Theory of Magnetism

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In this paper, a new Quantum Theory of Magnetic Interaction is proposed. This is done under a relaxation of the requirement of covariance for Lorentz Boost Transformations. A modified form of local gauge invariance in which fermion field phase is allowed to vary with each space point but not each time point, leads to the introduction of a new compensatory field different from the electromagnetic field associated with the photon. This new field is coupled to the magnetic flux of the fermions and has quanta called magnatons, which are massless spin 1 particles. The associated equation of motion yields the Poisson equation for magnetostatic potentials. The magnatons mediate the magnetic interaction between magnetic dipoles including magnets and provide plausible explanations for the Pauli exclusion principle, Chemical Reactivity and Chemical Bonds. This new interaction has been confirmed by numerical experiments. It establishes magnetism as a force entirely separate from the electromagnetic interaction and converts all of classical magnetism into a quantum theory.

1 Introduction

Quantum Electrodynamics (QED) is the most accurate theory available. The associated electromagnetic interaction, which is embodied in Maxwell's equations, is universally viewed as a unification of the electric force and the magnetic force. Such an interpretation, however, encounters difficulty when applied to a rather basic situation. Specifically, consider two electrons with parallel spins that are arranged spatially alongside each other ($\uparrow \uparrow$). From the theory of QED based on the Gordon decomposition [1, see p. 198], the electric charge of the electron along with its spin results in an electromagnetic interaction between the two particles which is made up of a dominant electric (Coulomb) repulsion and a weaker attractive magnetic component. That the magnetic component is attractive is stated explicitly by Fritzsche in his discussion of chromomagnetic forces among quarks [2, see p. 170]). This explains why orthopositronium, where the particle (electron and positron) spins are parallel and hence the magnetic component of the electromagnetic interaction is repulsive, has a higher energy state than parapositronium where the particle spins are anti-parallel and the magnetic component of QED is attractive. However, from the classical theory of magnetism, the magnetic moment of the two electrons results in a magnetic repulsion between the electrons rather than an attraction [3]. The commonplace occurrence of two bar magnets interacting with each other presents a further problem for the electromagnetic interaction since magnets, in general, carry a net zero charge and therefore cannot interact by exchanging photons. These examples appear to call into question the universally adopted practice of interpreting the magnetic force as part of the electromagnetic interaction and suggest the need

for some level of re-examination. In attempting to address these problems associated with the magnetic interaction, we observe that according to the relativistic world-view, all physical laws of nature must have the same form under a proper Lorentz transformation [4]. With respect to quantum field theories, this means that the field equations describing the various interactions of elementary particles must be Lorentz-covariant, a requirement that places certain restrictions on the allowed interaction models. Lorentz covariance is however not an observed law of nature but is rather a mathematical requirement that is assumed to apply universally. We wish to relax the restrictions imposed by this condition and therefore advance the following postulate:

Postulate 1

Not all interactions are covariant under Lorentz boost transformations. On the basis of this conjecture, we develop a new model of the magnetic interaction. Postulate 1 is the only assumption used in this development and is no more far-fetched than any of the several assumptions of the widely considered superstring theory for which there is no firm supporting evidence and which includes (i) strings rather than particles as fundamental entities, (ii) supersymmetry, the interchangeability of fermions and bosons and (iii) 9 dimensional rather than 3 dimensional spatial existence! On the other hand, the validity of our model and the likely correctness of the postulate are demonstrated by the significant extent to which the consequences of the model accord with or provide plausible explanations for observed phenomena. In particular, the model achieves the following:

- It predicts the existence of a new massless vector particle different from the photon that satisfies the wave

equation for magnetic fields. This particle mediates the magnetic interaction between magnetic dipoles thereby establishing the magnetic interaction as one separate from the electromagnetic interaction and converts all of classical magnetism into a quantum theory.

- It provides plausible explanations for a wide range of hitherto unexplained phenomena including phenomena associated with the Pauli exclusion principle, chemical reactivity and chemical bonds.

2 The electromagnetic interaction

At present, it is believed that the interaction of the electromagnetic field with charged point-like (Dirac) particles is governed by the Principle of Minimal Interaction [4]; all charged particles have only current-type interactions with the electromagnetic field given by $j^\mu A_\mu$ where A_μ is the 4-vector potential of the electromagnetic field and j^μ is the 4-vector current. The minimal concept implies that all electromagnetic properties can be described by this interaction and that no other interactions are necessary. The interaction involves both the charge of the particle and its magnetic moment resulting from its spin magnetic moment (SMM) derived from the Dirac theory and the quanta of the 4-vector electromagnetic field are spin 1 photons. Consider a “spinless” Dirac particle. For such a particle, the SMM is zero and hence electromagnetic interaction is only via the charge with the associated electric field being mediated by the 4-vector A_μ [5]. If on the other hand, the charge of the Dirac particle with spin goes to zero, the SMM again goes to zero and the interaction between the 4-vector A and the uncharged particle disappears. Roman [4, see p. 436] used the proton-photon interaction in the form $j^\mu A_\mu$ and the absence of a neutron-photon interaction (since the neutron is uncharged) to account for the experimental fact that the electromagnetic interaction destroys the isotropy of isospin space, an effect that Sakurai [6] considered as “one of the deepest mysteries of elementary particle physics”.* It seems therefore that for neutrons, where the electric charge is zero but the magnetic moment is non-zero, interaction cannot be of the type $j^\mu A_\mu$ i.e. the associated magnetic field is not mediated by the 4-vector A_μ . The well-known absence of interaction between (relatively stationary) electric charges and magnets does perhaps suggest that different mediating quanta are involved in these interactions. We note from the electrodynamic equation $B = \nabla \times A_k$ that, unlike the electric field E that requires both the 3-vector potential A_k and a scalar potential ϕ for its definition, the magnetic field B is completely defined by A_k , which we know, satisfies [3]

$$\square A_k = \mu J_k. \quad (2.1)$$

*Using this same nucleon-photon interaction, Roman also proved that the electromagnetic interaction conserves the third component of isospin, T_3 , a known experimental fact.

where J_k is current density, and which, as established by the Aharonov-Bohm Effect [7], has independent physical existence. We therefore ask, is the 3-vector A_k a magnetic interaction field that is separate from the 4-vector A_μ electromagnetic interaction field?

It is generally believed that all interactions are mediated by gauge fields and hence if A_k is an interaction field, then it should result from the gauge invariance principle [5]. According to this principle, changing the phase of a fermion locally creates phase differences, which must be compensated for by a gauge field if these differences are not to be observable. In other words, a gauge field results from fermion field phase changes. The electromagnetic field of QED and the gluon field of QCD (quantum chromodynamics) are examples of such compensating fields. Reversing this rule, we suggest that an independently created gauge field should produce local phase changes in the fermion field through interaction, i.e. fermion field phase changes should result from a gauge field. We believe that this is precisely what is demonstrated by the Aharonov-Bohm Effect [7]. Here, a 3-vector field A_k independently generated by an electric current, directly produces phase changes in a beam of electrons, in a region where the associated magnetic field B is zero. It follows, we believe, that A_k can be produced by an appropriate fermion field phase change, and that it represents an interaction field.

In order to model A_k as a gauge field, an appropriate conserved quantity, like electric charge, which will determine the strength of the coupling of A_k to the fermion, must be identified. In this regard, we note that an extensive quantum field theory describing magnetic monopoles carrying magnetic charges has been developed [8]. The quanta of this field theory are the quanta associated with the gauge field A_μ of QED, namely photons, which in this theory couple to both electric charge and magnetic charge. However magnetic monopoles have not been found despite strenuous efforts and therefore this theory remains unverified. Towards the development of a new theory having A_k as the gauge field, we adopt an approach sometimes employed in magnetostatics [3, see p. 325] and define a magnetic charge ν which, though physically unreal, is treated as the source of magnetic flux for the purposes of the development.

3 A gauge theory of magnetism

For a fermion with magnetic moment μ_m , we define [3]

$$\nu = \nabla \cdot \mu_m. \quad (3.1)$$

where we refer to ν as magnetic charge and regard it as the source of the magnetic flux associated with the magnetic moment μ_m . Now consider the Lagrangian density $L(x)$ of the fermion field $\psi(x)$ given by

$$L(x) = \bar{\psi}(x)(i\gamma^\mu \partial_\mu - m)\psi(x). \quad (3.2)$$

L is clearly invariant under the transformation

$$\psi'(x) = e^{-i\nu\alpha}\psi(x), \quad (3.3)$$

where α is a constant and ν is the magnetic charge of the fermion. From Noether's theorem [4], it follows that the magnetic charge is conserved i.e.

$$\partial_t \nu = \partial_t \left\{ \sum \nu_i \int \bar{\psi}_i \gamma^0 \psi_i d^3x \right\} = 0. \quad (3.4)$$

In practical terms, this means that magnetic flux is conserved. Thus, like electric charge, the conservation of magnetic charge (flux) can be viewed as a consequence of the invariance of the fermion Lagrangian density under the global transformation (3.3). Towards the generation of A_k through local phase changes, we recall that the electromagnetic field is the gauge field which guarantees invariance of the Lagrangian density under space-time local $U(1)$ gauge transformations, i.e. α is a function of space \bar{x} and time t . Here, noting that the electron interference pattern produced by A_k in the Aharonov-Bohm effect varies spatially as A_k is changed, we let the parameter α , in (3.3) be a function of space \bar{x} , $\alpha = \alpha(\bar{x})$ i.e. it may have different values at different points in space but continues to be the same at every time t . Considering a neutron field ψ_n say, (3.3) becomes

$$\psi'(x) = e^{-i\nu\alpha(\bar{x})}\psi(x). \quad (3.5)$$

Under this space-local transformation, the Lagrangian density is not invariant. Invariance is achieved by the introduction of a 3-vector massless field A_k , $k = 1, 2, 3$, such that

$$L = \bar{\psi}_n (i\gamma^\mu \partial_\mu - m) \psi_n - \nu \bar{\psi}_n \gamma^k \psi_n A_k, \quad (3.6)$$

where $A_k \rightarrow A_k + \frac{\partial\alpha(\bar{x})}{\partial\bar{x}^k}$ as

$$\psi_n \rightarrow e^{-i\nu\alpha(\bar{x})} \psi_n. \quad (3.7)$$

The quantity $\bar{\psi}_n \gamma^k \psi_n$ varies like a vector under space rotation and space inversion but not under a Lorentz boost. However, under postulate 1, such a term is allowed in the interaction. Hence, by demanding space-local invariance, a 3-vector field A_k is introduced. When we add to the fermion Lagrangian density a term representing kinetic energy of A_k [4], we arrive at the equation of motion for A_k given by

$$\square A_k = \nu \bar{\psi}_n \gamma^k \psi_n. \quad (3.8)$$

This is a 3-vector Klein-Gordon equation whose associated quanta have spin 1 charge 0 and mass 0. Variation of (3.6) with respect to ψ_n gives

$$(i\gamma^\mu \partial_\mu - m)\psi_n = -\nu \gamma^k A_k \psi_n, \quad (3.9)$$

which is the modified Dirac equation in the presence of the field A_k . Analogous to the electromagnetic case, we associate the quantity $\nu \bar{\psi}_n \gamma^k \psi_n$ with current density J_k such that

$$\square A_k = \mu J_k, \quad (3.10)$$

where μ is the permeability constant. This is equation (2.1) of classical electrodynamics. In the case of magnetic material, the equivalent current density is referred to as magnetization or Amperian current density J_m [3, see p. 315] given by

$$J_m = \nabla \times M, \quad (3.11)$$

where M is the magnetic dipole moment/unit volume or magnetization. Equation (3.10) is the well-known wave equation for magnetic potentials. [3]. If the magnetic charge distribution is time-independent, the wave equation (3.10) reduces to

$$\nabla^2 A_k = -\mu J_k. \quad (3.12)$$

Equation (3.12) is the Poisson equation for magnetostatic potentials that contains all of classical magnetism. It leads, under appropriate conditions, to the inverse square law for magnetic poles as well as an inverse higher-order law for magnetic dipoles given by

$$F = \frac{3\mu\mu_1\mu_2}{4\pi r^4}, \quad (3.13)$$

where the dipoles are parallel and spatially opposite each other $\uparrow\uparrow$ [4, see p. 311, problem 19.10]. Thus, J_k is the source of the potential A_k and we interpret A_k as the magnetic gauge field with quanta of spin 1, mass zero, charge zero and odd parity which we shall call magnatons. It is the gauge field which guarantees invariance under space-local $U(1)$ gauge transformations. The conservation of magnetic charge is directly associated with the universality of the magnetic coupling constant for all particles with a magnetic moment and the strength of the coupling is the magnetic charge (flux) of the particle. Thus, while for electrically charged particles the interaction with an electromagnetic field — the Quantum Electrodynamic Interaction or electromagnetic interaction — is mediated by the photon and involves the electric charge and the associated SMM, the interaction of a “magnetically charged” particle with a magnetic field is mediated by the magnaton and involves the particle's magnetic moment. This is a new quantum interaction, which we shall refer to as the Quantum Magnetodynamic Interaction or magnetic interaction. It is in general different from the magnetic component of the electromagnetic interaction. To demonstrate this difference, consider again two electrons with parallel spins ($\uparrow\uparrow$). Recall, from the theory of QED, (e.g. [1, see p. 198]), that the electric charge of the electron along with its spin results in an electromagnetic interaction between the two particles which is made up of a dominant electric repulsion and a weaker attractive magnetic component. In the new theory, the magnetic moment of the two electrons results in a magnetic repulsion given by (3.13) consistent with the classical theory of magnetism and different from the magnetic component of the electromagnetic force, which is attractive. Since the potential of the magnetic interaction is of the form $1/r^3$, its effect will not generally be noticed in QED interactions

where the potential is of the form $1/r$, but becomes dominant at short distances. Experimentally, in electron-positron high-energy scattering for example, there are indeed sharp resonances as well as novel asymmetries in the angular distributions, which cannot be accounted for in the QED perturbation theory, which Barut [9] has considered to be possibly of magnetic origin. In fact, Barut points out that in perturbation theory, the short distance behaviour of QED is completely unknown since the forces involved change completely at high energies or short distances. We believe that it is the magnetic interaction mediated by the magnaton, which becomes effective at short distances, that is the operative mechanism. We conclude then that the observed magnetic interaction between magnetic dipoles and magnets is mediated not by photons as is widely believed, but by magnetons. Because magnetons are massless vector particles, the associated magnetic field is long-range and results in interactions that are both attractive and repulsive, all in agreement with observation.

4 Application of the quantum magneto-dynamic interaction

The quantum magnetodynamic interaction effectively converts all of classical magnetism into a quantum theory and is therefore supported by 400 years of scientific discovery in magnetism, started by Gilbert in 1600. We expect new detailed predictions from the theory because of its quantum mechanical nature but defer this substantial exercise. Instead, we examine simple and direct tests of the model and show that it offers plausible explanations in precisely those areas where there are no simple answers. The larger the number of applications where it provides a persuasive account, the greater will be our confidence in its correctness and consequently our preparedness to engage in more detailed analysis. In the following sub-sections, three areas are discussed: The Pauli exclusion principle, chemical reactivity and chemical bonds.

4.1 The Pauli Exclusion Principle

The Pauli Exclusion Principle is an extremely important principle in science [10]. It is the cornerstone of atomic and molecular physics and all of chemistry. It states that two electrons (or other fermions) cannot have the same spatial wave function unless the spins are anti-parallel ($\uparrow\downarrow$) i.e. apart from the electric repulsion, parallel spin electrons tend to repel each other while anti-parallel spin electrons tend to attract each other. The operative force of attraction/repulsion is unknown. It cannot be the magnetic component of the electromagnetic force since it has the wrong sign and because of the inability to identify this so-called "Pauli Force", the tendency is to label this behaviour a "quantum-mechanical effect, having no counterpart in the description of nature according to classical physics" [10, see p. 564]. We suggest that the tendency for parallel spin electrons to repel each other and

anti-parallel spin electrons to attract each other arises as a result of the quantum magnetodynamic interaction. The magnetic moment of an electron is aligned with its spin, making it effectively a tiny magnet. Therefore, parallel spin electrons will experience mutual repulsion according to equation (3.13) arising from the exchange of magnetons, while anti-parallel spin electrons will experience mutual attraction. This, of course, is consistent with classical magnetism represented by (3.13).

Periodic Table of Elements

An immediate application of the magnetic attraction between anti-parallel spin electrons is in the energy levels of atoms. The attractive magnetic force in the anti-parallel spin electrons accounts for the anti-parallel pairing of electrons in atomic orbitals where the electrons are close together, this leading to the Periodic Table of elements. We further suggest that the attractive component of the long-range electromagnetic force between parallel spin electrons accounts for the experimental fact that unpaired electrons in different atomic orbitals having the same energy are parallel spin-aligned.

Solidity of matter

In solids, inter-atomic and inter-molecular forces are in general considered to be manifestations of the electromagnetic interaction between the constituents, and the electric (Coulomb) component plays the dominant role. This interaction provides an attractive force that holds the constituent atoms in a regular lattice. This is very evident in solids such as sodium chloride. For small inter-atomic distances such that the orbitals of inner electrons overlap, a repulsive force component arises. This repulsive force at short distances is called the repulsive core and is a general feature of atomic interaction. It prevents the interpenetration of atoms and thereby provides the solidity of matter [11]. The repulsive core is attributed to the Pauli Exclusion Principle and Gillespie explains this as follows [12, see p. 69]: "... because of the Pauli principle, in any region of space around a nucleus in which there is a high probability of finding a pair of electrons of opposite spin, there is only low probability of finding any other electrons. Since most molecules have an equal number of electrons of opposite spin, no other electrons can penetrate into each other to a significant extent." Again no force is identified and in fact Gillespie refers to the unknown Pauli forces as apparent forces that are not real. We propose that the quantum magnetodynamic interaction between the magnetic fields of the orbiting anti-parallel electron pairs in the various atoms is the missing component in Gillespie's explanation and that this along with the electric force prevents collapse in solids. The magnetic interaction neutralizes the associated magnetic field of the anti-parallel pair such that there is no magnetic interaction (which could be attractive) between the pair and the magnetic field of other electrons. As a result the electric field of the pair repels other electrons and prevents them from

penetrating to any significant extent. This, we suggest, is responsible for the solidity of matter with the magnetic neutralization being a critical feature of the process. The existence of the magnetic interaction in the repulsive core mechanism is supported by Earnshaw's theorem [13] according to which a system of only interacting electric charges cannot be stable.

4.2 Chemical reactivity

Chemical reaction generally involves the union or separation of atoms. While the Coulomb force is a dominant feature of this activity, we suggest that the primary basis of chemical reactivity is the magnetic interaction. This interaction explains why atoms and molecules with unpaired electrons in the valence shell like the alkali metals, the halogens and free radicals, tend to be highly reactive. The unpaired electrons in such substances have a magnetic field that interacts with the magnetic field of unpaired electrons of other atoms and molecules. The hydroxyl radical (OH) is an example of an odd electron molecule or free radical having an unpaired electron. It is extremely reactive because the radicals can combine with each other or with odd electron carriers, each contributing an electron to form pairs with the constituents drawn together and bound by the magnetic interaction. The magnetic interaction causes unpaired electrons to be points of high reactivity and hence free radicals have no more than a fleeting existence at room temperature [14]. The presence of this magnetic field in substances with unpaired electrons is evident in nitric oxide, boron and oxygen, all of which have one or more unpaired valence electron and are paramagnetic. Liquid oxygen will actually cling to a magnet. On the other hand, atoms and molecules with paired electrons like the noble gases of Group 8 on the Periodic Table tend to be unreactive. This occurs because the paired electrons in such substances are anti-parallel in spin alignment and this results in a substantial neutralization of the overall magnetic field associated with the pair. Since this magnetic field is being proposed as the agent responsible for promoting reactions, such substances would be expected to be less chemically reactive, as is observed. Because of this unavailability of unpaired electrons, the atoms of the members of Group 8 all exist singly.

Experimental confirmation

Important numerical experiments carried out by Greenspan [15] provide strong confirmation of this magnetic interaction and the attraction it produces between anti-parallel electron pairs. This researcher found that classical dynamical calculations for the ground-state hydrogen molecule using a Coulombic force between the bond electrons along with spectroscopic data yielded a vibrational frequency of 2.20×10^{14} Hz, which was a significant deviation from the experimentally determined value of 1.38×10^{14} Hz. By assuming the force between the electrons to be fully attractive rather than fully repulsive, Greenspan obtained the correct vibrational frequency. This approach was successfully tested for the following

ground-state molecules: H_2^1 , H_2^2 , $H^1 H^2$, $H^1 H^3$, and Li_2^7 . In all, these cases, deterministic dynamical simulations of electron and nuclei motions yielded correct ground-state vibrational frequencies as well as correct molecular diameters under the assumption that the binding electrons attract. In another paper [16] Greenspan showed that the assumption of electron attraction also yields the correct vibrational frequencies and average molecular diameters for ground-state molecules Li_2^7 , B_2^{11} , C_2^{12} , and N_2^{14} . Obtaining correct ground-state results for both vibrational frequencies and average molecular diameters in this large number of molecules was most unexpected and is an extremely strong indication of the correctness of the magnetic interaction model proposed in this paper.

4.3 Chemical bonds

Chemical bonding is due to the attraction of atoms for the electrons of other atoms toward their unfilled orbitals. We suggest that the basis of this attraction is the magnetic interaction between the unpaired electrons associated with these unfilled orbitals. Here we consider ionic bonds, covalent bonds and the concept of the rule-of-two that is central to chemistry.

Ionic bonds

In ionic bonds, donor atoms such as sodium tend to lose electrons easily while acceptor atoms such as chlorine tend to acquire additional electrons. When atoms of these two kinds interact, a re-arrangement of the electron distribution occurs; an electron from the donor atom migrates to the acceptor atom thereby making the acceptor atom negatively charged and the donor atom positively charged. The Coulomb interaction between these ions then holds them in place in the resulting crystal lattice. [11]. In this explanation of the formation of an ionic bond, while the role of the Coulomb force is clear, it is not clear what makes the electron from the donor atom migrate to the acceptor atom. We suggest that apart from the action of the electric force, the migration of the electron from a donor atom to an acceptor atom during a chemical reaction results from the magnetic interaction. As the chemicals are brought together, the electron of the donor atom is close enough to interact with the electron of the acceptor atom via their magnetic fields. The operative quantum magnetodynamic interaction causes the electron of the donor atom and the electron of the acceptor atom to be drawn together in an anti-parallel spin alignment consistent with magnetic attraction. The resulting magnetically bound pair becomes attached to the acceptor atom because of its greater electric attraction (electronegativity), precisely as observed.

Covalent bonds

While some bonds are ionic, the majority of chemical bonds have a more or less covalent character. This bond is the foundation of organic chemistry and is the basis of the chemistry of life as it binds DNA molecules together. According to the current understanding [11], atoms with incomplete shells

share electrons, with the electrons tending to concentrate in the region between the atoms. This concentration of electrons exerts a Coulombic attraction on the positive nuclei of the two atoms and this gives rise to a covalent bond. What is not evident in this explanation though is why the shared electrons cluster between the atoms, despite their mutual electric repulsion. The accepted approach is to solve the Schrodinger equation arising from the application of wave mechanics to the system and on this basis attempt to show that the electrons occupy the region where they are observed to cluster. This approach to the explanation of the nature of the covalent bond has been described by Moore [17] as the most important application of quantum mechanics to chemistry. However, this quantum-mechanical method is at best only an approximation as the only atoms that can be described exactly by wave mechanics are hydrogenic (single-electron) atoms such as H, He^{+1} and Li^{+2} . As a result, most of the claimed predictions are really systematized experimental facts as pointed out by Luder [18]. Moreover, wave mechanics does not identify the force that causes the clustering. The quantum magnetodynamic interaction offers an immediate explanation for this clustering: the two electrons involved in a covalent bond always have opposite spin arising from the interaction of the associated magnetic fields and this results in magnetic attraction between them, and hence the clustering. The strong directional characteristic of covalent bonds is a significant indicator of the magnetic nature of the bond, and the close proximity of the associated electron orbitals is consistent with dominant magnetic interaction. The general saturable nature of this bond and the empirical fact that an electron pair cannot normally be used to form more than one covalent bond arise because the intensity of the magnetic field of the anti-parallel electron pair constituting the bond is significantly reduced due to the anti-parallel alignment. This reduction in reactivity resulting from magnetic field neutralization in the anti-parallel pair has already been observed in the noble gases where only electron pairs exist.

To illustrate covalent bond formation based on the magnetic interaction, we examine the covalent bonds in hydrogen gas (like atoms) and hydrogen chloride (unlike atoms). The hydrogen atom has one electron in the 1s orbital. Consider the approach of two hydrogen atoms in the formation of a hydrogen molecule. If the electron spins are parallel (triplet state), then there will be magnetic (and electric) repulsion between the electrons as their orbitals overlap. This repulsive state with spin-aligned electrons in triplet state hydrogen atoms is spectroscopically detectable, thus confirming the overall correctness of this description. Magnetic repulsion along with electric repulsion between the nuclei prevents the formation of a stable molecule. If the electron spins are anti-parallel (singlet state), then for sufficient electron orbital overlap, the resulting magnetic attraction between the electrons is enough to overcome the electric repulsion between them (as well as between the nuclei), and the electrons cluster in a region be-

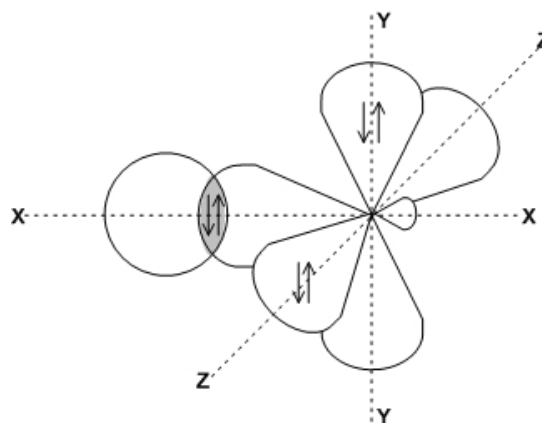


Fig. 1: Covalent bond formation in hydrogen chloride: the s orbital of the hydrogen atom overlaps with a p orbital of the chlorine atom.

tween the two nuclei. The electric force of attraction between this electron cluster and the two nuclei establishes the covalent bond and a stable hydrogen molecule H_2 results. It is an observed fact [19] that atomic hydrogen is highly unstable as the atoms tend to recombine to form H_2 molecules. We attribute this to the action of the magnetic interaction between the unpaired electrons as described. Similar action occurs in chlorine and oxygen molecules. As a second example, consider the formation of hydrogen chloride from an atom of hydrogen and an atom of chlorine. Hydrogen has one unpaired electron in the K shell in a spherical orbital and chlorine has seven valence electrons in the M shell, 2 filling the 3s orbital and 5 in the 3p orbitals comprising 3 orthogonal dumbbell-shaped orbitals about the nucleus. Two of these 3p orbitals are filled with paired electrons while the remaining 3p orbital has a single unpaired electron. When a hydrogen atom and a chlorine atom approach, the spherical orbital of the hydrogen overlaps with the unfilled elliptical orbital of the chlorine and the magnetic interaction between the unpaired electrons in these two orbitals causes these 2 electrons to cluster between the 2 atomic nuclei in an anti-parallel spin formation. The elliptical shape of the chlorine's 3p orbital is altered in the process. This magnetic interaction between these unpaired electrons establishes the covalent bond and the consequent formation of hydrogen chloride (HCl). The arrangement is shown in Figure 1.

The bound electrons are situated closer to the chlorine atom because of its higher electronegativity though they are not completely transferred to the chlorine atom as in sodium chloride. This imbalance causes the HCl molecule to be polar with a positive pole near the hydrogen atom and a negative pole near the chlorine atom. Thus, both the ionic bond and the covalent bond involve a magnetically bound (anti-parallel spin-aligned) electron pair that is attracted to two positively charged atomic nuclei by Coulomb forces. The relative strength of these two electric forces in a specific bond determines the exact position of the electron pair between

the atomic nuclei and hence its location along the bonding continuum represented by pure covalent (H_2)-polar covalent (HCl)-ionic (NaCl) bonding.

Rule-of-two

The “rule of two” [12] is a central concept in chemistry that is more significant than the well-known “rule-of-eight” or stable octet for which there are many exceptions. It is recognition of the observational fact that electrons are generally present in molecules in pairs, despite their mutual electric repulsion. We attribute this tendency to electron pair formation to the magnetic attraction between the two anti-spin aligned electrons forming the pair as verified by the Greenspan data. The new magnetic interaction therefore explains the universal “rule-of-two” simply and naturally.

5 Conclusion

In this paper, we have proposed a new magnetic interaction — quantum magneto-dynamics or QMD — that is mediated by massless spin 1 quanta called magnatons. These mediators are different from photons, the quanta of the electromagnetic interaction in QED. QMD is associated with the magnetic moment of the fermions and accounts for all magnetic interactions between magnets. Magnatons are massless vector particles that give the magnetic field its long-range attractive/repulsive character. They satisfy the Poisson equation of classical magnetism and are, we believe, the transmission agents in the Aharonov-Bohm effect. QMD provides plausible explanations for various hitherto unexplained phenomena including the Pauli exclusion principle, chemical reactivity and chemical bonds. It explains the “Pauli Force” that leads to electron pairing in atomic orbitals. It also explains covalent bonds which are the foundation of organic chemistry as well as the “rule of two” according to which electrons are present in molecules in pairs with only a few exceptions, despite their mutual electric repulsion. Greenspan [15, 16] has confirmed this attractive magnetic force between anti-parallel spin aligned electrons for several molecules in important numerical experiments. The effects of QMD are not evident in low-energy QED interactions because the potential of the magnetic interaction is of the form $1/r^3$ but become dominant at high energies or short distances. The extent to which the new quantum theory of magnetism accords with observation and its success in providing simple answers in several areas where relativistic models provide none all strongly suggest that the theory may be right and that a more detailed investigative programme should be pursued. Issues that need to be explored include:

1. The renormalizability of the new interaction to enable calculations;
2. Quantitative application of the magnetic interaction to the Pauli Exclusion phenomenon, chemical reactivity and chemical bonds;

3. Application to molecular geometry;
4. Analysis of the new interaction in order to reveal new quantum mechanical phenomena such as may occur in electron-positron high-energy scattering [9], polarised proton-proton collisions [20] and elastic electron-neutron scattering [5].

We have been led to this new interaction by breaking away from the excessively restrictive idea of Lorentz covariance. An alternative modification of $U(1)$ gauge invariance explored in ([21], where we demand that the Lagrangian density be invariant under a time-local (rather than space-local) $U(1)$ gauge transformation $\psi \rightarrow \psi' = U\psi$ with U being time-dependent (rather than space-dependent), generated a scalar spin0 field (rather than a 3-vector spin1 field) which we identify as the gravitational field (instead of the magnetic field). This field satisfies a wave equation, which contains the Poisson equation for gravitational potentials and hence 300 years of Newtonian gravitation. This is a further indication that the basic approach may be valid. In future research, therefore, we intend to pursue the modified gauge invariance approach used in this paper and demand that nucleon interaction be invariant under an isotopic gauge transformation $\psi \rightarrow \psi' = U\psi$ with U being a space-dependent isospin rotation $U(\vec{x})$. The hoped-for result is massless rho-mesons which when unified with the spin1 magnatons are given mass through spontaneous symmetry breaking thereby yielding massive rho-mesons. Such an approach in [22] involving a time-dependent isospin rotation $U(t)$ and unification with spin0 gravitons yielded pimesons!

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