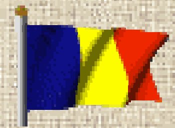
I.

VIolation of the Pauli (VIP) exclusion principle experiment

II.

Personal considerations about Pauli principle and electron spin

VIP Collaboration:

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Scientific goal of VIP:

The VIP experiment aims to reduce the limits on possible violations of the Pauli exclusion principle for electrons by four orders of magnitude.

From…

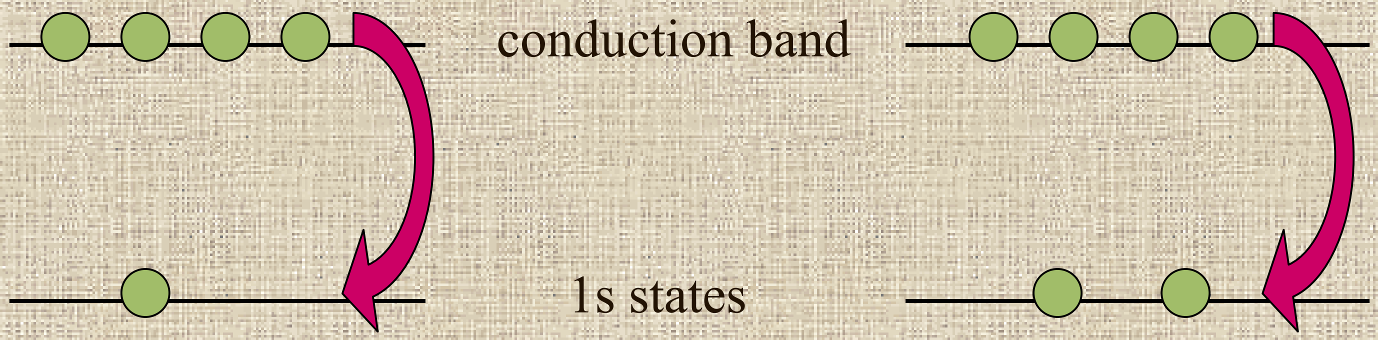
$$\beta^2 / 2 \le 1.7 \cdot 10^{-26} (> 95\% \; C.L.)$$

…to

$$\beta^2 / 2 \le 10^{-30} (> 95\% \; C.L.)$$

Experimental method:

Search for Pauli-violating X-ray transitions



Normal K edge transition   Pauli-violating K edge transition

Experimental signature of the anomalous" X-ray transitions: energy shift due to the extra-electron shielding. E.g., K edge moves from 8979 to 8566 eV.

2 CCD test setup February 2005

Interest in experimental test of the Pauli principle for electrons:

O.W. Greenberg: AIP Conf.Proc.545:113-127,2004

"Possible external motivations for violation of statistics include: (a) violation of CPT, (b) violation of locality, (c) violation of Lorentz invariance, (d) extra space dimensions, (e) discrete space and/or time and (f) noncommutative spacetime. Of these (a) seems unlikely because the quon theory which obeys CPT allows violations, (b) seems likely because if locality is satisfied we can prove the spin-statistics connection and there will be no violations, (c), (d), (e) and (f) seem possible………

"More recently … membrane theorists have been speculating on a large compactification radius for one of their eleven dimensions, which could give a ratio (for PEP violation) of 10^{-30}" [1]

[1] I. Duck and E. C. G. Sudarshan: Towards an understanding of the spin-statistics theorem, Am. J. Phys, 66 (1998) 284.

History of PP

1) A.H. Compton, J. Franklin Inst.. **192**, 145 (1921) – "The magnetic electron"

2) E.C. Stoner, Phil. Mag. **38**, 749 (1924) – "…double the inner quantum numbers…"

3) W. Pauli, Zeits. f. Phys. **31**, 765 (1925) – The General Rule:
"There can never be two or more equivalent electrons in an atom"

4) G.E. Uhlenbeck, and S. Goudsmith, Nature **117**, 264 (1926) – "…electron spin…"

5) P.A.M. Dirac, Proc. Roy. Soc. **A112**, 661 (1926) – "Wave function antisymmetrization"

6) P.A.M. Dirac, Proc. Roy. Soc. **A114**, 243 (1927) – "Quantum theory of radiation"

7) P. Jordan, and E. Wigner, Zeits. f. Phys. **47**, 631 (1928) – "On the PEP"

8) P.A.M. Dirac, Proc. Roy. Soc. **A117**, 610 (1928), **A126**, 360 (1930) – "Dirac equation"

9) M. Fierz, Helv. Phys. Acta **12**, 3 (1939) – "Force-free particles for arbitrary spin"

10) F. Belinfante, Physica VI **9**, 870 (1939) – "Spin-statistics from C-invariance"

11) J.S. de Wet, Phys. Rev. **57**, 646 (1940) – "Connection between spin and statistics"

12) W. Pauli, Phys. Rev. **58**, 716 (1940) – "Connection between spin and statistics"

PP in 4D space-time: Dirac equation

$$\left(\alpha_0 mc^2 + \sum_{j=1}^{3} \alpha_j p_j \, c\right) \psi(\mathbf{x}, t) = i\hbar \frac{\partial \psi}{\partial t}(\mathbf{x}, t)$$

with $\alpha_\mu \alpha_\nu + \alpha_\nu \alpha_\mu = 2\delta_{\mu\nu}$ (Clifford algebra)

⇒
1) usual four-component spinors
2) 4D space-time (real) algebra (D. Hestenes)

⇒ spin is a "bivector" (oriented area)

D. Hestenes, J. Math. Phys. **15**, 1768 (1974); **15**, 1778 (1974); **16**, 556 (1975)

Dynamical origin of spin (and PP)

(…for simplicity, NR limit…) from Schrodinger-Pauli current:

$$m\vec{v} = \vec{p} + \frac{\vec{\nabla}\rho\times\vec{s}}{\rho}$$ …but… $$\langle m\vec{v}\rangle = \langle\vec{p}\rangle$$ …however…

$$\vec{L}' \equiv \vec{r}\times m\vec{v} \neq \vec{L} \equiv \vec{r}\times\vec{p}$$ …and… $$\langle\vec{L}'\rangle = \langle\vec{L}\rangle + 2\langle\vec{s}\rangle$$

The contribution of the ZBW motion $\vec{w} = \dfrac{\vec{\nabla}\rho\times\vec{s}}{m\rho}$ in the Lagrangian is:

$$\frac{1}{2}mw^2 = \frac{s^2(\nabla\rho)^2}{2m\rho^2} = \frac{\hbar^2(\nabla\rho)^2}{8m\rho^2} \Rightarrow Q$$

Q = “quantum potential” in Bohm quantum mechanics or diffusion term in the Lagrangian of Madelung fluid…

Description of Hydrogen atom

Given the Hamilton-Jacobi equation: $$-\frac{\partial S}{\partial t} = \frac{(\nabla S)^2}{2m} + V(r) + Q \equiv E$$

where: $$Q = -\frac{\hbar^2}{2m}\frac{\nabla^2 R}{R}$$ and: $$\Psi(\vec{x},t) = R(\vec{x},t)e^{iS(\vec{x},t)/\hbar}$$

the spin kinetic energy term Q is responsible for H-atom eigenvalues:

$$Q(100) = E_{1s} - V(r)$$ $$Q(200) = E_{2s} - V(r)$$ $$Q(210) = E_{2s} - V(r)$$

$$Q(21\pm1) = E_{2s} - V(r) - \frac{\hbar^2}{2mr^2\sin^2\vartheta} = E_{2s} - V(r) - \frac{(\nabla S)^2}{2m}$$

➡ the spin velocity field **w**(**r**) stabilizes only “true” orbitals

The Helium atom in 3D

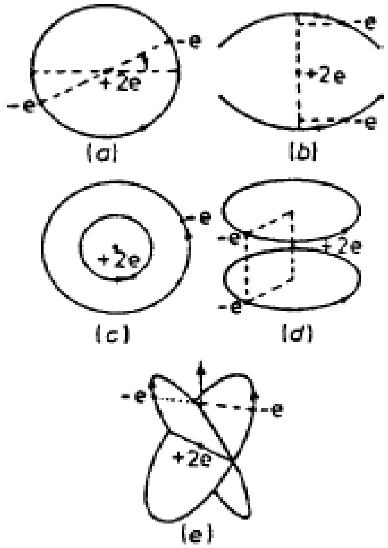


FIG. 2. Examples of periodic configurations of the electron pair in helium that served as classical models for the ground state: (a) Bohr, 1913; (b) and (d) Langmuir, 1921; (c) Landé, 1919; (e) Kemble, 1921 and Kramers, 1923 (from Leopold and Percival, 1980; see also Van Vleck, 1922).

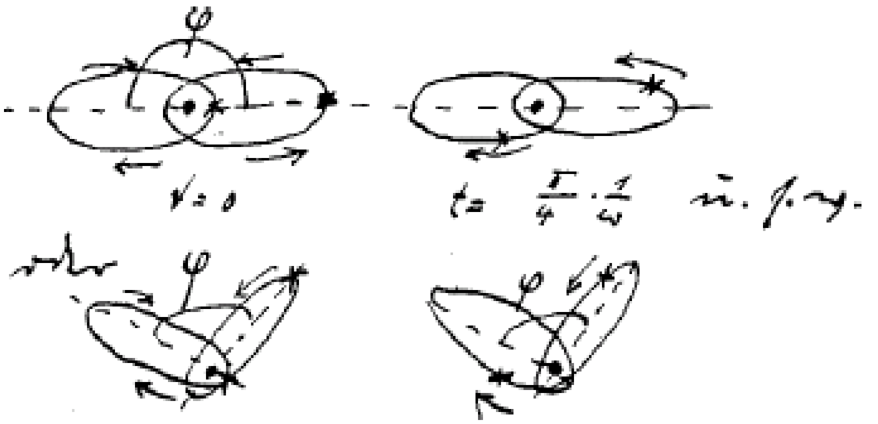


FIG. 3. Sketch of the periodic electron-pair motion proposed by Heisenberg and Sommerfeld as a candidate for a classical ground-state configuration of helium. The figure is copied from a letter of Heisenberg to Sommerfeld (Heisenberg, 1922). It was never published by Heisenberg.

1) ’20s: classical models endowed with BSW quantization rules → failure of O.Q.T.

2) ’90s: He Rydberg states explained with EBK quantization rules (RMP **72**, 497 (2000))

3) 2004: orbital 2-electron dynamics probed by laser pulses (Science, 303, 749 and 813)

New scenarios ?

If I can't picture it, I can't understand it

(A. Einstein)

…what is proved by impossibility proofs…

…is lack of imagination…

(J. Bell)

Sorry, work in progress…