Modeling the nS1/2 Lamb shifts in atomic hydrogen as magnetic monopole phenomena

Hans Peter Good
Sargans, Switzerland
e-mail: hp.good at catv.rol.ch

August 2, 2026

Abstract

The Dirac equation fails to provide an explanation for the Lamb shift. It is proposed that a point-like magnetic monopole associated with the nucleus or the vacuum interacts with the magnetic dipole moment of the electron, causing Zeeman energy shifts of the nS1/2 levels. If the 1S1/2–2S1/2 transition in atomic hydrogen, defined as the 15-digit frequency 2 466 061 413.187 01 MHz, is taken as a reference, the model predicts 2 922 743 278.669 71 MHz for the 1S1/2–3S1/2 and 770 649 350.463 33 MHz for the 2S1/2–8S1/2 centroid transitions, and 2 922 742 936 720.19 kHz for the 1S1/2(F=1)–3S1/2(F=1) hyperfine transition without the application of bound-state QED theory and the constants m_e, h, or c defined by CODATA.

A least-squares method is used to experimentally determine the dimensionless Lamb shifts of the nP and nD levels of atomic hydrogen, while those of the nS levels are considered to be theoretically fixed.

This paper also explores the impact on the spectroscopic transitions of deuterium and muonium when the dimensionless Lamb shifts of atomic hydrogen also apply to these systems. It appears that the 1S1/2–2S1/2 transition of deuterium is notable for a significant anomaly when compared to other transitions.

Keywords: Relativistic quantum mechanics, Lamb shift, magnetic monopole, atomic hydrogen, deuterium, muonium, nuclear structure.

In [1], the author presented a self-consistent mathematical formalism to characterize the atomic hydrogen spectrum, revealing that, considering the margins of error, the spectroscopic fine structure constant α aligns with $\alpha_{geom} \equiv 2^{-6}\pi^{-\frac{2}{3}} \approx 0.00\,72\,843\,\left(\alpha_{geom}{}^{-1} \approx 137.28\right)$. Throughout the text, including the tables and formulas that follow, the fine structure constant α is an exact parameter, and the symbol α always denotes the number constant α_{geom}.

The most recent data from Table 1 was used to supply the algorithm outlined in [1]. Only the measured values and uncertainties listed in Table 1 were used to estimate the parameters in Table 2. Other data, such as the electron mass m_e, the Planck constant h, or the speed of light in vacuum c, have no impact. They are embedded within the scaling factor γ_{zero}, which also adjusts for the recoil correction coming from nuclear motion.

The Dirac equation fails to provide an explanation for the Lamb shift. The current doctrine interprets it through quantum field theory, which constitutes a fundamentally different paradigm. Assuming that a point-like magnetic monopole μ of the proton interacts with the magnetic dipole moment of the electron μ_e, causing Zeeman energy shifts of the nS1/2 levels due to the proton magnetic monopole field. If the magnetic field is attributed to a magnetic charge and originates from a scalar potential, meaning the source of magnetism is a type of spherical bar magnet, then the factor $(-1/2)$ must be taken into account [4]. Electrons that are confined circulate due to the monopole field and create an induced magnetic field that opposes the monopole field, as per Lenz's

law, indicating the presence of local diamagnetic shielding characterized by the factor $\gamma_{diamag\_shielding}$. With all these aspects in mind, it is theorized that the dimensionless Lamb shift constant $B(\gamma_{zero})$ equals

$$B(\gamma_{zero})^{theo} = \frac{\mu}{\mu_B} \cdot \left(-\frac{1}{2}\right) \cdot \gamma_{diamag\_shielding} \cdot (2\alpha)^2 \tag{1}$$

where μ signifies an intrinsic magnetic moment of the proton, which needs to be defined so that the difference from the precisely estimated value $B(\gamma_{zero})$ in Table 2 is as small as possible. Simple numerical testing [2: p.175] gives

$$\frac{\mu}{\mu_B} = \frac{5}{\left(\frac{\lambda_{e\_bar}}{L_2(L)} + 3\right)} \approx 0.023025$$
$$\frac{\lambda_{e\_bar}}{L_2(L)} = 2^{16}\pi^{-5} \tag{2}$$

and

$$\gamma_{diamag\_shielding} \equiv \frac{1}{3}\left(1 + 2\sqrt{1-(3\alpha)^2}\right) \approx 1 - \frac{(3\alpha)^2}{3} \approx 0.999\,841 \tag{3}$$

being consistent with the relativistic adjustment to the magnetic moment for a central electric potential of charge $Z = 3$ and a uniform magnetic field of arbitrary strength [5: p. 213, eq. 47.2]. The energy building block $\frac{1}{L_2(L)}$ in the energy unit $\frac{1}{\lambda_{e\_bar}}$, where λ_{e_bar} corresponds to the reduced Compton wavelength of the electron, is also connected to the universal saturation density of matter established through elastic electron scattering experiments [6]. Furthermore, the phenomenological expression (1) is consistent with the concept that symmetries in quantum theory result in simple mathematical equations that include integers or fractions of integers.

According to the compact algebraic formula (1), the calculated value $B(\gamma_{zero})^{theo}$ is about **–2.443 049 ppm**, which is comfortably within the error limits of the experimental result –2.443 049(17) ppm presented in Table 2. The parameter $B(\gamma_{zero})^{theo}$ can also be utilized to establish a scaling factor γ_{zero}^{ref} based on a metrological reference in accordance with

$$\gamma_{zero}^{ref} = \frac{\Delta E_{1S-2S}^{meas}}{E(2)-E(1)} \quad \text{with} \quad E(n) \equiv E_D(n,1/2) \cdot \left\{1 + {}^{B}/_{n}\right\}$$
$$= \frac{\Delta E_{1S-2S}^{meas}}{X + B \cdot Y} \quad \text{with} \quad X \equiv E_D(2,1/2) - E_D(1,1/2) \quad \text{and} \quad Y \equiv \frac{E_D(2,1/2)}{2} - E_D(1,1/2) \tag{4}$$

Using input A7 of Table 1 as the reference ΔE_{1S-2S}^{meas} in formula (4), the resulting value for γ_{zero}^{ref}(H) is ≈1.239 352 998 271 x 10^{20} Hz, which aligns closely with the mean value obtained via least squares calculations presented in Table 2.

When the input A7 of Table 1, defined as the 15-digit frequency 2 466 061 413.187 01 MHz, is used as the metrological reference to determine the scaling factor γ_{zero}, the theoretical dimensionless value $B(\gamma_{zero})^{theo}$ predicts, according to formula (1), **2 922 743 278.669 71 MHz** for the 1S1/2–3S1/2 and **770 649 350.463 33 MHz** for the 2S1/2–8S1/2 centroid[1] frequencies.

The quantities γ_{zero}^{ref}(H) and $B(\gamma_{zero})^{theo}$, coupled with the experimentally measured hyperfine splitting of the ground state, also define the dimensionless parameter $\tilde{B}$ via [1: eq.6]

---

[1] Experimentally, the centroid value of a transition is often not the measured quantity but is calculated by adding a theoretical or semi-empirical correction to a measured hyperfine transition.

$$(\Delta E)_{n\ell j}^{hfs} = E(n,\ell,j,F) - E(n,\ell,j,F-1) = -E(n,\ell,j) \cdot \frac{2F}{j(j+1)(2\ell+1)I} \cdot Z \cdot \tilde{B}/n$$

For hydrogen, the calculated $\tilde{B}(H)$ is ≈ 0.080 997 276 ppm, yielding **2 922 742 936 720.19 kHz** for the 1S1/2(F=1)–3S1/2(F=1) unperturbed absolute hyperfine transition. The latest optical measurements are 2 922 742 936 722.5(2.8) kHz from Fleurbaey et al. 2018 [7: Table I, data set 2013] and 2 922 742 936 716.72(72) kHz from Grinin et al. 2020 [8: eq.4], deviating from each other by 2.1 combined standard deviations.

Calculation of the dimensionless Lamb shifts *C* through *F* while keeping *B* at its theoretical setting

The method outlined in [1] for empirically modeling the hydrogen spectrum involves six unknown dimensionless energy increments to Dirac energies (E_D) due to additional interactions. By setting variable *A* to zero, thus embedding it within the scaling factor γ_{zero}, and considering variable *B* as a constant, the overdetermined system of coupled equations has four unknowns: namely, *C*, *D*, *E*, and *F.*

For Instance, the constant *B* allows for the explicit determination of the parameter *C* by utilizing the 2P1/2–2S1/2 transition (classical Lamb shift), using

$$\Delta E/\gamma = E_D(2,1/2) \cdot \{1 + B/2\} - E_D(2,1/2) \cdot \{1 + C/2\} \quad (5)$$

Setting $\Delta E = \Delta E_{\mathrm{2P-2S}}^{meas} = 1057.847$ MHz (Table 5), $\gamma = \gamma_{zero}^{ref}(\mathrm{H})$, $B = B(\gamma_{zero})^{theo}$, and solving the simple equation (5) for *C* results in ≈ 0.130 705 ppm for *C*.

Coupled linear relations analogous to equation (5) can be established for the 45 transitions presented in the supplemented Kramida table of hydrogen (Table 5). The parameter *B* always equals $B(\gamma_{zero})^{theo}$, and the scaling factor γ always equals $\gamma_{zero}^{ref}(\mathrm{H})$ of formula (4). Without the 5S1/2–5P3/2 and the 5 pure nS transitions , the supplemented Kramida table of hydrogen yields a set of 36 overdetermined linear equations for the 4 unknowns *C* (nP1/2 states), *D* (nP3/2 states), *E* (nD3/2 states), and *F* (nD5/2 states), which has a rounded least squares solution represented in Table 3.

The mean absolute deviation between 41 calculated and measured transition values from the supplemented Kramida table of hydrogen is approximately 0.93 MHz, not accounting for three nF transitions and the 5S1/2–5P3/2 interval, but including the 5 pure nS transitions. Table 5 itemizes the distinctions. The parameters for the calculation are as specified in Table 3.

Bayer et al. 2017 [9: eq.6] report on a measurement of the 2S1/2(F=0)–4P1/2(F=1) transition with an observed linewidth of 20 MHz, delivering a value of 616 520 152.555(3) MHz. Applying $\tilde{B}(H)$ and the parameters in Table 3 produces 616 520 153.4 MHz. This transition also allows for the explicit calculation of the parameter *C*. The rounded outcome is 0.149 045 ppm, which is a marked deviation from the least squares solution in Table 3 or the figure explicitly derived from the classical Lamb shift via formula (5).

Universality check

For the purposes of this discussion, it is assumed that the dimensionless Lamb shift constants B, C, D, E, and F listed in Table 3 also extend to deuterium (D) and muonium (Mu), exhibiting universal properties for these hydrogen-like systems, meaning that these constants are independent of the nucleus. Thus, spectroscopic differences between H, D, and Mu are entirely contained within the constants γ_{zero} and $\tilde{B}$. Accordingly, determining the scaling factor γ_{zero}^{ref}(atom) and the dimensionless hyperfine constant $\tilde{B}^{ref}$ (atom) for each atom necessitates two experimentally and precisely validated nS transitions (ideally without corrections) that form a linear system of equations with two unknowns.

For example, if 1S1/2(F=1)–2S1/2(F=1) and $\Delta E_{1S1/2}^{hfs}$, or 1S1/2(F=0)–1S1/2(F=1), are the nS reference transitions, the subsequent relations hold:

$$\Delta \mathrm{E}_{1S1/2(F=1)-2S1/2(F=1)} = \gamma_{zero} \cdot \{E(2) - E(1)\} + \left\{\frac{2}{3}E(2) - \frac{4}{3}E(1)\right\} \cdot \frac{3}{16} \cdot \frac{\Delta E_{1S1/2}^{hfs}}{E(1)} \tag{6}$$

$$\tilde{B} = -\frac{3}{16} \cdot \frac{\Delta E_{1S1/2}^{hfs}}{E(1)} \cdot \frac{1}{\gamma_{zero}} \tag{7}$$

Formula (6) implies γ_{zero}, and formula (7) implies $\tilde{B}$. The energy $E(n)$ is defined in (4).

Bound-state QED theory, the natural constants m_e, h, c, as well as the masses[2] of D and Mu, are irrelevant, just as they are with H. Table 4 summarizes the experimental results for H, D and Mu concerning γ_{zero}^{ref}(atom) and $\tilde{B}^{ref}$ (atom).

Table 6 is a replica of the Kramida table for deuterium [1: Table 2], with its most precise transition frequencies serving as a check for universality. Unlike all other transitions, the 1S1/2–2S1/2 transition derived from the hydrogen–deuterium isotope shift of Huber et al. 1998 [19] stands out due to a considerable anomaly. New experimental results are required.

For muonium, there are little data available for verification. Table 7 presents a selection of predictions validated against available experimental data.

For consistency verification, it is essential to experimentally test and confirm all conjectures in this paper with accurate frequency measurements.

---

[2] The model is not suitable for accurately determining nuclear masses because the one-body Dirac equation fundamentally lacks exact solutions for non-stationary nuclei with finite masses. Deriving an exact formula linking nuclear mass M and γ_{zero} is impossible because in an analysis of high accuracy the method of reduced mass is not applicable in the relativistic case.

For Mu, H, and D, the relative deviations of γ_{zero}^{ref} in Table 4 from the estimate $\gamma_{zero} = \left(1 + \frac{m_e}{M}\right)^{-1} \left(\frac{\alpha_{Codata}}{\alpha_{geom}}\right)^2 \frac{m_e c^2}{h}$ defined in [1: eq.4] are 1.0 parts per 10^7, 1.3 parts per 10^8, and 9.7 parts per 10^9, respectively, based on CODATA 2018 [3] values.

References

[1] The Spectra of Hydrogen and Deuterium Interpreted with an Alternative Fine Structure Constant Compared to the Codata Recommended Value.
Hans Peter Good viXra 2411.0170 (2025)

[2] On the Origin of Natural Constants.
Hans Peter Good. De Gruyter Berlin (2018)

[3] CODATA recommended values of the fundamental physical constants (2018).
E Tiesinga et al J Phys Chem Ref Data **50** 033105 (2021)

[4] The nature of intrinsic magnetic dipole moments: what can the famous 21 cm astrophysical spectral line of atomic hydrogen tell us about the nature of magnetic dipoles?
J D Jackson. CERN 77−17 Lecture (1977)

[5] Quantum Mechanics of One− and Two−Electron Atoms.
H A Bethe. E E Salpeter. Springer−Verlag Berlin (1957)

[6] Calculation of the Nuclear Saturation Density.
Hans Peter Good viXra 2112.0111 (2024)

[7] New Measurement of the 1*S*−3*S* Transition Frequency of Hydrogen: Contribution to the Proton Charge Radius Puzzle
H Fleurbaey et al Phys Rev Lett **120** 183001 (2018)

[8] Two−photon frequency comb spectroscopy of atomic hydrogen
A Grinin et al Science **370** 1061 (2020)

[9] The Rydberg constant and proton size from atomic hydrogen
A Beyer et al Science **358** 79 (2017)

[10] Measurement of the Unperturbed Hydrogen Hyperfine Transition Frequency
H Hellwig et al IEEE Trans Instrum Meas **19** 200 (1970)

[11] Atomic Deuterium Maser
D J Wineland and N F Ramsey Phys Rev A **5** 821 (1972)

[12] Measurement of the 1S−2S Energy Interval in Muonium
V Meyer et al Phys Rev Lett **84** 1136 (2000)

[13] High Precision Measurements of the Ground State Hyperfine Structure Interval of Muonium and of the Muon Magnetic Moment
W Liu et al Phys Rev Lett **82** 711 (1999)

[14] Measurement of the transition frequency from 2S1/2, F = 0 to 2P1/2, F = 1 states in Muonium
G Janka et al Nature Communications **13** 7273 (2022)

[15] Measurement of the Lamb Shift in Muonium
C J Oram et al Phys Rev Lett **52** 910 (1984)

[16] Measurement of the Lamb shift in the n = 2 state of muonium
K A Woodle et al Phys Rev A **41** 93 (1990)

[17] Precision Measurement of the Lamb Shift in Muonium
B Ohayon et al Phys Rev Lett **128** 011802 (2022)

[18] Microwave Spectroscopy of the Muonium 2S1/2 − 2P3/2 Fine Structure Interval
P Blumer et al Phys Rev A **113** 012817 (2026)

[19] Hydrogen-Deuterium 1*S*−2*S* Isotope Shift and the Structure of the Deuteron
A Huber et al Phys Rev Lett **80** 468 (1998)

Table 1: Theoretical (exact) and experimental (stochastic) input data.

	value	error	unit	reference	
α	$2^{-6}\pi^{-\frac{2}{3}}$	exact		[2: p.42]	
1S1/2–2S1/2	2 466 061 413.187 03	0.000 01	MHz	Table X, A6	[3]
1S1/2–2S1/2	2 466 061 413.187 01	0.000 01	⋮	**Table X, A7**	[3]
1S1/2–3S1/2	2 922 743 278.659	0.017	⋮	Table X, A8	[3]
1S1/2–3S1/2	2 922 743 278.678	0.013	⋮	Table X, A22	[3]
1S1/2–3S1/2	2 922 743 278.671 5	0.002 6	MHz	Table X, A23	[3]

Table 2: Output values obtained from the input data (Table 1) by means of formula (1) provided in [1]. The least squares solutions $A(\gamma = 1)$ and $B(\gamma = 1)$ were calculated by setting $\gamma = m_e = h = c = 1$. The parameter $B(\gamma_{zero})$ is given by $B(\gamma_{zero}) = B(\gamma = 1) / \gamma_{\text{zero}}$ with $\gamma_{\text{zero}} = 1+A(\gamma = 1)$. The statistical analysis involved 1000 data sets (Table 1) whose five experimental transitions were randomly varied within the error margins.

parameter	mean value(1σ, random)	unit	rel. std. uncert.
γ_{zero}	1.239 352 998 270(25) x 10^{20}	Hz	2.0 x 10^{-11}
$B(\gamma_{\text{zero}})$	**−2.443 049(17)**	**ppm**	7.1 x 10^{-6}
mean abs. dev. of the 5 data sets	0.0048(24)	MHz	
Lamb shift $\mathcal{L}(1S1/2)$	8 032.976(57)	MHz	7.1 x 10^{-6}
Ionization	3 288 086 857.911(9)	MHz	2.9 x 10^{-12}

Table 3: Rounded least squares solution using 36 input data of the supplemented Kramida table of hydrogen (Table 5) and keeping the parameter B (≈ −2.443 049 ppm) fixed. The scaling factor γ_{zero}^{ref}(H) is set by the energy difference ΔE_{1S-2S}^{meas} (H) via formula (4).

parameter	rounded least squares solution $A = 0\ and\ B = B(\gamma_{zero})^{theo}$	unit
C	**0.132 178**	ppm
D	**−0.023 840**	ppm
E	**0.024 750**	ppm
F	**−0.026 072**	ppm

Table 4: Results for H, D and Mu concerning γ_{zero}^{ref}(atom) and $\tilde{B}^{ref}$(atom).

	I	γ_{zero} (Hz)/10^{20}		$\tilde{B}/10^{-6}$	
H	1/2	1.239 352 998 270 74	1)	0.080 997 275 913 1035	2)
D	1	1.239 690 221 548 82	3)	0.024 884 933 918 2199	4)
Mu	1/2	1.234 059 759 837 89	5)	0.255 607 250 827 316	5)

Experimental references:

	reference transition	frequency (MHz)	reference
1)	1S1/2–2S1/2	2 466 061 413.18701	[3: Table X, A7]
2)	1S1/2(F=0)–1S1/2(F=1)	1 420.405 751 768	[10]
3)	2S1/2–8S1/2	770 859 041.246	[3: Table X, A13]
4)	1S1/2(F=1/2)–1S1/2(F=3/2)	327.384 352 5222	[11]
5)	1S1/2(F=1)–2S1/2(F=1)	2 455 527 964.6	[12: Table I]
	1S1/2(F=0)–1S1/2(F=1)	4 463.302 765	[13: eq.9]

Table 5: A replica of the supplemented Kramida table of hydrogen [1: Table 1], with measured values used to derive parameters *C*, *D*, *E*, and *F* of Table 3, while parameter *B* remained constant at $B(\gamma_{zero})^{theo}$. Column diff (MHz) displays the differences between observed and predicted frequencies, of which 71% are negative.

interval		measured value (MHz)	unc. (MHz)	diff (MHz)
1S1/2–2S1/2		2466061413.187074	0.000034	0.0
2P1/2–2S1/2		1057.847	0.09	−0.6
2P1/2–2P3/2		10969.13	0.1	0.5
2S1/2–2P3/2		9911.201	0.012	1.0
2P1/2–3D3/2		456685852.8	1.7	−1.6
2S1/2–3P1/2		456681549.9	0.3	−2.0
2S1/2–3P3/2		456684800.1	0.3	−1.8
2P3/2–3D5/2		456675968.3	3.4	−0.6
2S1/2–4P1/2		616520017.568	0.015	−0.8
2S1/2–4S1/2		616520150.636	0.01	−0.1
2S1/2–4P3/2		616521388.672	0.01	−0.8
2S1/2–4D5/2		616521843.441	0.024	−0.5
2S1/2–6S1/2		730690017.097	0.021	−0.5
2S1/2–6D5/2		730690518.592	0.011	−0.7
2S1/2–8S1/2		770649350.012	0.09	−0.5
2S1/2–8D3/2		770649504.45	0.08	−0.5
2S1/2–8D5/2		770649561.584	0.06	−0.5
2S1/2–10D5/2		789144886.411	0.039	−0.6
2S1/2–12D3/2		799191710.473	0.09	−0.6
2S1/2–12D5/2		799191727.404	0.07	−0.6
3P1/2–3S1/2		314.818	0.048	1.2
3P1/2–3D3/2		3244.9	3.1	0.8
3S1/2–3P3/2		2933.5	1.2	−2.9
3S1/2–3D3/2		2929.9	0.8	−0.6
3S1/2–3D5/2		4013.155	0.048	−0.4
3D3/2–3P3/2		5.5	0.9	−0.4
3D3/2–3D5/2		1083	0.29	−0.1
3P3/2–3D5/2		1078	1.1	0.8
4P1/2–4S1/2		133.2	0.6	0.9
4P1/2–4P3/2		1370.85	0.22	−0.2
4P1/2–4D3/2		1371.1	1.2	2.5
4S1/2–4D3/2		1235	2.1	−1.3
4S1/2–4P3/2		1237.79	0.29	−1.0
4S1/2–4D5/2		1693	0.4	−0.2
4D3/2–4F5/2	not used	456.8	1.6	
4D3/2–4D5/2		458	2.2	1.0
4P3/2–4D5/2		455.7	1.6	1.2
4D5/2–4F7/2	not used	227.96	0.41	
5P1/2–5S1/2		64.6	5	−3.1
5P1/2–5D3/2		704	7	3.3
5S1/2–5P3/2	not used	622	10	
5P3/2–5D5/2		232.2	2.9	−0.5
5D5/2–5F7/2	not used	117	1.5	
1S1/2–3S1/2		2922743278.678	0.013	0.0
2S1/2–8D5/2		770649561.5709	0.02	−0.5

Table 6: A replica of of the Kramida table of deuterium [1: Table 2] to test the universality of the parameters *B* to *F* of Table 3 for deuterium. Column diff (MHz) displays the differences between observed and predicted frequencies.

interval		measured value (MHz)	unc. (MHz)	diff (MHz)
1S1/2–2S1/2		2466732407.52171	0.00015	**−11.7**
2P1/2–2S1/2		1059.28	0.06	0.5
2S1/2–2P3/2		9912.61	0.3	−0.3
2P1/2–3D3/2		456810113.8	0.19	−3.1
2S1/2–3P1/2		456805811.7	0.3	−1.5
2S1/2–3P3/2		456809062.6	0.3	−1.5
2P3/2–3S1/2		456796251	30	
2P3/2–3D5/2		456800225.9	1.6	−2.8
2P1/2–4D3/2		616690180	40	
2S1/2–4P1/2		616687769.99	0.19	−1.2
2S1/2–4S1/2		616687903.573	0.02	**0.05**
2S1/2–4P3/2		616689141.73	0.17	−0.9
2S1/2–4D5/2		616689596.72	0.4	−0.5
2P3/2–4D5/2		616679760	50	
2P1/2–5D3/2		690691810	50	
2P3/2–5D5/2		61681100	70	
2P1/2–6D3/2		730890320	60	
2P3/2–6D5/2		730879480	80	
2P1/2–7D3/2		755128600	60	
2P3/2–7D5/2		755117710	50	
2P1/2–8D3/2		770860360	210	
2S1/2–8S1/2	reference	770859041.246	0.07	**0.00**
2S1/2–8D3/2		770859195.702	0.006	−0.1
2S1/2–8D5/2		770859252.850	0.06	−0.1
2P3/2–8D5/2		770849570	210	
2P1/2–9D3/2		781645760	300	
2P3/2–9D5/2		781634790	300	
2S1/2–10D5/2		789359610.238	0.038	−0.1
2S1/2–12D3/2		799409168.038	0.09	−0.1
2S1/2–12D5/2		799409184.967	0.07	−0.1
3P1/2–3S1/2		315.3	0.4	1.6
3P1/2–3P3/2		3250.7	1	
3S1/2–3P3/2		2934.5	5	
3D3/2–3P3/2		5	5	
4P1/2–4S1/2		133	5	
4P1/2–4P3/2		1371.8	0.3	0.3

Table 7: Universality test of the parameters *B* to *F* of Table 3 for muonium.

interval	calculated (MHz)	measured (MHz)	ref
2S1/2(F=0)–2S1/2(F=1)	557.9	559.6 (7.2)	[14: Table 2]
2P1/2(F=1)–2S1/2(F=0)	589.0	580.6 (6.8)	[14: Table 2]
2P1/2–2S1/2	1053.9	1070+12−15	[15]
		1042+21−23	[16]
		1045.5 (6.8)	[14: Table 2]
		1047.2 (2.3)stat (1.1)syst	[17]
2S1/2–2P3/2	9867.9	9871.0 (7.0)	[18]
1S1/2–2S1/2	2 455 528 940.9	2 455 528 941.0(9.8)	[12: Table I]
Mu–D isotope shift $\Delta\nu_{1S2S}$	11 203 478.3	11 203 456.2(13.1)	[12]
3S1/2–3D5/2	3996.4	no data	
1S1/2–3S1/2	2 910 260 332.3	no data	
2S1/2–8D5/2	767 358 141.6	no data	