

On the Magnetism: Qualitative Description

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ABSTRACT

This paper modifies the Hund' rule, explains the macroscopic phenomenon that the orbital magnetic moment and most substances are not magnetic, discusses the microscopic mechanism of ferromagnetism, and obtains the position of magnetic generating elements in the periodic table. It has been found, by research, that the p -area elements in the second period, the d -area elements in the fourth period, and the f -area elements in the sixth period are most likely to become the main elements for magnetic generation.

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Introduction

Magnetism has always been a fascinating physical phenomenon that has not been fully understood to this day. When it comes to magnetism, the first thing people think of is the compass. The predecessor of the compass is Sinan, one of the Four Great Inventions in ancient China. As shown in Figure 1, the shape of Sinan, which was first used in ancient China, is roughly spoon shaped and can rotate freely on a flat plate. It is used as a guiding tool to determine the direction of walking and is the result of the ancient Han people's long-term practice of understanding the magnetism of objects. According to the "Gu Kuang Lu", Sinan first appeared in the Cishan area of Zhao State during the Warring States period in China, and was made from natural magnetic stones. According to the Geographical Records of the Ming Dynasty, "Cishan is located in the southwest of Wu'an County, Cizhou, producing magnetite and iron stones," and this state is named after it. The Warring States period was in the early stage of the widespread promotion and use of Chinese characters. Therefore, we speculate that the discovery of Sinan and magnetite in the Cishan area should have occurred much earlier than written records. According to the reference [1,2], the use of magnetite and magnetic compass in navigation began in China in 4000 BC.

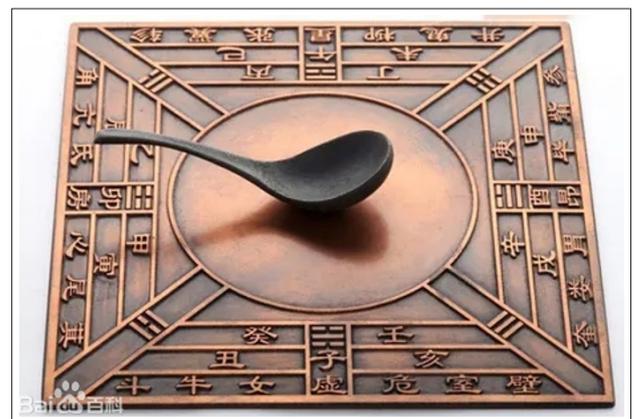


Figure 1: Sinan in Ancient China, Picture Quoted from Baidu Baike

Scientific study of magnetism started in the 16th century with the investigations of William Gilbert (1544-1603) of England. He found that when iron is in a red-hot state, it is no longer attracted to magnets [2]. Gilbert's most important discovery was his realization that the Earth itself is a large magnet, and the north-south pointing characteristics of the compass can be understood from the attraction of different magnetic poles of the magnet, thus providing a correct scientific explanation for the mysterious pointing characteristics of the compass.

In 1820, Danish physicist Christian Oersted (1777-1851) discovered that electric current produces magnetic effects. In experiment he observed that a current carrying wire has the capacity to deflect a nearby placed magnetic needle [2].

The most important contribution of French scientist Andre Marie Ampere (1775-1836) was his Ampere's law and his interpretation of ferromagnetism from the microscopic perspective of circulating currents [2].

After Michael Faraday's experimental discovery of Paramagnetism and Diamagnetism Materials, Pierre Curie (1859-1906) thoroughly studied the magnetism of about 20 kinds of materials. He found that:

- The magnetic susceptibility (ratio of induced magnetism to external magnetic field) in various salts is inversely proportional to temperature (called Curie's law ($\chi \propto 1 / T$)),
- When the temperature rises above the critical temperature known as the Curie temperature (T_c), ferromagnetism completely disappears,
- Diamagnetism is approximately independent of temperature [2].

Paul Langevin (1872-1946) understood the behavior of diamagnetic and paramagnetic matter from a "microscopic" perspective. In 1905, he put forward the concept of magnetic moment of tiny atoms, and found that the paramagnetic magnetic susceptibility is inversely proportional to temperature, while the diamagnetic magnetic susceptibility is independent of temperature. He believes that molecules contain at least one closed electronic orbital with a fixed magnetic moment outside any external field, and different orbitals within each molecule have such moments and orientations that the torque they generate may or may not disappear [2].

Although several subsequent approximate treatments have also gained insights, so far there is no theory that can truly explain why iron cobalt nickel in the fourth period and gadolinium in the sixth period can exhibit elemental ferromagnetism in metal elements? How is ferromagnetism generated in alloys and compounds? Which elements in the periodic table are most likely to become magnetic elements? This article will first analyze why most substances have no macroscopic magnetism, and then qualitatively elucidate these issues.

The Bohr-van Leeuwen (BvL) Theorem of No Magnetism

In the early 20th century, the Bohr-van Leeuwen theorem of no magnetism appeared, seemingly denying that the magnetic moment in an atom originates from the orbital motion of unpaired electrons. In 1905, P Langevin's paper should be the root of the BvL theorem. Bohr pointed out in his 1911 doctoral thesis that "a metal in electrical and thermal equilibrium, regardless of the presence or absence of free electrons, will not have any magnetic properties. His result became the foundation of the BvL theorem [3,4].

H. J. van Leeuwen's 1921 article was later regarded as a groundbreaking paper on the BvL theorem. Considering the molecules carrying current or charge in the external constant magnetic field, she calculated the thermal average magnetization (i.e. the composite magnetic moment per unit volume) and magnetic susceptibility within the framework of classical statistical mechanics. Later generations will refer to their views as The Bohr van Leeuwen theorem [2].

Bohr's Nonmagnetic, Half Frequency Difficulty and Corresponding Principles

The nonmagnetic theorem influenced Bohr's model of hydrogen atoms and also influenced his life. In his 1913 paper, he only

considered the Coulombic force between electrons and protons, without considering the Lorentz force between moving electrons and protons [5,6].

Bohr substituted the experimental values of the following constants into his formula [7]:

$$e = 4.7 \times 10^{-10}, e / m = 5.31 \times 10^{17}, h = 6.5 \times 10^{-27}$$

He obtained the radius a of the ground state hydrogen atom and the electron rotation frequency ω .

$$2a = 1.1 \times 10^{-8} \text{ cm.}, \omega = 6.2 \times 10^{15} \text{ sec}^{-1} \quad (1)$$

The radiation frequency obtained by the expression of Rydberg's constant is,

$$\frac{2\pi^2 m e^4}{h^3} = 3.1 \times 10^{15} \text{ (sec}^{-1}\text{)} \quad (2)$$

In order to distinguish formula (1) and (2), we call formula (2) Rydberg frequency, and the corresponding atomic radius Rydberg radius (r). Obviously, the Rydberg frequency obtained from spectral experiments is just half of the electronic frequency (ω) obtained by Bohr. The Rydberg radius (r) is just twice the Bohr radius (a) [6]. The difference between the experimental and theoretical derivation values was a great headache for Bohr. In the first of the three derivations of the Balmer formula, he introduced the relationship: "the frequency of the radiation emitted during the passing of the system from a state in which no energy is yet radiated out to one of the stationary states, is equal to half the frequency of revolution of the electron in the latter state" [7]. In fact, Bohr's result can only be obtained through the following calculations. That is, considering free electrons from infinity, when they combine into a stationary state within an atom, the radiation frequency emitted is equal to the average value between the orbital frequency of the bound electron within the atom and that of the free electron.

Then the orbiting frequency of the free electron is 0, and the orbiting frequency of the electron bound within the atom is ω , we have

$$\nu = \frac{\omega + 0}{2} = \frac{\omega}{2} \quad (3)$$

Bohr did not confidently write equation (3), but only equation (3) can obtain his result. Obviously, equation (3) is only suitable for the transition of a free electron to a certain level in the atom, and not for the transition between any two levels. In the third section of his first paper in 1913, Bohr devoted the majority of his time to addressing this difference. He dealt with it in two cases

- Large Quantum Numbers
- Ordinary Quantum Numbers

For Large Quantum Number

"For the frequency of revolution of the electron before and after the emission we have

$$\omega_N = \frac{\pi^2 m e^2 E^2}{2c^3 h^3 N^3} \text{ and } \omega_{N-1} = \frac{\pi^2 m e^2 E^2}{2c^3 h^3 (N-1)^3}. \quad (4)$$

If N is great the ratio between the frequency before and after the emission will be very near equal to 1." Of course, in this case, the radiation frequency and electron rotation frequency are also close to equal. In equation (4), e and E represent the charges of electron and proton, respectively. The c is a correction coefficient introduced by Bohr to solve the half frequency problem, but is not the speed of light.

Of course, Bohr knows that N is not mathematically infinite. Because in the second section of his paper, he wrote: "It may be remarked that the fact, that it has not been possible to observe more than 12 lines of the Balmer series in experiments with vacuum tubes, while 33 lines are observed in the spectra of some celestial bodies". That is to say, for the former case, N is not greater than 13, and for the latter case, N is not greater than 34. Obviously, treating 13 and 34 as infinity is not appropriate.

For Ordinary Quantum Number

Bohr continued to write "according to the ordinary electrodynamics we should therefore expect that the ratio between the frequency of radiation and the frequency of revolution also is very nearly equal to 1. This condition will only be satisfied if $c = 1/2$." That is to say, according to Bohr's model, only by multiplying the rotational frequency by a 1/2 factor can it be consistent with the experimental spectral data. This became a half frequency puzzle that puzzled Bohr's life.

Bohr later wanted to use the correspondence principle to solve this problem, but it was still unreasonable in reasoning. Bohr's "correspondence principle" is generally considered that there is statistical consistency between the quantum frequency and the classical frequency of a large quantum number ($n \rightarrow \infty$), which is the first case above. However, upon careful reading of Bohr's works on the principle of correspondence, one will find that this explanation is incorrect [8]. Strictly speaking, this correspondence is accurate only in the limit of large quantum number, and cannot be generalized to the second case of small quantum number.

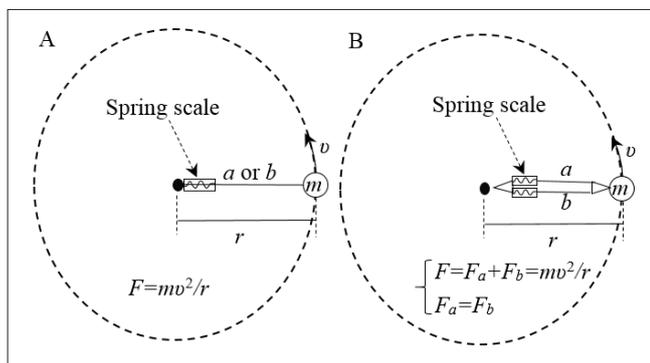


Figure 2: The schematic diagram of a simple mechanical experiments. A) The pulling force of a single rope is equal to the centrifugal force; B) The pulling force of a double ropes is equal to the centrifugal force

The calculation of magnetic susceptibility within the scope of the old quantum theory does not seem to support Bohr's correspondence principle. In the calculations of Pauli and Paulin, there is no asymptotic connection with the Langevin theory [2].

If Bohr considered the Lorentz force acting on electron in a hydrogen atom, that is, a force equal to the Coulomb force in

magnitude and in the same direction, he would not encounter difficulties with half frequency, nor would he need to propose his corresponding principles. We can understand the relationship between Lorentz force and Coulomb force when they coexist with centrifugal force by the simple mechanical experiment shown in Figure 2.

In Figure-2A, a single rope a (or b) connected in series with a spring dynamometer is connected to a small ball with a mass m for uniform circular motion at a speed of v . The tension displayed on the spring scale is equal to the centrifugal force, $F = mv^2/r$. In Figure-2B, when using double ropes ($a+b$) to tie the small ball m , $F = F_a + F_b = mv^2/r$, and $F_a = F_b$.

I have already speculated and proven this in the previous paper [6]. Simply put, in a ground state hydrogen atom, when the Coulomb force F_C and Lorentz force F_L that electron is subjected to coexist and reach equilibrium with centrifugal force, they must exist

$$\begin{cases} F_C = F_L \\ F_C + F_L = m \frac{v^2}{r} \end{cases} \quad (5)$$

$$F_C + F_L = m \frac{v^2}{r} \quad (6)$$

We obtained by (5) and (6)

$$2F_C = 2F_L = \frac{2ke^2}{r^2} = 2e(v \times B) = m \frac{v^2}{r} \quad (7)$$

When using the quantization condition

$$mvr = \frac{h}{\pi} \quad (8)$$

By equations (7) and (8), we obtain

$$v = \frac{2\pi ke^2}{h} = 2.188 \times 10^6 \text{ m/s} \quad (9)$$

$$r = \frac{h}{\pi m v} = 1.058 \times 10^{-10} \text{ m} \quad (10)$$

$$B = \frac{ke}{vr^2} = 5.878 \times 10^4 \text{ T} \quad (11)$$

$$f = \frac{v}{2\pi r} = 3.291 \times 10^{15} \text{ s}^{-1} \quad (12)$$

The ground state hydrogen atom has a circular orbit, and the calculated electron rotation frequency (f) here is consistent with the Rydberg frequency [6]. That is to say, the radiation frequency is consistent with the electron rotation frequency, and Bohr's half frequency problem has been eliminated here. Equation (11) indicates that the magnetic field intensity felt by the electron, $B = 5.878 \times 10^4$ T. Of course, this does not comply with the Bohr-van Leeuwen no magnetism theorem. Below, I will prove that the micro-orbital magnetic moment is magnetic.

The Magnetic Moment of the Atomic Orbit is Micro Magnetic but Macro Nonmagnetic

For the discussion of orbital magnetic moment, we start with the simplest hydrogen atom.

Hydrogen Atom

Hydrogen atom is a two-body electromagnetic system composed of a proton and an electron. According to the definition of the

center of mass of a two body, $M \cdot r_+ = m \cdot r_-$, where M and m represent the masses of proton and electron, r_+ and r_- represent the distance between proton and electron to the center of mass of the two body, respectively, and the Coulomb radius of electronic orbit $r_z = r_+ + r_-$.

As shown in Figure-3A, both proton and electron rotate in the same frequency ν around their common center of mass (O). Because proton and electron have equal and opposite charge, the proton current and electron current passing through half plane P are of equal magnitude and opposite direction, and this current is only proportional to their rotational frequency f .

$$I = ef = \frac{ev}{2\pi r} = \frac{1.6022 \times 10^{-19} \times 2.188 \times 10^6}{2\pi \times 1.058 \times 10^{-10}} = 5.2735 \times 10^{-4} \text{ (A)} \quad (13)$$

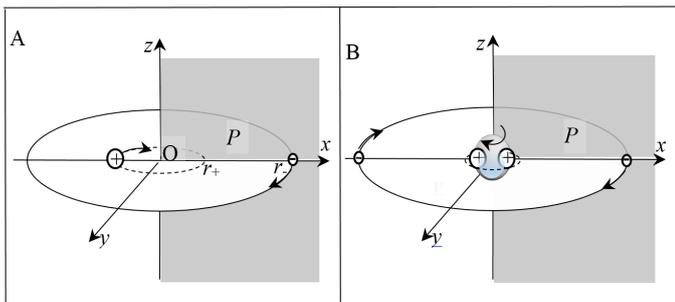


Figure 3: In the Ground State Hydrogen Atom (A) and Helium Atom (B), their Proton Current is Equal to their Electron Current, but the Direction of Two Currents is Opposite

Because the magnitude of two currents is equal, the magnetic field intensity generated by them in the electron or proton orbital must be equal, with opposite magnetic poles. Two magnetic fields are coaxial and concentric, with opposite magnetic poles. They can completely couple and cancel each other inside the atom, and all of their magnetic field lines are closed inside the atom, without generating macroscopic magnetic effects outside the atom.

The Ampere force and Lorentz force are actually equivalent, because $IL = qv$. However, the former focuses on the macro level, while the latter focuses on the micro level. The magnetic field and interaction generated by two annular currents in a hydrogen atom can be analyzed using the Ampere force formula ($F = B \cdot I \cdot L$) or Lorentz force formula ($F = B \cdot qv$).

On the proton orbit, $F_+ = B_+ \cdot I \cdot L_+ = qvB_+$, where F_+ is the Ampere force or Lorentz force sensed by proton, L_+ is the circumference of the proton orbit, and $|B_+|$ is equal to the magnetic induction intensity generated by the proton current or the electron current.

On the electron orbit, $F_- = B_- \cdot I \cdot L_- = qvB_-$, where F_- is the Ampere force or Lorentz force sensed by electron, L_- is the circumference of the electron orbit, and $|B_-|$ is equal to the magnetic induction intensity generated by the proton current or by the electron current.

Because F_+ and F_- are a pair of forces and reactions, $F_+ = F_-$, and because the magnitude of the two currents is equal, we obtain

$$B_+ \cdot L_+ = B_- \cdot L_- \quad (14)$$

Considering

$$\frac{L_-}{L_+} = \frac{r_-}{r_+} = \frac{M}{m} = 1836$$

We get

$$B_+ = \frac{L_-}{L_+} \times B_- = 5.878 \times 10^4 \times 1836 = 1.079 \times 10^8 \text{ (T)} \quad (16)$$

Equation (16) represents the magnetic induction intensity generated by electron or proton in the proton orbit.

The orbital magnetic effect is different from the Coulomb effect. For the Coulomb effect, although a hydrogen atom is neutral, after ionization, we can measure both the positive charge on the atomic nucleus and the negative charge on the ionized electron. For the orbital magnetic effect, after ionization, the orbital currents of electron and proton disappear, and the orbital magnetic field also disappears. Therefore, the existence and disappearance of orbital magnetic fields have no macroscopic measurement effects. This may be the reason for the emergence of the Bohr-van Leeuwen no magnetism theorem.

However, unlike Coulomb forces, both Lorentz and Ampere forces are not dependent on the presence of central nuclear charges, but only on magnetic fields and motion charges or currents. Therefore, we can extend the electron orbital radius to the macroscopic coil radius. Lorentz or Ampere forces are used to constrain the movement of electrons or currents along the wire direction of a coil. The magnetic field direction of the coil can be determined by the right-hand rule. The magnetic field generated around a straight conductor can be seen as a special case when the coil radius approaches infinity. The force direction of the current rotates around the wire, and the generated magnetic field also rotates around the wire.

Helium Atom and Other Multi-Electron Atoms

In a helium atom, its mass center is also the center of its nucleus. The two nuclear charges also generate proton currents with the rotation of the nucleus. Note that the nuclear spin mentioned here is not the spin of every nucleon in the nucleus. As shown in Figure-3B, as long as the spin frequency of the nucleus is the same as that of the electrons outside the nucleus, the proton current passing through the half plane P will be equal to the electron current.

For a neutral helium atom, the magnetic moment generated by nuclear spin with the orbital magnetic moment of electrons cancel out each other within the atom, and do not exhibit macroscopic magnetism.

For other multi electron atoms with a nuclear charge greater than 2, using nuclear spin current, we can also obtain the result that the total proton current is equal to the total electron current outside the nucleus. Therefore, for all atoms, the orbital magnetic moment and the nuclear spin magnetic moment cancel each other, and there is no magnetism in the macro.

The Spin Pairing of Two Electrons in an Orbit, with No Macroscopic Magnetism

For the orbital magnetic moment, due to the fact that the orbital current formed by electrons is not continuous throughout the entire orbital circumference, the magnetic field formed by the orbital magnetic moment within the atom exhibits significant

circumferential fluctuation, resulting in both remaining waves and residual magnetism (RWRM) of the orbital magnetic moment within a certain range of the atom.

For spin magnetic moment, an orbit can accommodate two electrons with opposite spin directions. Their spin magnetic field is different from the orbital magnetic field, although it is also of equal size and opposite magnetic poles, it is not coaxial and concentric. Therefore, RWRM of spin magnetic moment is also generated along the orbital space, and it is more susceptible to interference from external magnetic fields. The interaction between two RWRMs generates mutual cancellation and closure effects. Under the closure of the orbital RWRM, the spin RWRM generated by a pair of electrons with opposite spin directions in the same orbit is locked, which has stronger resistance to external magnetic field interference. In most cases, this will form the basis of diamagnetism of materials.

By the above calculation for hydrogen, it can be seen that the magnetic field induction intensity B of the orbital magnetic moment is about the order of 10^4T at the electron orbit. The external magnetic field strength is usually on the order of 1T or less, with a difference of 3-4 orders of magnitude between the two. Even considering the interaction between only two types of RWRM, this magnetic field strength is usually greater than the order of magnitude of 1T.

The magnetic moment of two paired electrons in the same orbit can be completely locked by the orbital magnetic moment. The magnetic moment of the closed and locked spin electric pair can completely resist the magnetization of the external magnetic field and produce diamagnetism. For example, all electrons in all orbits of atoms of all rare gas elements have been paired and locked by their respective orbital magnetic moments, and they all have diamagnetism. Thermal movement cannot change this locking, so diamagnetism is independent of temperature.

For isolated atoms or molecules (such as gaseous molecules) containing single electron in the same orbit, the electron spin magnetic moment can interact with an external magnetic field. Even if the spin magnetic moment is locked by the orbital magnetic moment, the entire atom or molecule can still rotate and enter a coupled state in an external magnetic field. Such substances belong to paramagnetism substances.

Modifications for the Hund's Rules

In school, guiding students to write electronic layouts often requires the use of the Hund's rule. In addition to this use, the Hund's rule has not played a good role in the study of magnetism. The expression of the Hund's rule can be divided into two meanings: To occupy as many equivalent orbitals as possible with a single electron state; These single electron states must spin parallel. It seems that the latter is the reason for the former. Indeed, due to the existence of the latter, the former is easy to understand. But the latter is inconsistent with the following facts.

It is well known that the pairing of electrons between atoms forms chemical bond. The formation of chemical bond indicates that electron pairing can take place between different atoms. For example, molecules such as hydrogen, water, ammonia, hydrogen sulfide, hydrogen halide and halogen elements all have electron paired covalent bond. So, why can electrons pair between different atoms, but cannot pair between different equivalent orbitals of the

same atom? This seems to be inconsistent with the Hund's rule.

In addition, spectral experiments can only prove that single electron states occupy as many equivalent orbitals as possible, but cannot prove that these single electron states belong to spin parallelism. If these single electron states spin parallel, there must be a macroscopic magnetic effect. People have already associated the microscopic mechanism of ferromagnetism with the coupling of the Hund's rule [9,10]. After all, ferromagnetism is only a special case among a large number of material properties. Therefore, we believe that the first meaning of the Hund's rule is correct and should be retained, while the second meaning is incorrect and should be discarded. The second meaning is only suitable in special cases of ferromagnetism.

The correct Hund's rule should be expressed as follows: when electrons are filled, they always first occupy as many equivalent orbitals as possible in a single electron state. When there is no external magnetic field, parallel spins are not taken, but can pair between different orbitals within the atom. This is manifested in the fact that the d electrons of transition metals are easily paired to gain or lose. For example, manganese exhibits +2, +4, and +6 valence. Of course, manganese also has a +7 valence state, but that is the highest valence state. If the five d electrons in the manganese atom are arranged in parallel spins, there will be no preferential oxidation states of +2, +4, and +6 valences. In metal crystals, free electrons from different atoms can pair up nearby. The Cooper electron pair is proposed to explain the superconducting mechanism. In fact, the conduction mechanism of traditional conductors also depends on their atomic structure, and use free electron pairs to conduct electricity [11].

By utilizing the newly modified Hund's rule, the electrons can pair between different equivalent orbitals or between different atoms in metal crystals, which explains that all substances are macroscopic without magnetism before being magnetized by an external magnetic field.

Ferromagnetism Spin Flip of Electron

According to my research, in the hydrogen atom, only the ground state 1s orbit is circular, and other orbits are ellipses with different eccentricity [6]. In a multi electron atom, in each electron layer, only the s orbital of the first sublayer is circular, and the other sublayer orbitals are ellipses with different eccentricity. No matter what kind of orbit, each orbit can hold up to two electrons. Usually, the second electron needs to adjust its spin direction before entering orbit in order to pair with the first electron that was already in orbit.

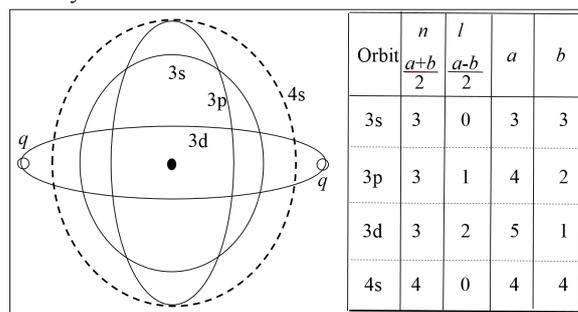


Figure 4: The Left Figure shows the Orbital Shape and Orbital Eccentricity, where, q represents the Electron Spin Flip Point of the 3d Orbit. The right table lists the Orbital Parameters.

For multi electron atoms, the magnetic induction intensity in the near nuclear orbital space is usually multiple times of that in the hydrogen atomic orbital. The farther away from the nucleus in orbit or space, the smaller the magnetic field intensity. The spin flip of an already in orbit electron usually occurs at the farthest point in the orbit. The greater the azimuthal quantum number, that is, the greater the orbital eccentricity, the easier it is to flip the spin direction. Figure 4 shows the relationship between the eccentricity of 3s, 3p, 3d and 4s orbits and the azimuthal quantum number, where the q points represent the possible position of the electron spin flip in the 3d orbit.

The Radius of Locking Action on Spin Flip

When carefully studying the atomic structure of ferromagnetic elements, we found two important locking factors that affect the spin flip. One is the effect locking radius (R_o) generated by the orbital magnetic moment; The second is the effect locking radius (R_s) generated by the sublayer-orbital magnetic moment. R_s is an effect of sublayer global orbital magnetic moment.

Locking Radius of Orbital Magnetic Moment (R_o)

The orbital magnetic moment is actually the mutual coupling between the nuclear spin (not the spin of nucleon) magnetic moment and the electron orbital magnetic moment. The RWRM after this coupling produces a blocking and locking effect on the spin of the in-orbit electrons. Because it is a RWRM, its magnetic induction intensity is much smaller than the magnetic induction intensity B of the orbital magnetic moment, and is much less than $10^4 T$. Because it is coupled with the orbital magnetic moment of the in-orbit electron, its radius of action (R_o) is always consistent with the orbital radius of the electron. On the one hand, the spin flip point always occurs at the farthest point of the orbit. The larger the azimuthal quantum number, the greater the eccentricity of the orbit, the flip point is the greater the distance from the nucleus, and the weaker the locking of the orbital magnetic moment on the spin. The spatial radius of this locking effect is basically consistent with the major axis of the orbit. The longer the long axis of the orbit, the weaker the locking effect. The d orbit of the transition element and the f orbit of the inner transition element have greater eccentricity. Therefore, the element whose orbital magnetic moment is weakest in electron spin locking should exist in the transition element and the inner transition element.

The Effect Locking Radius (R_s) Generated by the Sublayer-Orbital Magnetic Moment

In multi electron atoms, except for the s sublayer, all other sublayers have multiple equivalent degenerate orbitals. There is a close mutual coupling between the orbital magnetic moments of these degenerate orbitals. The RWRM after sublayer coupling still has a strong locking effect on spin, usually several times that of a single orbital magnetic moment locking effect. The coupling results exhibit the properties of an overall sublayer orbits. The sublayer magnetic moment locking space tends to be more spherical and has a stronger locking effect.

The Spatial Expansion Effect of R_s

The RWRM after sublayer coupling exhibits outward leakage, which is here called the expansion effect of sublayer coupling magnetic moment.

• The Influence of Outer Sublayer Space

In the same electronic layer, the expansion effect is particularly significant for those sublayers that still have outer sublayer space.

The expansion effect causes the R_s to be greater than the R_o . At this point, the spin of the electron is firmly locked in by both R_s and R_o , and is not flipped by an external magnetic field.

For example, in addition to the p -region elements in the second period, there is $3d$ space outside the $3p$ sublayer in the third period; There is $4d$ space outside the $4p$ sublayer in the fourth period; There is $5d$ space outside the $5p$ sublayer in the fifth period; There is $6d$ space outside the $6p$ sublayer in the sixth period; The elemental elements belonging to these regions are almost nonmagnetic macroscopically.

As another example, in addition to the d -region elements in fourth period, there is $4f$ space outside the $4d$ sublayer in fifth period; There is $5f$ space outside the $5d$ sublayer in sixth period; There is $6f$ space outside the $6d$ sublayer in seventh period; The elemental elements belonging to these regions are almost nonmagnetic macroscopically.

For other instance, in addition to the f -region elements in sixth period, there is $5g$ space outside the $5f$ sublayer in seventh period; The elemental elements belonging to this region are almost nonmagnetic macroscopically.

• The Influence of Degenerate Orbits on Expansion Effect

The less orbits occupied by electron for those equivalent orbits, the greater the expansion effect of that occupied orbital. As for the first few elements in the transition element of the fourth period, due to the expansion effect, $R_s > R_o$, the electron spin is firmly locked in by two effects and cannot be flipped by an external magnetic field. So, they are almost non magnetic macroscopically.

• Influence of Azimuthal Quantum Number on Expansion Effect

The smaller the azimuthal quantum number is, the smaller the eccentricity of the sublayer orbit is, the closer the sublayer magnetic moment is to the orbital magnetic moment, and the greater the expansion effect is. For example, the s sublayer has only one circular s orbit without eccentricity, and its spin is firmly locked. The locking causes to almost nonmagnetic macroscopically for all both alkali metals and alkaline earth metals. This expansion effect also affects the change of atomic radius. As in the period table, the atomic radius of alkaline earth metals is smaller than that of alkaline metals; The atomic radius of silicon is smaller than that of aluminum; In the transition elements of the fourth period, the atomic radius according to order, Sc, Ti, V, Cr, Mn, Fe, Co, and Ni, decreases sequentially.

• The Influence of Temperature on R_s

Thermal motion can increase the amplitude of vibration of the nucleus, and R_s is directly affected by the amplitude of vibration of the nucleus and increases with temperature. For diamagnetism materials, at any temperature, $R_s > R_o$, and the spin of the electron is firmly locked and cannot be reversed by the external magnetic field. For a ferromagnetic material, below the Curie temperature T_C , $R_s < R_o$, and it will enter the ferromagnetic state; When $T = T_C$, $R_s = R_o$, it will exit the ferromagnetic state.

Spatial Contraction Effect of R_s

The spatial contraction effect of R_s is opposite to the expansion effect. The lower the temperature, the greater the number of nuclear charges, and the more equivalent orbitals the electrons occupy are, the greater the spatial contraction effect of R_s , and the smaller

the Rs are. In the same electronic layer, the contraction effect for a sublayer magnetic moment without outer sublayer space is particularly prominent, which can achieve a smaller locking radius of the sublayer magnetic moment than of the orbital magnetic moment, and the spin can flip in the external magnetic field.

The $2p$ orbit in the p sublayer satisfies the conditions. So, boron, carbon, nitrogen, and oxygen in the second period can participate in ferromagnetic materials in a form of alloys or compounds. In addition, in the external magnetic field, the two electrons with the highest energy in the oxygen molecule can take a parallel spin arrangement, showing paramagnetism.

Only the $3d$ orbit of the d sublayer meets the conditions. So, iron, cobalt, and nickel in the fourth period can become ferromagnetic materials.

The $4f$ orbit of the f sublayer meets the conditions. So, the middle part of the inner transition elements in the sixth period can become ferromagnetic materials or alloys. So, the elements that can form ferromagnetic materials or alloys or compound are mainly located in the second, fourth, and sixth period.

Co-Locking of Rs and Ro to Spin Magnetic Moment and Polarization of Orbital Eccentricity

When $Rs \sim Ro$, or $Rs > Ro$, it can generate the strongest locking of electron spin. For example, atomic kernel and rare gases can produce strong diamagnetism.

The eccentricity of the p sublayer is very small, and it is difficult for the elements in the p region of the second period to form a simple magnetic material. However, in compounds or alloys, under the eccentric polarization of the d orbit of the fourth periodic element or the f orbit of the sixth periodic element, the p orbit of the second periodic element increases the eccentricity of the $2p$ orbit, resulting in $Ro > Rs$, and its electron spin can turn over in the external magnetic field, becoming a magnetic generating element.

For example, the magnetism of carbon and nitrogen in carbon steel, the magnetism of oxygen in magnetite, and the magnetism of boron in neodymium-iron-boron. The susceptibility of the eccentricity of the p orbit can even occur on the aluminum element in the third period. In Al-Co-Ni alloy, the $3p$ orbit of aluminum is polarized under the polarization effect of the eccentricity of the $3d$ orbit of Co and Ni, and becomes a magnetic generating element after polarization. For another example, there is element Bi in the p -region in the sixth period. Because of the strong eccentric polarizability of the $4f$ orbital in the inner layer, its five valence electrons in the specific lattice can be polarized to the $5d$ orbital, and can also become polarized magnetic elements.

Ferromagnetic Substances

Based on the above analysis, this article only qualitatively describes the microscopic mechanism of ferromagnetism generation. In the elements of the fourth period, when the nuclear charge increases to 26 (iron), $Rs < Ro$. The flip of d electron spin is only locked by weak Ro . Below the Curie temperature TC , substances enter the ferromagnetic state. When the temperature increases, Rs increases. When the Curie temperature is reached, $Rs = Ro$, ferromagnetism disappears. The temperature is higher than the Curie temperature, $Rs > Ro$, and the spin of the d electron is firmly locked by two magnetic moments, causing the substance to enter a paramagnetic state.

Iron Based Ferromagnets

For pure iron, d electrons pair within atoms and also between atoms, and are only locked by weak orbital magnetic moments. When there is no external magnetic field, there is almost non magnetic macroscopically.

When in an external magnetic field with a strength greater than the orbital magnetic moment, half of the d electrons take spin over, and almost all d electrons spin in parallel in the external magnetic field, entering the Hund's rule coupling state, generating a magnetic field opposite to the magnetic pole of the external magnetic field. Therefore, pure iron can be attracted by magnets. When the external magnetic field is removed, the internal d -electron pairing is restored, indicating a macroscopic demagnetization state.

When a small amount of carbon with small radius are added into iron, the spin of the carbon atom's own p electron is the same as that of the iron's d electron, which can be reversed with the external magnetic field, and can separate the d electron pairing between the two iron atoms. When magnetization and the magnetic field is removed, it is difficult to eliminate the ordered arrangement of Hund's rule coupling, indicating hysteresis. Therefore, carbon steel can be magnetized into a permanent magnet that can be maintained for a long time.

When chromium and nickel are appropriately doped in proportion in iron, because the sublayer magnetic moment locking radius of chromium is much larger than the locking radius of orbital magnetic moment, it cannot only lock the d electron spin of chromium atoms, but also couple the sublayer magnetic moment locking of iron atoms and a small amount of nickel atoms, generating non magnetic austenitic stainless steel. The strong locking of the d electron spin of iron atom reduces the chemical activity of iron, making stainless steel have good corrosion resistance. However, when lattice phase transition occurs, changes in the locking radius of the sublayer magnetic moment can also occur. For example, magnetic properties will be generated when cold work hardening of austenitic stainless steel generates martensite transformation. Heat treatment can eliminate this martensite structure and restore its non-magnetic properties. Carbon steel, ferritic and martensitic stainless steels are magnetic.

For the lattice conditions of iron oxides, especially Fe_3O_4 , the magnetic moment locking radius of the d sublayer within the iron atom is not increased, and the d electron pairing between the iron atoms can be appropriately separated. When the external magnetic field is removed, it can maintain good permanent magnetism. During the slow cooling process of Fe_3O_4 , transitioning from a molten state to a crystalline state, the very weak strength of the Earth's magnetic field can magnetize and fix its permanent magnetism. For example, Cishan in Hebei Province, China produces natural iron oxide magnetite.

Neodymium Iron Boron Permanent Magnet

Compared with the d orbits of the transition element in the fourth period, the f orbit of the inner transition element in the sixth period has a larger eccentricity, and the effective nuclear charge felt by the electron is also larger, so the magnetic elements of the sixth period are more. Nd-Fe-B permanent magnet is the most powerful permanent magnet material discovered in 1982 to date. Its approximate molecular formula is $Nd_2Fe_{14}B$ (2:14:1 phase for short), and its main phase unit cell is tetragonal in crystallography. The boron, iron, and neodymium elements that

make up neodymium iron boron permanent magnets come from the second, fourth, and sixth period, respectively. The magnetic elements fully comply with the structure and performance analysis of the magnetic elements in the periodic table mentioned above.

Ferromagnetism of Metal Element Gadolinium

Gadolinium is element 64, belonging to the inner transition element of the sixth period, with a peripheral electron layer arrangement of $4f^75d^16s^2$. The peripheral electronic arrangement of iron is $3d^64s^2$. The two are very similar, with their outermost layers containing two s electrons. The secondary outer layer of iron has only one more d electron than the half full $3d^5$; The secondary outer layer of gadolinium also has one more d electron than the half full $4f^7$. Although the two elements differ by two periods in the periodic table, their elemental densities are very close, with gadolinium at 7.90 g/cm^3 and iron at 7.86 g/cm^3 . Both elemental elements exhibit ferromagnetism at room temperature. Their $RS < Ro$ results in an increase in their chemical activity, and they are all relatively active metals.

Formation of Earth's and Other-Celestial Magnetic Fields

The magnetic field of both the Earth and other celestial bodies is definitely not generated by the ferromagnetic core, as ferromagnetic materials no longer have magnetism at high temperatures. The celestial magnetic field originates from the charge that rotates within the celestial body, which forms the celestial rotating current, which generates the celestial magnetic field [12]. So, how is the rotational charge of celestial bodies generated?

The generation of electric charges in celestial bodies shares the same mechanism as the formation of lightning charges in clouds, namely the gravitational polarization mechanism [13]. In the interior of the earth, from the lower mantle, through the upper mantle, to the upper asthenosphere, due to the strong gravity, the atomic nucleus in the atoms move downward (in the geocentric direction), and the external electronic layer of the atoms moves upward, causing the atom to become a polar atom. The lower part of each atom is the positive pole, and the upper part is the negative pole. The polarized atoms then re-polarize the other atoms above and below, so that gravity polarization and polarity polarization propagate in a chain up and down manner. Although the polarization eccentricity of each atom is very small, when it accumulates to the upper asthenosphere, it has obviously more negative charges. The phenomenon of lightning during volcanic eruptions has been reported. The negatively charged asthenosphere rotates eastward with the earth, which is equivalent to a current moving westward. By the right-hand rule, it can be determined that the N pole of the Earth's magnetic field is facing the geographical South Pole, and the S pole of the Earth's magnetic field is facing the geographical North Pole. Therefore, the N pole of our compass points to the geographical North Pole. We believe that the claim that the Earth's magnetic poles have experienced a reversal may be due to the historical traces of geological plate movements left by the Earth's plate movements near the North or South Poles. The formation of magnetic fields in other celestial bodies is similar to that of Earth.

Conclusion

Permanent magnetism originates from electron spin, while coil magnetism originates from the current passing through the coil. This article is the part I of the discussion on magnetism, and only provides a qualitative description of the generation of magnetism. The part II will calculate the magnetism quantitatively, and its

content depends on whether the other two articles "On Atomic Structure" and "On the Structure of Atomic Nucleus" have been published. If those two articles have already been published by then, the part II of this article will be relatively simple.

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