Hydrogen and Antihydrogen spectra in presence of external fields

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    D. Solovyev, V. Sharipov, L. Labzowsky and G. Plunien, J. Phys. B **43**, 074005 (2010).
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  - Level widths: $\Gamma_{\overline{ns}} = \sum_{k=1}^{n-1} W^{(1\gamma)}_{\overline{ns}\,\overline{ks}}$ (to be published).
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- Conclusions

L. Labzowsky and V. Sharipov, Phys. Rev. A **71**, 012501 (2005).

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Motivation

- Experiments of highest order of accuracy for the hydrogen atom two-photon transitions 2s-1s and 3s-1s, 3d-1s

  D. Arnoult. F. Nez, L. Julien and F. Biraben, Eur. Phys. J. D 60, 243 (2010); C. G. Parthey et al., Phys. Rev. Lett. 107, 203001 (2011); E. Peters et al., Ann. Phys. (Berlin), 1-6 (2013).

- Recent experimental successes on the synthesis of antihydrogen atoms

  The ALPHA Collaboration, Nature Physics 7, 558-564 (2011). $\sim 1000s$ of anti-H atom

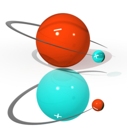
- Signals for CPT and Lorentz violation may arise in hydrogen and antihydrogen spectroscopy

  R. Bluhm, V. A. Kostelecky and H. Russel, Phys. Rev. Lett. 82, 2254 (1999).

- Gravity measurements: P. Hamiltonet et al., Phys. Rev. Lett. **112**, 121102 (2014)

- CP invariance violation to explain baryon asymmetry in the universe

  A. D. Sakharov, Pis'ma Zh. Eksp. Teor. Fis. 5, 32-35 (1967) [JETP Lett. 5, 24-27 (1967)].



Static electric field: 2s-2p mixing

Ya. I. Azimov et al., Sov. Phys.JETP **40**, 8 (1975) (Engl. Transl.); P. J. Mohr, Phys. Rev. Lett. **40**, 854856 (1978)

$$|\overline{2s}m_s\rangle = |2sm_s\rangle + \eta\sum_{m_p}\langle 2pm_p|e\mathbf{D}\mathbf{r}|2sm_s\rangle|2pm_p\rangle,\ \ \eta = (\Delta E_L + i\Gamma_{2p}/2)^{-1}. \quad (1)$$

Then in Pauli approximation:

$$U^P_{A'A}(\mathbf{k},\,\mathbf{e}) = \left((\mathbf{e}\hat{\mathbf{p}} + i\mathbf{e}\left[\mathbf{k}\times\mathbf{s}\right])\,e^{-i\mathbf{k}\mathbf{r}}\right)_{A'\,A}, \quad (2)$$

$$W^{(1\gamma)}_{A'A} = \frac{e^2\omega_{AA'}}{2\pi}\sum_{\mathbf{e}}\int d\mathbf{n_k}\left|U^P_{A'A}(\mathbf{k},\,\mathbf{e})\right|^2,\ \ ns\to 1s + 1\gamma(M1). \quad (3)$$

In the presence of an external electric field $\overline{ns}\to 1s + 1\gamma(E1)$ decay channel:

$$U^P_{\overline{2s}m_s,\,1sm'_s}(\mathbf{k},\,\mathbf{e}) = U^P_{2sm_s,\,1sm'_s}(\mathbf{k},\,\mathbf{e}) + \eta\sum_{m_p}\langle 2sm_s|e\mathbf{D}\mathbf{r}|2pm_p\rangle\,U^P_{2pm_p,\,1sm'_s}(\mathbf{k},\,\mathbf{e}). \quad (4)$$

$$dW^{(1\gamma)}_{\overline{2s}\,1s}(\mathbf{n_k}) = \frac{3}{8\pi}dW^{(1\gamma)}_{2s\,1s}(\mathbf{n_k})\left[1 + eD(\mathbf{n_D}\mathbf{n_k})\frac{\Gamma_{2p}}{w\Delta^2} + \frac{e^2D^2}{w^2\Delta^2}\right]d\mathbf{n_k}. \quad (5)$$

$$\Delta = \sqrt{\Delta E_L^2 + \frac{1}{4}\Gamma^2_{2p}},\ \ w = \sqrt{\frac{W^{(1\gamma)}_{2s\,1s}}{W^{(1\gamma)}_{2p\,1s}}}. \quad (6)$$

Static electric field: 2s-2p mixing

$$dW_{\overline{2s}\,1s} = W_0\left[1 \mp \beta(D)\mathbf{n_D}\mathbf{n_k}\right],\;\; W_0 = \frac{3}{8\pi} dW^{(1\gamma)}_{2s\,1s}\left(1 + \frac{e^2D^2}{(w\Delta)^2}\right), \tag{7}$$

$$\beta(D) = \frac{|e|D\Gamma_{2p}w}{(w\Delta)^2 + e^2D^2}. \tag{8}$$

The maximum value of $\beta(D)$ is

$$D_{\max} = \frac{w\Delta}{|e|},\;\; \beta_{\max} = \frac{\Gamma_{2p}}{2\Delta} \approx \frac{\Gamma_{2p}}{2\Delta E_L} \approx \frac{1}{20}. \tag{9}$$

The relative difference for the H and $\bar{H}$ atoms at $D_{\max}$

$$\frac{dW^{(1\gamma)}_{\overline{2s}\,1s}(H)}{dW^{(1\gamma)}_{2s\,1s}} - \frac{dW^{(1\gamma)}_{\overline{2s}\,1s}(\bar{H})}{dW^{(1\gamma)}_{2s\,1s}} = \frac{W_0(D_{\max})2\beta(D_{\max})}{\frac{3}{8\pi}W^{(1\gamma)}_{2s\,1s}}\mathbf{n_D}\mathbf{n_k} \approx \frac{1}{5}\mathbf{n_D}\mathbf{n_k}. \tag{10}$$

The formal T-noninvariance of the factor $\mathbf{n_D}\mathbf{n_k}$ ($\mathbf{n_k}$ and $\mathbf{n_D}$ are T-odd and T-even vectors, respectively) is compensated by the dependence on Γ_{2p}: Ya. B. Zeldovich, Sov. Phys. JETP **12**, 1030 (1961) (Engl. Transl.).

However, theoretical analysis of the influence of an external electric field on the Rydberg states is also required: The ALPHA Collaboration, Nature Physics **7**, 558-564 (2011).

Static electric field: Rydberg states mixing

The same procedure for the *ns* states in hydrogen

$$|\overline{ns}m_s\rangle = |nsm_s\rangle + \eta_n \sum_{m_p} \langle npm_p|e\mathbf{D}\mathbf{r}|nsm_s\rangle |npm_p\rangle, \quad (11)$$

$\eta_n = (\Delta E^{(n)}_{L(f)} + i\Gamma_{np}/2)^{-1}$, $\Delta E^{(n)}_{L(f)}$ is the Lamb shift (fine structure splitting) of the *n*sth state, Γ_{np} is the level width.

$$U^P_{\overline{ns}m_s,\,\overline{ks}m'_s}(\mathbf{k},\,\mathbf{e}) = U^P_{nsm_s,\,ksm'_s}(\mathbf{k},\,\mathbf{e}) + \quad (12)$$

$$\eta_n \sum_{m_p} \langle nsm_s|e\mathbf{D}\mathbf{r}|npm_p\rangle U^P_{npm_p,\,ksm'_s}(\mathbf{k},\,\mathbf{e}) + \eta_k \sum_{m_p} \langle kpm_p|e\mathbf{D}\mathbf{r}|ksm'_s\rangle U^P_{nsm_s,\,kpm_p}(\mathbf{k},\,\mathbf{e}).$$

$$dW^{(1\gamma)}_{\overline{ns}\,\overline{ks}}(\mathbf{n_k}) = \frac{3}{8\pi} dW^{(1\gamma)}_{ns\,ks}(\mathbf{n_k}) \left[1 - (-1)^{\frac{1}{2}+j_p} eD(\mathbf{n_D}\mathbf{n_k}) \frac{n\sqrt{n^2-1}}{2\sqrt{3}} \frac{\Gamma_{np}}{w_1\Delta_1^2} \right. \quad (13)$$

$$\left. -(-1)^{\frac{1}{2}+j_p} eD(\mathbf{n_D}\mathbf{n_k}) \frac{k\sqrt{k^2-1}}{6} \frac{\Gamma_{kp}}{w_2\Delta_2^2} + \frac{e^2D^2}{w_1^2\Delta_1^2} \frac{n^2(n^2-1)}{12} + \frac{e^2D^2}{w_2^2\Delta_2^2} \frac{k^2(k^2-1)}{36} \right] d\mathbf{n_k},$$

$$\Delta_1 = \sqrt{\left(\Delta E^{(n)}_{L(f)}\right)^2 + \frac{1}{4}\Gamma^2_{np}},\ \Delta_2 = \sqrt{\left(\Delta E^{(k)}_{L(f)}\right)^2 + \frac{1}{4}\Gamma^2_{kp}},\ w_1 = \sqrt{\frac{W^{(1\gamma)}_{ns\,ks}}{W^{(1\gamma)}_{np\,ks}}} \text{ and } w_2 = \sqrt{\frac{W^{(1\gamma)}_{ns\,ks}}{W^{(1\gamma)}_{ns\,kp}}}. \quad (14)$$

Static electric field: Rydberg states mixing

Therefore,

$$dW^{(1\gamma)}_{\overline{ns}\,\overline{ks}} = \frac{3}{8\pi} dW^{(1\gamma)}_{ns\,ks} \left(1 + e^2 D^2 a^2\right) \left[1 \pm (-1)^{\frac{3}{2}+j_p} \frac{eDb(\mathbf{n_D n_k})}{1 + e^2 D^2 a^2}\right], \tag{15}$$

where a and b are defined as

$$a^2 = \frac{n^2(n^2-1)}{12 w_1^2 \Delta_1^2} + \frac{k^2(k^2-1)}{36 w_2^2 \Delta_2^2}, \quad b = \frac{n\sqrt{n^2-1}}{2\sqrt{3}} \frac{\Gamma_{np}}{w_1 \Delta_1^2} + \frac{k\sqrt{k^2-1}}{6} \frac{\Gamma_{kp}}{w_2 \Delta_2^2}. \tag{16}$$

Then the relative difference for the H and $\bar{H}$ atoms at $eD_{\max} = 1/a$

$$\delta(D_{\max}) = \frac{dW^{(1\gamma)}_{\overline{ns}\,\overline{ks}}(H) - dW^{(1\gamma)}_{\overline{ns}\,\overline{ks}}(\bar{H})}{\frac{3}{8\pi} W^{(1\gamma)}_{ns\,ks} \left(1 + e^2 D^2 a\right)} = (-1)^{\frac{3}{2}+j_p} (\mathbf{n_D n_k}) \frac{b}{a} \tag{17}$$

$$= (-1)^{\frac{3}{2}+j_p} (\mathbf{n_D n_k}) \frac{\frac{n\sqrt{n^2-1}\Gamma_{np}}{2\sqrt{3} w_1 \Delta_1^2} + \frac{k\sqrt{k^2-1}\Gamma_{kp}}{6 w_2 \Delta_2^2}}{\sqrt{\frac{n^2(n^2-1)}{12 w_1^2 \Delta_1^2} + \frac{k^2(k^2-1)}{36 w_2^2 \Delta_2^2}}} \approx (\mathbf{n_D n_k}) \frac{\Gamma_{np}}{\Delta E_L^{(n)}}$$

with the account for $\Gamma_{np} \ll \Delta E_L^{(n)} \ll \Delta E_f^{(n)}$, $\Delta_1(j_p = 1/2) \ll \Delta_1(j_p = 3/2)$.

Static electric field: Rydberg states mixing

Numerical results for the electric field magnitude $D_{\max}$ and 500 V/m. The last magnitude of the electric field is associated with the experimental value.

n	k	$D_0^{\max}$, V/m	$\delta(D_{\max})$ V/m	$\delta(D)$ at $D = 500$ V/m
2	1	0.005	0.094	$1.97 \cdot 10^{-6}$
3	1	0.0009	0.087	$3.14 \cdot 10^{-7}$
3	2	0.0001	0.094	$3.77 \cdot 10^{-8}$
4	1	0.0002	0.097	$7.94 \cdot 10^{-8}$
4	2	0.00003	0.098	$1.18 \cdot 10^{-7}$
4	3	$5.9 \cdot 10^{-6}$	0.11	$2.60 \cdot 10^{-9}$
100	1	$1.6 \cdot 10^{-11}$	0.099	$6.33 \cdot 10^{-15}$
100	2	$4.2 \cdot 10^{-11}$	0.099	$1.65 \cdot 10^{-14}$
100	3	$7.2 \cdot 10^{-11}$	0.099	$2.85 \cdot 10^{-14}$

The linear in the field term is proportional to the electron (positron) charge and, therefore, has the opposite sign for the H and $\bar{H}$ atoms. Thus, the linear in the field summand produces the difference for the differential (depending on the photon emission directions, here $(\mathbf{n_D n_k}) = 1$) transition probabilities. The linear dependence vanishes in the total decay rate. However, the measurements of the differential quantities are closer to the experimental situation where the photon emission is detected in certain angles.

Static electric field: Level widths

The total transition probability of the partial decay channel $\overline{ns} \to \overline{ks} + 1\gamma$

$$W^{(1\gamma)}_{\overline{ns}\,\overline{ks}} = W^{(1\gamma)}_{ns\,ks} + \frac{e^2 D^2}{\Delta_1^2}\frac{n^2(n^2-1)}{12} W^{(1\gamma)}_{np\,ks} + \frac{e^2 D^2}{\Delta_2^2}\frac{k^2(k^2-1)}{36} W^{(1\gamma)}_{ns\,kp} \tag{18}$$

$$\Gamma_{\rm tot} = \Gamma_{ns} + \Gamma_{\overline{ns}} = \sum_{k=1}^{n-1} W^{(1\gamma)}_{ns\,kp} + \sum_{k=1}^{n-1} W^{(1\gamma)}_{\overline{ns}\,\overline{ks}}, \tag{19}$$

Γ_{ns} is the natural width and $\Gamma_{\overline{ns}}$ - the additional decay channels.

$\Gamma_{\overline{ns}}$ as a function of n can be defined with $W^{(1\gamma)}_{np\,ks} \sim \frac{W^{(1\gamma)}_{2p\,1s}}{k^3 n^3}$, $W^{(1\gamma)}_{ns\,kp} \sim \frac{W^{(1\gamma)}_{3s\,2p}}{k^3 n^3}$, $\Delta E^{(n)}_{L(f)} \sim \frac{\Delta E^{(2)}_{L(f)}}{n^3}$.

$$\Gamma_{\overline{ns}} \sim \sum_{k=1}^{n-1} e^2 D^2 \frac{n^2(n^2-1)}{12k^3} + \sum_{k=1}^{n-1} e^2 D^2 \frac{k^2(k^2-1)}{36 n^3}. \tag{20}$$

Application of Eq. (11) should obey

$$\left| \frac{\langle np | e\mathbf{D}\mathbf{r} | ns \rangle}{\Delta E^{(n)}_{L(f)} + i\Gamma_{np}/2} \right| < 1 \;\Rightarrow D^{(n)}_c \sim \frac{1}{n^5}. \tag{21}$$

Such scale for $\mathbf{D_c}$ is known as **Inglis-Teller limit** T. F. Gallagher, *Rydberg Atoms*, Cambridge University Press, Cambridge 1994.

Static electric field: Level widths

Numerical results: the field strength $D_c^{(n)}$.

Table 2: the contribution of quadratic in the field terms Eq. (18) depending on the value of principal quantum numbers n and k; $W^{(1\gamma)}_{ns\,ks}$, $W^{(1\gamma)}_{ns\,kp}$, $W^{(1\gamma)}_{np\,ks}$ and $W_n \equiv \frac{n^2(n^2-1)}{12\Delta_1^2} e^2 D_c^2 W^{(1\gamma)}_{np\,ks}$, $W_k \equiv \frac{k^2(k^2-1)}{36\Delta_2^2} e^2 D_c^2 W^{(1\gamma)}_{ns\,kp}$ in s^{-1}; the Lamb shift $\Delta E_L^{(n)}$ in MHz.

n	k	$W^{(1\gamma)}_{ns\,ks}$	$W^{(1\gamma)}_{ns\,kp}$	$W^{(1\gamma)}_{np\,ks}$	$\Delta E_L^{(n)}$	Γ_{np}	Γ_{ns}	W_n	W_k
2	1	2.495[−6]	—	6.265[8]	1057.911	6.265[8]	8.229	2.063[8]	0
3	1	1.109[−6]	—	1.672[8]	344.896	1.897[8]	6.314[6]	5.394[6]	0
3	2	1.877[−9]	6.314[6]	2.245[7]	344.896	—	—	7.2398[6]	1.2021[5]
4	1	5.303[−7]	—	6.819[7]	133.084	8.092[7]	4.414[6]	2.771[7]	0
4	2	1.617[−9]	2.578[6]	9.668[6]	133.084	—	—	3.929[6]	276.37
4	3	2.047[−11]	1.836[6]	3.065[6]	133.084	—	—	1.246[6]	1.111[4]
100	1	3.949[−11]	—	4.185[3]	1.058[−3]	≈ 5.25[3]	≈ 0.324[3]	6.371[3]	0
100	2	2.033[−13]	153.31	613.19	1.058[−3]	—	—	933.7	1.077[−17]
100	3	9.195[−15]	101.105	206.37	1.058[−3]	—	—	314.2	4.011[−16]
100	4	—	66.866	96.728	1.058[−3]	—	—	147.	5.937[−15]
100	5	—	46.506	54.171	1.058[−3]	—	—	82.48	3.989[−14]
100	6	—	33.856	33.896	1.058[−3]	—	—	51.61	1.821[−13]
100	7	—	25.580	22.877	1.058[−3]	—	—	34.84	6.474[−13]
100	8	—	19.916	16.311	1.058[−3]	—	—	24.84	1.925[−12]
100	9	—	15.890	12.123	1.058[−3]	—	—	18.46	5.005[−12]
100	10	—	12.938	9.3092	1.058[−3]	—	—	14.17	6.225[−12]

The field strength is defined as $D_c \sim 475 \cdot 2^5/n^5$ V/cm, where 475 V/cm corresponds to the absolute mixing of $2s$ and $2p$ states. For the $n = 100$ $D_c \approx 3.8 \cdot 10^{-7}$ V/cm. The values of the one-photon decay rates:

O. Jitrik and C. F. Bunge, J. Phys. Chem. Ref. Data **33**, 1059 (2004).
W. L. Wiese and J. R. Fuhr, J. Phys. Chem. Ref. Data **38**, 565-726 (2009).
A. M. Puchkov and L. N. Labzovskii, Optics and Spectroscopy **106**, 153-157 (2009).

Static electric field: Level width $n = 55$

Numerical results: the field strength $D_c = 3.02 \cdot 10^{-5}\ V/cm$.

The induced transition probability as a function of k. It is shown that mixing of the lower state becomes significant for the transitions between nearest atomic levels. In Table 3 notations are the same as in Table 2.

n	k	$W^{(1\gamma)}_{ns\ ks}$	$W^{(1\gamma)}_{ns\ kp}$	$W^{(1\gamma)}_{np\ ks}$	W_1	W_2
55	1	2.37202[−10]	—	2.5158[4]	1.104[4]	—
55	2	1.21907[−12]	921.77	3.6859[3]	1.617[3]	4.091[−13]
55	3	5.49996[−14]	608.11	1.2404[3]	544.3	1.524[−11]
55	4	—	402.39	581.47	255.2	2.257[−10]
55	5	—	280.06	325.7	142.9	1.517[−9]
55	6	—	204.06	203.86	89.46	6.931[−9]
55	7	—	154.33	137.64	60.41	2.467[−8]
55	8	—	120.3	98.19	43.09	7.346[−8]
55	9	—	96.111	73.028	32.05	1.912[−7]
55	10	—	78.372	56.12	24.63	4.482[−7]
55	15	—	35.0001	20.657	9.066	1.161[−5]
55	30	—	8.7556	4.05	1.777	2.984[−3]
55	40	—	5.2734	2.2317	0.979	0.0319
55	45	—	4.5069	1.8316	0.804	0.0886
55	50	—	4.2245	1.6413	0.721	0.238
55	54	—	4.4807	1.6496	0.724	0.546

$\boldsymbol{\Gamma_{55p} \approx 3.2 \cdot 10^4}\ s^{-1}$, $\boldsymbol{\Gamma_{55s} \approx 6.5 \cdot 10^3}$ and $\boldsymbol{\Delta E_L^{(n=55)}} \approx \mathbf{50.9}\ kHz$. Then $\boldsymbol{\Gamma_{\overline{55s}} \approx 1.4 \cdot 10^4}\ s^{-1}$.

$$\Gamma_{\overline{ns}} \approx \sum_{k=1}^{n-1} \frac{e^2 D^2}{\Delta_1^2} \frac{n^2(n^2-1)}{12} W^{(1\gamma)}_{np\ ks} + \sum_{k=1}^{n-1} \frac{e^2 D^2}{\Delta_2^2} \frac{k^2(k^2-1)}{36} W^{(1\gamma)}_{ns\ kp}.$$

Second term becomes important for the transitions between neighboring states.

The fields of the order of $D_c^{(n)}$ can be attributed to the casual fields, the strict control of fields is required.

Magnetic field: 21 cm absorption/emission line

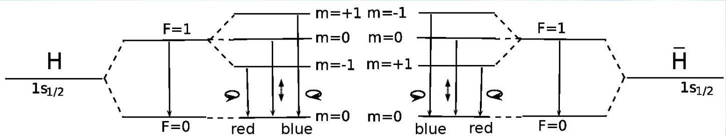
Circular polarizations of H and $\bar{H}$ atoms.
L. Labzowsky and V. Sharipov, Phys. Rev. A **71**, 012501 (2005),
D. Solovyev and L. Labzowsky, Prog. Theor. Exp. Phys., 111E01 (2014).

$$\langle n\,F\,M_F|(\vec{e}[\vec{k}\times\vec{\mu}])|n\,F'\,M_{F'}\rangle = \sum_q (-1)^q[\vec{e}\times\vec{k}]_{-q}\langle n\,F\,M_F|\mu_q|n\,F'\,M_{F'}\rangle.$$

Associating the photon emission direction with the z-axis

$$\langle n\,1\,M_F|(\vec{e}[\vec{k}\times\vec{\mu}])|n\,0\,0\rangle = \left(-i\sqrt{\frac{2}{3}}\right)(-1)^{M_F}\sum_r C^{1\,-M_F}_{1r\,10}\,e_r k_0\langle n\frac{1}{2}||\mu^1||n\frac{1}{2}\rangle,$$

$$\vec{\mu} = \mu_0(\vec{l}+2\vec{s}),\ \ \mu_0 = \frac{e\hbar}{2c\,m_e}.$$



$C^{1\,-M_F}_{1r\,10} \neq 0$ for $r = -M_F$. Thus the circular polarization with $r = \pm 1$ (clockwise and anticlockwise) $\to M_F = \mp 1$ lower and upper hyperfine sublevels in hydrogen, respectively.
The Zeeman energy splitting is defined as $\mu_0 g M_F H$, H is the magnetic field $\Rightarrow$ opposite signs at the fixed field direction.

Magnetic field: 21 cm absorption/emission line

Linear polarizations of H and $\bar{H}$ atoms: Faraday rotation.

Faraday rotation: the rotation of the plane of linear polarization around the direction of the light propagation.

The linear polarization corresponds to the transition $n\,1\,0 \to n\,0\,0$ ($M_F = 0$).

$$\langle n\,1\,0|(\vec{e}[\vec{k} \times \vec{\mu}])|n\,0\,0\rangle \sim C^{1\,0}_{1r\,1s} e_r k_s .$$

The polarization plane of the central component rotates around the direction of the light propagation in opposite directions in H and $\bar{H}$ atoms. Thus the Faraday effect on this central line can be also used to distinguish between H and $\bar{H}$ atoms provided that the direction of the external magnetic field is known.

The high-resolution observations of Zeeman absorption in HI region toward the radio sources:

D. A. Roberts, H. R. Dickel and W. M. Goss, Astrophys. J. **476**, 209-220 (1997),
A. M. Wolfe, R. A. Jorgenson, T. Robishaw, C. Heiles and J. X. Prochaska, Astrophys. J. **733**, 24 (2011).

The Faraday rotation of the plane of linear polarization for the 21 cm absorption line (not for the search of $\bar{H}$)
A. M. Wolfe, R. A. Jorgenson, T. Robishaw, C. Heiles and J. X. Prochaska, Nature **455**, 638 (2008).

The magnetic fields can be measured also for the galaxies at high redshifts

M. L. Bernet, F. Miniati, S. J. Lilly, P. P. Kronberg and M. DessaugesZavadsky. Nature **454**, 302-304 (2008).

Thus, in principle, observations of the 21 cm absorption line profile can be used as a tool for the search of anti-matter in universe.

Conclusions

- The mixing of *ns* and *np* states in the electric field was described analytically.
- Such mixing leads to the linear dependence on the field in differential transition probability
- The casual electric field can trigger significant changes in spectra of H and $\bar{H}$ atoms
- Quadratic in the field terms lead to a essential increase of the level width
- Presence of a magnetic field leads to the opposite polarizations in the wings of the 21 cm line
- Faraday rotation of the linear polarized component in 21 cm line has opposite direction for the H and $\bar{H}$ atoms
- In principle, observations of the 21 cm absorption line profile can be used as a tool for the search of anti-matter in universe.

Thank you for the attention

Hydrogen and Antihydrogen spectra in presence of external fields

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