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On the Einstein-de Haas and Barnett Effects

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Abstract:- The orthogonal relation between the magnetic aspect (spin) of scatterable elementary particles' energy with respect to their direction of motion can be demonstrated at the macroscopic level by mechanical means. It can be proven that force aligning the spins of unpaired electrons in ferromagnetic materials causes the unidirectional carrying energy of the electrons involved to align orthogonally to the macroscopic magnetic field generated, which can cause a motion detectable at the macroscopic level when this motion is not mechanically restrained (The Einstein-de Haas Effect). Alternately, it can also be proven that mechanically forcing unpaired electrons in ferromagnetic materials to move in a common direction forces the spin of their carrying energy to align parallel, causing their combined magnetic field to become detectable at the macroscopic level (the Barnett Effect).

Keywords:- Einstein-de Haas effect, Barnett effect, spin alignment, ferromagnetic material, spin, carrying energy, 3-spaces model.

I. THE SUSPENDED FERROMAGNETIC CYLINDER EXPERIMENT

In 1911, Albert Einstein and Johannes Wander de Haas, a renowned Dutch experimentalist, conceived of and performed a quite revealing experiment regarding the magnetic behavior of electrons, that came to be known as the Einstein-de Haas effect([1]).

Understanding, even before the property named "spin" was discovered, that macroscopic magnetic fields were due to some sort of alignment of electrons, they deduced that if, in a cylinder of ferromagnetic material, iron for example, that was made to hang from a thin thread, electrons were suddenly forced to align orthogonally with respect to the rotation axis provided by the supporting thread, by submitting the cylinder to a magnetic field, then electrons in the material would suddenly align and their microscopic local angular momenta should then combine to become observable at the macroscopic level as an angular momentum of the suspended ferromagnetic cylinder.

At the time, it was still assumed that electrons were orbiting nuclei in atoms and it was this angular momentum that they were trying to cause to combine and observe at the macroscopic level.

And yes! As soon as the suspended cylinder was magnetized, it started to rotate! But to their surprise, the observed macroscopic angular momentum of the cylinder resolved upon calculation to only half the combined angular momenta that electrons would have if they orbited the nuclei, which caused them to dismiss the notion that motion of electrons on their orbits could be the cause of magnetism. The direct cause of macroscopic magnetism was identified only about a decade later when "spin" was discovered and its function understood.

But their remarkable result was obtained all the same. They successfully demonstrated that it is possible to cause an observable rotating motion in ferromagnetic materials by simply forcing parallel alignment of the spins of individual unpaired electrons in such material. The same effect is also observed when trying to magnetize paramagnetic materials.

II. THE EXPERIMENT OF THE ROTATING FERROMAGNETIC ROD

But a still more intriguing effect had been observed a little earlier by Samuel Jackson Barnett. He discovered in 1909 that if a rod of demagnetized ferromagnetic material is suspended to a thin wire and made to rotate by any mechanical means, the rod becomes magnetized!

Moreover, the strength of the resulting macroscopic magnetic field was directly proportional to the angular velocity of the rod! This is the Barnett Effect ([2]).

III. INTERPRETATION OF THE EXPERIMENTS

This means that when ferromagnetic materials, which contain unpaired electrons that the local electromagnetic equilibrium leaves free to locally pivot as if mounted on gimbals, are mechanically set in motion, these electrons tend to pivot in such a way that their spins align as parallel as they possibly can, even if when at rest, they naturally tendency to stabilize in the lowest energy mutually anti-parallel equilibrium configuration possible inside the material, like so many small magnets that would be left to freely swivel close to one another while being prevented from moving towards each other.

A. No explanation from Quantum Mechanics

Now what in such mechanically induced motion could possibly force such an alignment of the spins of unpaired electrons in materials? It must be said that no mechanical explanation was ever proposed to explain this phenomenon besides Quantum Mechanics' "mathematical explanation".

The 3-spaces model however definitely hints at a possible mechanical explanation. This explanation stems from the manner in which the internal dynamic structures of both carrier-photon and electron are likely to interact, as explained in two separate papers ([9]) and ([10], Section D)

This interaction explains how and why an electron's carrier-photon's magnetic aspect has no choice but to align as anti-parallel as it can with respect to the electron's magnetic aspect that they "carry".

Presently, since the frequency of a carrier-photon will seldom be an exact multiple of that of its companion electron, this alignment will be at best the closest to anti-parallel that the vectorial resultant of the dynamic interactions of their respective cyclic motion will allow ([5], Section "25.11 Relation between Carrier-Photon and Carried Particle").

But as long as the carrier-photon's energy remains stable, this "best-fit" anti-parallel alignment between the carrier-photon magnetic aspect and that of its captive electron will have no choice but to be quite rigidly maintained in such a relatively isolated two-particle system.

B. Motion of the electron in the isolated hydrogen atom

Without getting into the details of relativistic variation of electron inertia due to elliptical orbits ([6], p.329), it is well understood that the theoretical velocity of a freely moving electron in the ground state of an isolated hydrogen atom is a function of the de Broglie wavelength of the energy of its carrier-photon, which happens to be, in this case, the length of the ground orbit, multiplied by its frequency, which is the number of times that the electron would circle the nucleus each second if local electromagnetic equilibrium allowed.

We know that this translation motion of the electron in atomic hydrogen is real on account of the hypothesized wobble of the nuclei of such atoms that allowed Bohr to calculate very precisely the Rydberg constants of hydrogen and ionized helium from his model.

Presently, Bohr's establishment of the Rydberg constant in this manner is the proof, without any doubt, that electron and nucleus are physically located at all times as they move in the isolated hydrogen and ionized helium atoms, and this, despite the theoretically infinite extent of the Quantum mechanics statistical spread of the electron and carrier-photon energy. Actually, only the maximum extent of that QM statistical stretch coherent with the moving electron being permanently localized appears physically possible ([7], Section M).

However complex the trajectory of the electron in an isolated hydrogen atom may be, Bohr's results are proof that the electron orbital pattern is cyclic in the isolated hydrogen atom, and that eventual better understanding of the interaction between electrostatic attraction and magnetostatic repulsion between electron and nucleus will one day allow precise calculation of the electron's motion, at least in isolated hydrogen and ionized helium atoms.

C. Immobilization of electrons in molecules

We also know that when two hydrogen atoms join to form a hydrogen molecule, it becomes impossible for the electrons to translate any more since they mutually capture in anti-parallel spin orientation midway between the nuclei (covalent bounding), like two microscopic interpenetrating magnets, so that their de Broglie wavelength, which fundamentally can be only the actual distance covered by the electron per cycle of its carrying energy, becomes zero, even if the carrying-photon energy is still totally induced by the steady electrostatic force exerted by the nuclei at the distances involved.

Consequently, the electro-magnetic aspect of the two carrier-photons of these covalently bound electrons is left with no other option but to pulsate locally, the unidirectional half of their energy now constantly fighting against each other as they push in opposite directions, which immobilizes completely the two electrons, which are at the same time also locked together in antiparallel magnetic interaction (anti-parallel magnetic capture).

In solid materials, only the electrons of the outermost electronic layer of atoms are involved in associating atoms together to form molecules and these electrons obviously play the same role in ferromagnetic materials.

D. Unpaired electron free to locally freely pivot

Some electrons remain unpaired however in the immediately inner layers of atoms in ferromagnetic materials. While being maintained relatively immobile in their location by the local electromagnetic equilibrium, they remain relatively free to locally pivot even though the unidirectional half of their carrier-photon energy, even if unopposed by that of an immediate antiparallel companion, is not intense enough to cause the electron to move against strength of the local electromagnetic equilibrium.

Without entering into the details of domain alignment and resonance harmonizing of the phase of the frequencies of the carrier-photons of these freely rotating electrons within each domain, it can be surmised that this forced suppression of the normal unidirectional velocity component of their carrier-photons must then amount to a constant "pressure" for that velocity to be restored, and that any favorable circumstance is likely to cause this velocity component to start being expressed again in a direction being externally forced on them.

Consequently, it is not illogical to think that a forced mechanically induced motion of ferromagnetic material could provide such a favorable circumstance.

Let us recall here that in the 3-spaces model, the unidirectional half of a photon's energy (whether carrier or free) is unable by structure to orient otherwise than perpendicularly to the local magnetic field made up of the other oscillating half of that photon's energy.

IV. SETTING THE EINSTEIN AND DE HAAS CYLINDER IN MOTION

When the cylinder used by Einstein and de Haas was at rest and not subjected to an external magnetic field, all unpaired but free to locally pivot electrons in the material of the cylinder were then by default free to align by mutual interaction in a configuration as antiparallel as the local electromagnetic equilibrium allowed, leaving at the macroscopic level no perceptible magnetic field or a barely perceptible magnetic field.

When the strong external magnetic field is applied longitudinally (parallel to the rotation axis) to the cylinder however, all these electrons free to pivot have no other option, due precisely to this freedom, but to all align their individual magnetic fields as antiparallel as possible with respect to this strong external field, thus forcing all the unidirectional half of their carrier-photons to re-orient in order to remain perfectly perpendicular to their own local magnetic field, which results in all of these individual unidirectional quantities of energy to add up in the same direction perpendicular to the axis determined by the sustaining thread, in a number sufficient to induce a rotating motion of the whole mass of the cylinder, a rotation that becomes measurable at the macroscopic level.

When the external magnetic field is deactivated, all of these electrons resume their lower rest energy mutual antiparallel state and the rotating motion of the cylinder stops.

V. ESTABLISHMENT OF A MAGNETIC FIELD IN A BARNETT'S ROD

In the case of the ferromagnetic cylinder, it is a forced reorientation of the individual magnetic fields of the electrons free to pivot to align parallel to the rotation axis that forces all the unidirectional energy quantities of these carrier-photons to align perpendicular to the rotation axis. In the case of Barnett's ferromagnetic rod (same material as for the Einstein and de Haas cylinder) however, the opposite is true.

When the suspended bar is mechanically forced into rotation, the unidirectional quantities of energy of the electrons free to pivot find at last a common direction in which to apply, which forces the individual magnetic fields of these carrier-photons to all align parallel with respect to each other, adding up to become a larger magnetic field that can be measured at the macroscopic level.

If the rotation velocity of the bar is increased yet again, the unidirectional energies of all of these electrons will also increase in the only manner possible for them. As described in ([9], Section VII), this added energy will be shared in equal parts between the unidirectional half and the electromagnetic half in the carrier-photon structure, which will have as an automatic consequence a corresponding increase in intensity of the magnetic fields of all of the individual carrier-photons concerned and consequently of the macroscopically measurable magnetic field that results from their addition.

It is utterly certain also that if the Einstein and de Haas cylinder was forced into a similar mechanical rotation, the same auto-magnetisation phenomenon as a function of angular velocity would occur.

VI. ON FORCED IMMOBILISATION OF CARRIER-PHOTONS UNIDIRECTIONAL ENERGY

This leads to observe that in Nature, the unidirectional half of the carrier-photons of most elementary particles tend to be restrained in their motion by local electromagnetic equilibriums forced on them by the vectorial sum of all electromagnetic interactions that they are immersed into in the larger atomic and molecular structures that they are part of.

To better grasp this situation, let's consider by similarity a much more concrete equilibrium case, but this time induced by gravitation. The type of immobilization by local electromagnetic equilibrium that we just considered for carrier-photons, with full energy inducing force still being applied happens to be quite similar, paradoxically, to that of a mass lying at the surface of the Earth.

In a gravitational context, it was found convenient to express this relation as a ratio of *force per unit of mass* F/m (Newton per kg, or N/kg). This ratio is determined by the acceleration (g) at a specific distance from the center of the central mass (the Earth) at which a test mass of 1 kg will lie. So

$$F/m = g \quad \text{or} \quad F = mg$$

where F is the force expressed in Newtons (kg.m/s^2).

The value of g generally used is 9.8 m/s^2, which is the mean acceleration at the surface of the Earth. It is a means between the precise acceleration of 9.83208 m/s^2 at the poles and the precise acceleration of 9.78036 m/s^2 at mean sea level at the equator. The reason for this difference is that the poles are located closer to the center of the Earth than any point at the equator, due to a flattening of the planet resulting from the centrifugal "force" caused by the rotation of the Earth.

So since g is an acceleration, we can of course write

$$F = mg = ma$$

Now, we know that orbital acceleration is given by the product of the square of the angular velocity by the radius of the orbit, or alternately, by the square of the transverse velocity divided by the radius of the orbit, which is expressed as $a = \omega^2 r = v^2/r$, so similarly

$$a = g = \omega^2 r = \frac{v^2}{r} \quad \text{and} \quad F = mg = m\frac{v^2}{r}$$

Knowing that the equatorial radius of the Earth is 6378140 m, we can find the transverse velocity that a body would have if it was orbiting at ground level at the equator (hypothetically, of course). So, from $g = v^2/r$ we obtain the following figure:

$$v = \sqrt{(g\, r)} = \sqrt{(9.78036 * 6378140)} = 7898.133028 \text{ m/s}$$

If we come back to equation $F = ma = mg = mv^2/r$, and if we assume a mass of 1 kg, we can now much more clearly observe that the force permanently being applied to this mass is

$$F = 1 \text{ kg} \times (7898.133028 \text{ m/s})^2 \div 6378140 \text{ m}$$
$$F = 9.78036 \text{ kg.m /s}^2 \text{ (Newton)}$$

This means that a 1 kg mass is maintained against the ground by a force of 9.78036 N at the equator. It also means that a force of 9.78036 N need be exerted to lift that 1 kg mass from the ground to offset the 9.78036 N force of attraction that maintains it against the ground.

Also, since the presence of surrounding matter prevents bodies from easily moving on their own transversally at ground level, the velocity of objects relative to surrounding matter at the surface of the Earth is typically zero, even though the orthogonal force acting on them would be sufficient to keep them orbiting at 7898.133028 m/s if they were left free to do so and if an impulse was provided to start them moving transversally.

VII. ROTATION VELOCITIES AT THE SURFACE OF THE EARTH

Let's compare this velocity with the actual transverse velocity at the Earth equator due to its daily rotation (approximately 464 m/s), which is about 17 times slower than that required for bodies at its surface to become weightless and truly be in orbit at ground level, if transverse motion was induced and if physical hindrance was not in the way.

Due to this rotation velocity, the Earth mass bulges at the equator and flattens at the poles causing the Earth be shaped like an oblate spheroid rather than an actual sphere. While the mean equatorial radius is estimated at about 6378 km, the polar radius falls down to 6357 km approximately, a difference of about 21 km.

This oblateness is however close to insignificance for most general estimation purposes since it lies in the same range as the widest spread of altitude difference between the highest summit and the deepest oceanic trench, which are the Everest (8,8 km altitude) and the Mariana trench (11 km depth) for a total spread of 19,8 km. The poles would in fact be closer to the center of the Earth by only about 10 km than the bottom of the Mariana trench, which is located relatively close to the equator.

Note that a score of methods, some very complex, have been devised to calculate the radius of the earth at any point of its surface, but that all of them remain approximate for a number of reasons. So here is a simplified equation to estimate ballpark figures of surface velocities at any location of the Earth surface:

$$v = \frac{2\pi\left[r + 21\sin(90 - \text{latitude})\right]\sin(90 - \text{latitude})}{24 \times 60 \times 60}$$

Where r is the Earth polar radius. The first occurrence of sin(90 - latitude) ensures that the difference between equatorial and polar radius is at maximum at the equator (21 km) and diminishes to zero at the pole (90 deg latitude). The second occurrence of sin(90 - latitude) allows calculation of the approximate radius normal to the Earth polar axis at the latitude considered. The 2π constant then allows calculating the mean circumference of the Earth at this latitude, which is the distance that a location at this parallel travels in 24 hours. The 24 x 60 x 60 divisor gives of course the number of seconds in 24 hours.

For example, the estimated velocity of the city of Columbus Ohio, which lies very precisely at the 40th parallel, would be:

$$v = \frac{2\pi\left[r + 21\sin(50)\right]\sin(50)}{24 \times 60 \times 60} = 355\,\text{m/s}$$

which in the more familiar km/h notation amounts to the astonishing rotation velocity of 1279 km/h! Nome Alaska for comparison, which lies at parallel 64.5, rotates at a mere 717 km/h!

VIII. COMPENSATED VERSUS UNCOMPENSATED ROTATION AND TRANSLATION

A clear distinction must be made also between *uncompensated mechanically induced rotation or translation* and *permanently compensated electrostatically or gravitationally induced rotation or translation*, as analyzed in ([5], Section "23.7 Permanently Compensated Translational Motion").

The first will gradually spend their rotational or translational energy according to an exponential curve as analyzed in the chapter mentioned, while the second will permanently maintain their motion as the energy expended by constant change in direction is naturally and constantly replenished by the fixed quantity of energy naturally induced at their stable distance of rotation or translation by the causal energy inducing force being permanently applied.

The Barnett effect belongs by definition to the uncompensated mechanically induced category, since required energy is artificially, thus temporarily provided.

IX. CONCLUSION

But the question does come to mind as to whether stable permanently compensated Einstein-de Haas systems could naturally exist, since this effect is magnetically induced, considering the Solar System wide extent of the Sun's magnetic field!

What about the very stable rotation of the Earth about its axis? To start with, we know that the core of the Earth is mostly iron, and that generally speaking, all planets of the Solar system that have satellites have rotation periods that are shorter than their translation period about the Sun ("day" shorter than their "year") while planets having no satellites tend not to rotate ("day" generally equal to their "year"), meaning that they always present the same side to their primary, local oscillation notwithstanding.

So, could the Moon's magnetic field, however weak, be strong enough to align a sufficient number of electrons in the Earth core to induce and maintain the age old stable rotation of the Earth? Could the tandem Earth-Moon be a stable giant Einstein-de Haas system? Or is the Sun's magnetic field at play here, or a combination of both?

Could the Einstein-de Haas effect be a factor in the rotation of all planets having satellites?

What a mind-boggling perspective!

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