The Schuster-Wilson-Blackett hypothesis

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ABSTRACT

Many authors have considered a gravitational origin of the magnetic field of celestial bodies. In this approach the Wilson-Blackett or Schuster hypothesis has been playing an important role for more than a century. This hypothesis connects the magnetic moment *M* of the body to its angular momentum *S*. In this paper the gravitomagnetic ratios *M*/*S* deduced from observational data for a series of very different rotating massive bodies are compared with predicted values.

The considered magnetic moments *M* and corresponding angular moments *S* of the rotating bodies range from metallic cylinders in the laboratory, moons, planets, pulsars, white dwarfs and Ap stars to the Milky Way. Furthermore, the lightest neutrino of mass m_1 has also been added to the list.

For huge intervals of more than 100 decades for the values of *M* and *S* the so-called Wilson-Blackett relation seems to be approximately valid. On smaller scales deviations become more manifest. Effects from electromagnetic origin may be responsible for these deviations.

1. INTRODUCTION

The subject of magnetism from gravitational origin has been going through a long and turbulent history. In 1891, Schuster [1], considering the magnetic field of the Earth and the Sun, already put the question: “Is every large rotating mass a magnet?” He suggested that every moving molecule causes a magnetic field, as if it was electrically charged. Following Schuster, Wilson [2] proposed in 1923, that electrically neutral moving matter bears a residual charge Q^* of magnitude $\beta\ G^{½}\ m$. Here β denotes a dimensionless constant, G is the gravitational constant and m the mass of the moving body (Gaussian units are used throughout this paper). Wilson tried to measure the magnetic field of a swinging bar in the laboratory, but he found no detectable field. In this experiment he tested his assumption in the case of translational motion, but not for rotational motion. Applying the theory of electromagnetism to a massive rotating sphere like the Earth, he implicitly deduced an approximate form of the relation

$$\mathbf{M} = -\tfrac{1}{2}\beta c^{-1} G^{\frac{1}{2}} \mathbf{S}, \tag{1.1}$$

where c is the velocity of light, **M** the magnetic dipole moment and **S** the angular momentum of the rotating sphere.

In 1947 Blackett [3] reinvestigated a gravitational origin of the magnetic field of rotating celestial bodies. He explicitly proposed relation (1.1) and calculated a value of β of 0.3, 1.14 and 1.16 for the Earth, the Sun and the Ap star 78 Virginis, respectively. In addition, Blackett [4] tried to measure the magnetic field of a 10×10 cm gold cylinder, at rest in the laboratory and so rotating with the Earth, but he detected no measurable field.

Due to the growing number of observed magnetic of planets and stars, the validity of relation (1.1) was reconsidered by several authors since 1977. Ahluwalia and Wu [5] and Sirag [6] extended the series of celestial bodies approximately obeying to (1.1) and proposed to measure the possible magnetic field generated by a rotating metallic sphere in the laboratory, a test already discussed by Blackett [4].

Such an experiment was performed by Surdin [7, 8], who measured a mean value of the square of the magnetic field generated by a rotating cylinder of both brass and tungsten. The values of the magnetic field squared appeared to be in reasonable agreement with the fields predicted by (1.1), but the sign did not follow from the experiment. Moreover, the observed fields appeared to fluctuate.

Attempts to derive relation (1.1) from a more general theory have been made by many authors [9–16]. Luchak [9], for example, generalized the Maxwell equations by introducing a gravitational field. Considering rotational motion only, he obtained (1.1). Other authors [10–15] tried to explain relation (1.1) as a consequence of general relativity. For example, it is possible to deduce (1.1) from a special version of the gravitomagnetic theory [10–12]. In this interpretation the so-called "magnetic-type" gravitational field or gravitomagnetic field **B**(gm) generated by rotating mass and the electromagnetic induction field **B**(em) due to moving charge are supposed to be equivalent. A review of alternative explanations has been given in ref. [11]. For example, Vasiliev [16] tried to explain the magnetic moments of moons, planets and stars in terms of electric polarization induced by their gravitational field.

It is noticed that the angular momentum **S** in (1.1) for a spherical star of radius R can be calculated from

$$\mathbf{S} = I\mathbf{\Omega}_{\mathrm{s}},\ \text{or}\ S = I\Omega_{\mathrm{s}} = \tfrac{2}{5}\, f\, m R^2 \Omega_{\mathrm{s}}, \tag{1.2}$$

where m is the mass of the star, $\Omega_{\mathrm{s}} = 2\pi P_{\mathrm{s}}^{-1}$ is its angular velocity (P_{s} is the rotational period of the star) and $I = 2/5\ f\ m\ R^2$ is its moment of inertia. The factor f is a dimensionless factor depending on the homogeneity of the mass density in the star (for a homogeneous mass density $f = 1$).

Furthermore, the value of the gravitomagnetic dipole moment **M**(gm) = **M** in (1.1) and the electromagnetic dipole moment **M**(em) can both be calculated from the expression

$$\mathbf{M} = \tfrac{1}{2} R^3 \mathbf{B}_{\mathrm{p}},\ \text{or}\ M = \tfrac{1}{2} R^3 B_{\mathrm{p}}. \tag{1.3}$$

Here $\mathbf{B}_{\mathrm{p}}$ is the magnetic induction field at, say, the north pole of the star, at distance R from the centre of the star to the field point where $\mathbf{B}_{\mathrm{p}}$ is measured.

Combination of (1.1), (1.2) and (1.3) yields the following gravitomagnetic prediction for $\mathbf{B}_{\mathrm{p}}$(gm) and B_{p}(gm), respectively

$$\mathbf{B}_{\mathrm{p}}(\mathrm{gm}) = -\beta c^{-1} G^{\frac{1}{2}} I R^{-3} \mathbf{\Omega}_{\mathrm{s}},\ \text{or}\ B_{\mathrm{p}}(\mathrm{gm}) = c^{-1} G^{\frac{1}{2}} I R^{-3} \Omega_{\mathrm{s}}\ \text{for}\ \beta = -1. \tag{1.4}$$

When β is negative, the directions of $\mathbf{B}_{\mathrm{p}}$(gm) and $\mathbf{\Omega}_{\mathrm{s}}$ are parallel. The sign and magnitude of β are unknown, however. See ref. [12] for an ample discussion of this point.

As pointed out earlier [11], moving electric charge in the magnetic field from gravitomagnetic origin may cause additional magnetic fields from electromagnetic origin. In general, the magnetic field generated by rotating neutral mass is much smaller than the magnetic field generated by moving charge. For a charge e ($e < 0$) with mass m one may compare the following magnetic moment to angular momentum ratios

$$\left(M/S\right)_{\text{electromagnetic}} = \tfrac{1}{2} e (mc)^{-1}\ \text{and}\ \left(M/S\right)_{\text{gravitomagnetic}} = -\tfrac{1}{2}\beta c^{-1} G^{\frac{1}{2}}. \tag{1.5}$$

Choosing $\beta = -1$, the following dimensionless ratio for an electron is obtained

$$(M/S)_{\text{gravitomagnetic}} / (M/S)_{\text{electromagnetic}} = G^{\frac{1}{2}} m / e = -4.899 \times 10^{-22}. \tag{1.6}$$

From this relation follows, that magnetic fields from gravitomagnetic origin are usually extremely small and difficult to isolate from fields due to electric charges.

In situations where both a magnetic induction field $\mathbf{B}_p$(gm) from gravitomagnetic origin and a field $\mathbf{B}_p$(em) from electromagnetic origin are present, e.g., at the north pole of a star, the total polar magnetic induction field $\mathbf{B}_p$(tot) is given by (see [17])

$$\mathbf{B}_p(\mathrm{tot}) = \mathbf{B}_p(\mathrm{gm}) + \mathbf{B}_p(\mathrm{em}). \tag{1.7}$$

According to (1.4), the direction of $\mathbf{B}_p$(gm) is parallel to $\mathbf{\Omega}_s$ for $\beta = -1$. Another dimensionless factor β^* following from observations will now be introduced

$$\mathbf{B}_p^{\parallel}(\mathrm{tot}) = \beta^* \mathbf{B}_p(\mathrm{gm}), \tag{1.8}$$

where $\mathbf{B}_p^{\parallel}$(tot) is the component of parallel to $\mathbf{B}_p$(gm). Usually, the sign of the empirical factor β^* does not follow from observations. For convenience sake, a positive sign for β^* is chosen in the calculations below. When the field $\mathbf{B}_p^{\parallel}$(tot) would only be due to gravitomagnetic origin, $\mathbf{B}_p$(em) = 0, the factor β^* would reduce to β^*(gm) = 1.

A more general expression for factor β^* has previously been deduced for accreting stars displaying quasi-periodic oscillations, like pulsars, white dwarfs and black holes [18]. In that case a term $\beta^*_{\mathrm{current}}$, due to toroidal currents, was added to the expression for β^*.

In section 2 observational data for a large sample of rotating electrically neutral bodies are gathered and values for S, M and β^* for these masses are calculated. These results are discussed in section 3. In section 4 conclusions are drawn.

2. OBSERVATIONAL DATA

In table 1 data are summarized for a series of rotating massive bodies, ranging from metallic cylinders in the laboratory, moons, planets, Ap stars, pulsars and white dwarfs to the Milky Way. Furthermore, attention is paid to the lightest neutrino of mass m_1. In particular, values are summarized for mass m, rotation period P_s, radius R, factor f and the absolute value of the observed total polar magnetic field B_p(tot). When data are available, estimates of the angle δ ($0^\circ \leq \delta \leq 180^\circ$) between the directions of $\mathbf{M}$ and $\mathbf{S}$ are also given. Note that equation (1.1) predicts parallel directions for $\mathbf{M}$ and $\mathbf{S}$ for $\beta = -1$.

Subsequently, the values of the angular momentum S and the magnetic moment M are calculated from (1.2) and (1.3), respectively. In addition, the absolute values of factor β^* have been calculated by combining (1.4), (1.8) and the observed polar magnetic field $\mathbf{B}_p^{\parallel}$(tot), or $\mathbf{B}_p$(tot). The quantity β^* is equal to β, when the Wilson-Blackett formula is valid. In table 1 all calculated absolute values for angular momentum S, magnetic dipole moment M and factor β^* are summarized. Additional details of the observations and calculations can be found in refs. [6, 11] or are given below:

1. Neutrino of mass m_1

It is noticed that the Wilson-Blackett formula (1.1) may be extended to fundamental particles like neutrinos with masses m_i, (i = 1, 2, 3). For the lightest neutrino of mass m_1 the following magnetic moment M_z and angular momentum S_z has been proposed [19, 20]

$$M_z = \tfrac{1}{2} c^{-1} G^{1/2} \hbar, \quad S_z = \tfrac{1}{2}\hbar \quad \text{and} \quad M_z/S_z = c^{-1} G^{1/2}, \tag{2.1}$$

where $S_z = \tfrac{1}{2}\,\hbar = 5.273\times10^{-28}$ g.cm^2.s^{-1}. It is noticed that a gravitomagnetic factor $g_1 = 2$ has been added to the ratio M_z/S_z, analogous to the derivation of the factor $g = 2$ for the electron. Analogous to the factor $g = 2$, the factor $g_1 = 2$ may be deduced from the Dirac equation [19].

An alternative formula for the magnetic moment M_z of neutrinos, proportional to the mass m_i of the neutrino i, has been deduced for massive Dirac neutrinos in the context of electroweak interactions. As has been shown in ref. [19], combination of this formula for M_z and M_z from (2.1) for the neutrino of mass m_1 yields a value of 1.530 meV/c^2 or 2.727×10^{-36} g for mass m_1. Note that the value of m_1 does not occur in S_z or M_z in (2.1).

14. Isolated pulsars

In ref. [17] the individual values of β^* for a sample of 96 isolated pulsars are given. The calculated arithmetic mean value $\overline{\beta^*} = 0.061$ of this class of pulsars is shown in ref. [21] and in table 1 of this work. This value is more representative than the value of some arbitrarily chosen single pulsar. In addition, the mean values of S and M of the total sample are calculated here, resulting in $\overline{S} = 1.6\times10^{46}$ g.cm^2.s^{-1} and $\overline{M} = 1.8\times10^{30}$ G.cm^3. From the ratio $\overline{M}/\overline{S}$ of these values a value $\beta^* = 0.026$ is obtained. In order to retain the mean value $\overline{\beta^*} \approx 0.061$, the mean values $\overline{S}$ and $\overline{M}$ in table 1 are modified.

15. Slowly rotating pulsars in binaries

In ref. [17] the individual values of β^* for a sample of 14 slowly pulsars in binaries are given. The mean value $\overline{\beta^*} = 14$ of this class of pulsars has been calculated in ref. [21] and is shown in table 1. In addition, the mean values of S and M of the total sample are calculated here, resulting in $\overline{S} = 7.9\times10^{44}$ g.cm^2.s^{-1} and $\overline{M} = 1.95\times10^{30}$ G.cm^3. From the ratio $\overline{M}/\overline{S}$ of these values a value $\beta^* = 0.57$ follows. In order to retain the mean value $\overline{\beta^*} = 14$, the mean values $\overline{S}$ and $\overline{M}$ in table 1 are modified.

16. Millisecond pulsars in binaries

In ref. [17] the individual values of β^* for a sample of 3 millisecond pulsars are given. The mean value $\overline{\beta^*} = 6.4\times10^{-6}$ of this class of pulsars has been calculated in ref. [21] and is shown in table 1. In addition, the mean values of S and M are calculated here, resulting in $\overline{S} = 2.9\times10^{47}$ g.cm^2.s^{-1} and $\overline{M} = 2.5\times10^{27}$ G.cm^3. From the ratio $\overline{M}/\overline{S}$ of these values follows a value $\beta^* = 2.0\times10^{-6}$. In order to retain the mean value $\overline{\beta^*} \approx 6.4\times10^{-6}$, the mean values $\overline{S}$ and $\overline{M}$ in table 1 are modified.

17. Isolated white dwarfs

In ref. [21] the individual values of β^*, the mean value $\overline{\beta^*} = 32$ and the mean values $\overline{S} = 2.7\times10^{47}$ g.cm^2.s^{-1} and $\overline{M} = 6.9\times10^{33}$ G.cm^3 for a sample of 10 isolated white dwarfs have been calculated. From the ratio $\overline{M}/\overline{S}$ of these values a value $\beta^* = 5.9$ follows. In order to retain the mean value $\overline{\beta^*} \approx 32$, the mean values $\overline{S}$ and $\overline{M}$ in table 1 are modified.

18. AM Herculis white dwarfs

In ref. [21] the individual values of β^*, the mean value $\overline{\beta^*} = 12$ and the mean values $\overline{S} = 2.8\times10^{47}$ g.cm^2.s^{-1} and $\overline{M} = 1.0\times10^{34}$ G.cm^3 for a sample of 11 AM Herculis white dwarfs have been calculated. From the ratio $\overline{M}/\overline{S}$ of these values a value $\beta^* = 8.3$ follows. In order to retain the mean value $\overline{\beta^*} = 12$, the mean values $\overline{S}$ and $\overline{M}$ in table 1 are modified.

19. Binary white dwarfs

In ref. [21] the individual values of β^*, the mean value $\overline{\beta^*} = 0.38$ and the mean values $\overline{S} = 2.0\times10^{48}$ g.cm^2.s^{-1} and $\overline{M} = 2.5\times10^{33}$ G.cm^3 for a sample of 3 white dwarfs in double-white-dwarfs binaries have been calculated. From the ratio $\overline{M}/\overline{S}$ of these values a value $\beta^* = 0.29$ follows. In order to retain the mean value $\overline{\beta^*} = 0.38$, the mean values $\overline{S}$ and $\overline{M}$ in table 1 are modified.

22. Milky Way galaxy

As an estimate for mass m of the Milky Way a value of $m = 8.9\times10^{11} m_\odot$ within the galactic radius of 200 kpc is taken from Karukes *et al.* [22]. The galactic constants R_0 = 8 kpc and V_0 = 240 km.s^{-1} are used to obtain a value for R and $\Omega_s = V_0/R_0$, respectively. The angular momentum S is calculated from the expression $S = ½\, m\Omega_s R^2$ for a cylinder. The polar magnetic field B_p has been approximated by $B_p = 2\, B_{eq}$, where B_{eq} is the local equatorial interstellar magnetic field of 3.75 μG (i.e., unperturbed by the interaction with the Sun) given by Izmodenov and Alexashov [23]. The data are given in table1.

Table 1. Calculated values of factor β* from magnetic moment *M* and angular momentum *S*. For details see text.

	Body [refs.]	f	m (g)	Ω_s (rad.s^{-1})	R (cm)	S (g.cm^2.s^{-1})	B_p(tot) (G)	M (G.cm^3)	β*	δ (º)
1	Neutrino of mass m_1 [19, 20]		2.727×10^{-36}			5.27×10^{-28}		4.54×10^{-42}	$g_1 = 2$	
2	Cylinder of brass [7, 8; 11]	1.00	1.04×10^4	2.83×10^3	5	3.68×10^8	3.6×10^{-8}	2.25×10^{-6}	1.42	
3	Cylinder of tungsten [7, 8; 11]	1.00	2.07×10^4	2.73×10^3	5	7.06×10^8	3.8×10^{-8}	2.38×10^{-6}	0.78	
4	Moon [6, 11]	0.998	7.35×10^{25}	2.66×10^{-6}	1.738×10^8	2.36×10^{36}	8.6×10^{-4}	2.26×10^{21}	0.22	≈ 0
5	Ganymede [11]	0.776	1.48×10^{26}	1.02×10^{-5}	2.63×10^8	3.24×10^{37}	1.5×10^{-2}	1.36×10^{23}	0.97	170
6	Mercury [11]	1.0	3.3×10^{26}	1.23×10^{-6}	2.44×10^8	9.67×10^{36}	5×10^{-3}	3.6×10^{22}	0.86	168
7	Mars [11]	0.943	6.45×10^{26}	7.088×10^{-5}	3.39×10^8	1.98×10^{39}	1.3×10^{-3}	2.5×10^{22}	0.0029	≈ 163
8	Venus [11]	0.85	4.87×10^{27}	2.99×10^{-7}	6.052×10^8	1.81×10^{38}	2.7×10^{-4}	2.99×10^{22}	0.038	
9	Earth [11]	0.827	5.98×10^{27}	7.292×10^{-5}	6.378×10^8	5.87×10^{40}	6.1×10^{-1}	7.91×10^{25}	0.31	168.5
10	Uranus [11]	0.575	8.72×10^{28}	1.01×10^{-4}	2.56×10^9	1.33×10^{43}	4.6×10^{-1}	3.86×10^{27}	0.067	60
11	Neptune [11]	0.725	1.03×10^{29}	1.09×10^{-4}	2.48×10^9	2.00×10^{43}	2.7×10^{-1}	2.06×10^{27}	0.024	47
12	Saturn [11]	0.55	5.69×10^{29}	1.71×10^{-4}	6.00×10^9	7.71×10^{44}	4.2×10^{-1}	4.54×10^{28}	0.014	1.0
13	Jupiter [11]	0.625	1.90×10^{30}	1.77×10^{-4}	7.14×10^9	4.29×10^{45}	7.4	1.35×10^{30}	0.073	9.6
14	96 isolated pulsars [17, 21]	0.898	2.785×10^{33} (1.4 $m_\odot$)		10^6	1.0×10^{46}		2.6×10^{30}	0.061	
15	14 slowly rotating pulsars [17, 21]	0.898	2.785×10^{33}		10^6	1.6×10^{44}		9.7×10^{30}	14	
16	3 binary millisec. pulsars [17, 21]	0.898	2.785×10^{33}		10^6	1.6×10^{47}		4.5×10^{27}	6.4×10^{-6}	
17	10 isolated white dwarfs [21]	1	1.7×10^{33} (0.86 $m_\odot$)		6.7×10^8	1.2×10^{47}		1.6×10^{34}	32	
18	11 AM Herculis white dwarfs [21]	1	1.6×10^{33} (0.81 $m_\odot$)		7.2×10^8	2.4×10^{47}		1.2×10^{34}	12	
19	3 binary white dwarfs [21]	1	1.9×10^{33} (0.98 $m_\odot$)		5.8×10^8	1.7×10^{48}		2.8×10^{33}	0.38	
20	Sun [6, 11]	0.145	1.99×10^{33}	2.8×10^{-6}	6.96×10^{10}	1.57×10^{48}	8	1.35×10^{33}	0.2	
21	78 Virginis [3, 6]	0.16	4.6×10^{33}	7.3×10^{-5}	1.4×10^{11}	4.2×10^{50}	1.5×10^3	2.1×10^{36}	1.16	
22	Galaxy [11, 22, 23]	1	1.8×10^{45}	9.6×10^{-16}	2.5×10^{22}	5.4×10^{74}	7.5×10^{-6}	5.9×10^{61}	25	

3. DISCUSSION OF THE RESULTS

The following general relationship between the magnetic moment *M* and the angular momentum *S* is tested

$$\log M = a \log S + b, \qquad (3.1)$$

where *a* and *b* are assumed to be constant.

For the complete series of 22 rotating bodies in table 1 values for the parameters *a* and *b*, the relative standard deviations in *a* and *b* and the correlation coefficient are obtained from a linear regression analysis. The summarized results are shown as case 1 in table 2. An almost linear relationship between log *M* and log *S* is found: *a* has nearly unity value and the correlation coefficient is high. In figure 1, the values of log *S* versus log *M* of all 22 rotating bodies are plotted. Note that the values of *M* and *S* and cover an interval of more than 100 decades.

These results mainly obtained from observational data are compared with the prediction following from the Wilson-Blackett relation (1.1) for $\beta = -1$

$$\log M = \log S + \log \tfrac{1}{2} c^{-1} G^{1/2} = \log S - 14.366. \qquad (3.2)$$

Combination of the value $b = -14.77$ from case 1 in table 2 and $b = -14.366$ from (3.2) yields a factor $\beta^* = 0.39$.

Table 2. Calculated constants *a* and *b* from (3.1), corresponding standard deviations and correlation coefficient for different series of rotating bodies. The corresponding factors β^* are also given.

Case		*a*	Standard deviation of *a*	*b*	Standard deviation of *b*	β^*	Correlation coefficient
	Wilson-Blackett eq. (1.1)	1		– 14.366		1	
1	Numbers 1-22 of table 1	0.995	± 0.017	– 14.77	± 0.65	0.39	0.997
2	Numbers 2-22 of table 1	1.006	± 0.025	– 15.26	± 1.07	0.13	0.994
3	Vasiliev [16]	-	-	– 14.82	± 0.87	0.35	-

Since the values for M_z and S_z of the neutrino m_1 are not yet measured, number 1 of table 1 will be omitted in a more reduced selection of rotating masses. The values of parameters *a* and *b*, corresponding standard deviations, correlation coefficient and value of β^* for the series with numbers 2 through 22 are also calculated and appear as case 2 in table 2. The intervals of *M* and *S* are then reduced to about 65 decades.

Another selection, only consisting of moons, planets and a number of Ap and Bp stars from Vasiliev [16] is denoted as case 3 in table 2. This less general selection covers intervals for *M* and *S* of about 20 decades. As can be seen from table 2, the obtained values for parameter *b* and factor β^* remain comparable to the corresponding values for cases 1 and 2.

Up to now, the selection of the celestial bodies has largely followed the availability of the necessary data, but such a selection need not to be representative. Schuster [1] and Wilson [2] only considered the Earth, whereas Blackett [3] added the Sun and the Ap star 78 Virginis to the list. Later on, Ahluwalia and Wu [5], Sirag [6] and Vasiliev [16] selected 13, 9 and 29 celestial bodies, respectively. Since the magnetic fields of stars may be changed by additional mechanisms from electromagnetic origin, like specific dynamo mechanisms, three different classes of pulsars and white dwarfs are distinguished in this work. Of course, such an introduction of classes is also arbitrary to a certain extent.

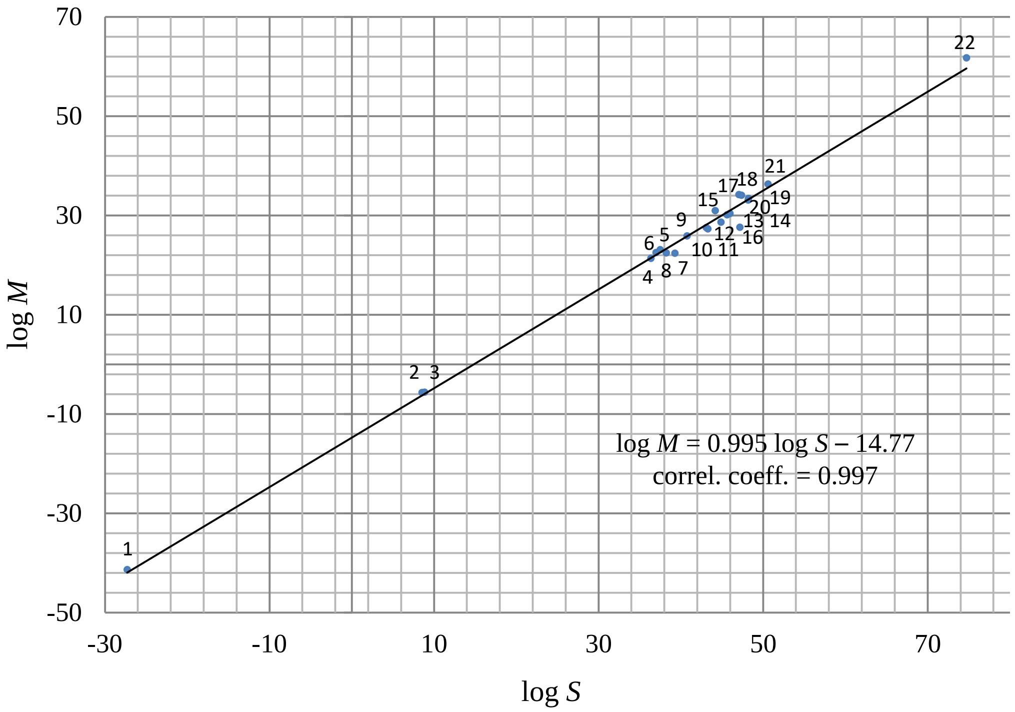

Figure 1. Log *M* versus log *S*. The units of *M* and *S* and the numbers 1 through 22 of the rotating bodies are the same as in table 1. The regression line of case 1 in table 2 is displayed as the solid line.

As an example of a smaller group of related pulsars, the class of 14 binary, slowly rotating, accretion-powered X-ray emitting pulsars (number 15 in table 1) can be chosen. The values of *S* vary over an interval of only 3 decades in this case, whereas the values of *M* remain almost constant. The deviations from (1.1) on this small scale may reveal an additional mechanism that changes the basic magnetic field from gravitational origin.

Another example of related pulsars is formed by the less abundant class of millisecond pulsars. Omission of this class (3 millisecond pulsars with a mean value of $\overline{\beta^*} = 6.4\times10^{-6}$; number 16 in table 1) from the series of case 2 in table 2 changes the value of β^* from the regression analysis from a value of $\beta^* = 0.13$ into $\beta^* = 0.11$, whereas the values of *a*, *b* and the correlation coefficient are nearly unchanged. So, the influence of a single outlier decreases in the large sample of case 2.

As has previously been discussed in refs. [17, 18], the small value of β^* in millisecond pulsars may be caused by a toroidal current, leading to a contribution $\beta^*_{\text{current}} \approx -1$. In that case the observed value of β^* is given by $\beta^* = \beta^*(\text{gm}) + \beta^*_{\text{current}} = +1 + \beta^*_{\text{current}} \approx 0$. It is noticed that values for β^*_{current} are calculated for a number of pulsars displaying high frequency quasi periodic oscillations (QPOs) [18].

4. CONCLUSIONS

The validity of the Schuster-Wilson-Blackett hypothesis, embodied in equation (1.1), is reinvestigated in this work. Especially, additional observational evidence is gathered and discussed. For attempts to deduce this relation from a more general theory, the reader is referred to refs. [9–18], in particular to ref. 11.

It appears that the values of the magnetic moment *M* and the angular momentum *S* for the complete series of 22 very different rotating massive bodies of table 1 vary over a huge interval of more than 100 decades. As can be seen from figure 1 and case 1 in table 2, reasonable agreement with the Wilson-Blackett or Schuster relation (1.1) is then obtained. The agreement between observations and formula (1.1) is still qualitative, however. For example, in many cases the directions of the vectors of **M** and **S** are unknown, or only partially parallel. Moreover, the proposed value M_z for the neutrino of mass m_1 has not yet been verified experimentally.

Omitting the neutrino m_1 is from the selection of table 1, results into case 2 of table 2. Both M and S then still vary over an interval of about 65 decades. Again, reasonable agreement between observations and formula (1.1) is found, but standard deviations in parameters a and b become bigger. As a result, the value of the dimensionless quantity β^*, a measure for the deviation from (1.1), becomes more uncertain.

Summing up, the Wilson-Blackett relation (1.1) seems to be approximately valid on large scales. Observed magnetic moments M and angular momenta S of massive rotating bodies are nearly proportional and the proportionality constant is of the expected order of magnitude. Many deviations occur, however, especially for smaller intervals of M and S and in particular for individual massive rotating bodies. Various dynamo mechanisms from electromagnetic origin may change a possible basic gravitomagnetic field B_p(gm) and may explain the discrepancies (see (1.6)).

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Acknowledgement

I thank my daughter Irene for careful correction of the English text.