International Symposium on Simplicity, Symmetry and Beauty of Atomic Nuclei

in honor of Professor Akito Arima's 88 year-old birthday (米寿)

Shanghai, September 26th-28th, 2018

Nuclear magnetic moments in Relativistic Density Functional Theory

Jie MENG （孟 杰）

School of Physics， Peking University（北京大学物理学院）

北京大學 PEKING UNIVERSITY

Co-authored Papers

1. **Pseudospin symmetry in relativistic mean field theory**
By: Meng, J; Sugawara-Tanabe, K; Yamaji, S; et al.
PHYSICAL REVIEW C Volume: 58 Issue: 2 Pages: R628-R631 Published: AUG 1998
Full Text from Publisher View Abstract
Times Cited: 287 (from All Databases) Usage Count

2. **Pseudospin symmetry in Zr and Sn isotopes from the proton drip line to the neutron drip line**
By: Meng, J; Sugawara-Tanabe, K; Yamaji, S; et al.
PHYSICAL REVIEW C Volume: 59 Issue: 1 Pages: 154-163 Published: JAN 1999
Full Text from Publisher View Abstract
Times Cited: 254 (from All Databases) Usage Count

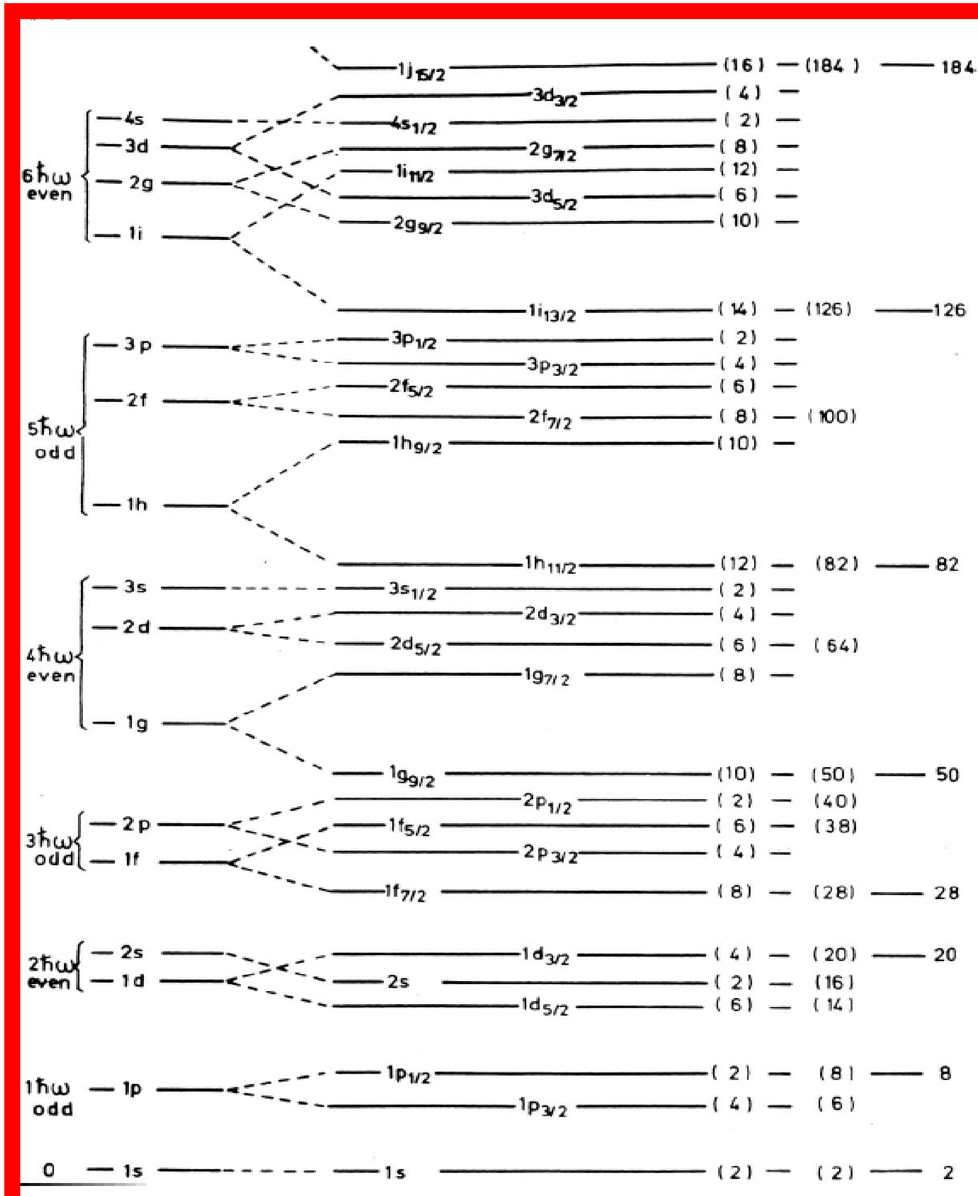
3. **Relativistic description of second-order correction to nuclear magnetic moments with point-coupling residual interaction**
By: Li Jian; Meng Jie; Ring, Peter; et al.
SCIENCE CHINA-PHYSICS MECHANICS & ASTRONOMY Volume: 54 Issue: 2 Pages: 204-209 Published: FEB 2011
Full Text from Publisher View Abstract
Times Cited: 27 (from All Databases) Usage Count

4. **One-Pion Exchange Current Corrections for Nuclear Magnetic Moments in Relativistic Mean Field Theory**
By: Li, Jian; Yao, J. M.; Meng, Jie; et al.
PROGRESS OF THEORETICAL PHYSICS Volume: 125 Issue: 6 Pages: 1185-1192 Published: JUN 2011
Free Full Text from Publisher View Abstract
Times Cited: 23 (from All Databases) Usage Count

5. **The pseudo-spin symmetry in a Dirac equation**
By: Sugawara-Tanabe, K; Meng, J; Yamaji, S; et al.
Conference: International Conference on the Physics of Nuclear Structure at the Extremes Location: LEWES, ENGLAND Date: JUN 17-19, 1998
Sponsor(s): Univ Brighton
JOURNAL OF PHYSICS G-NUCLEAR AND PARTICLE PHYSICS Volume: 25 Issue: 4 Pages: 811-813 Published: APR 1999
Full Text from Publisher View Abstract
Times Cited: 17 (from All Databases) Usage Count

6. **The nuclear spin-orbit interaction for the particle-state and the hole-state**
By: Sugawara-Tanabe, K; Arima, A; Lu, HF; et al.
Conference: International Symposium on Correlation Dynamics in Nuclei Location: Univ Tokyo, Sanjo Kaikan, JAPAN Date: JAN 31-FEB 04, 2005
International Symposium on Correlation Dynamics in Nuclei Book Series: JOURNAL OF PHYSICS CONFERENCE SERIES Volume: 20 Pages: 201-202 Published: 2005
Free Full Text from Publisher View Abstract
Times Cited: 0 (from All Databases) Usage Count

Shell model & Collective model



Strong spin-orbit interaction

Great for:

magic numbers

ground state properties

some low lying excited states

Lead to deformed Nilsson model

S. G. Nilsson, Mat. Fys. Medd. Dan. Vid. Selsk. 29, No.16(1955).

S. G. Nilssion, et al., Nucl. Phys. A131(1969) 1.

J. H. D. Jensen

M. G. Mayer

E. P. Wigner

Nobel Prize in Physics 1963

北京大學 PEKING UNIVERSITY

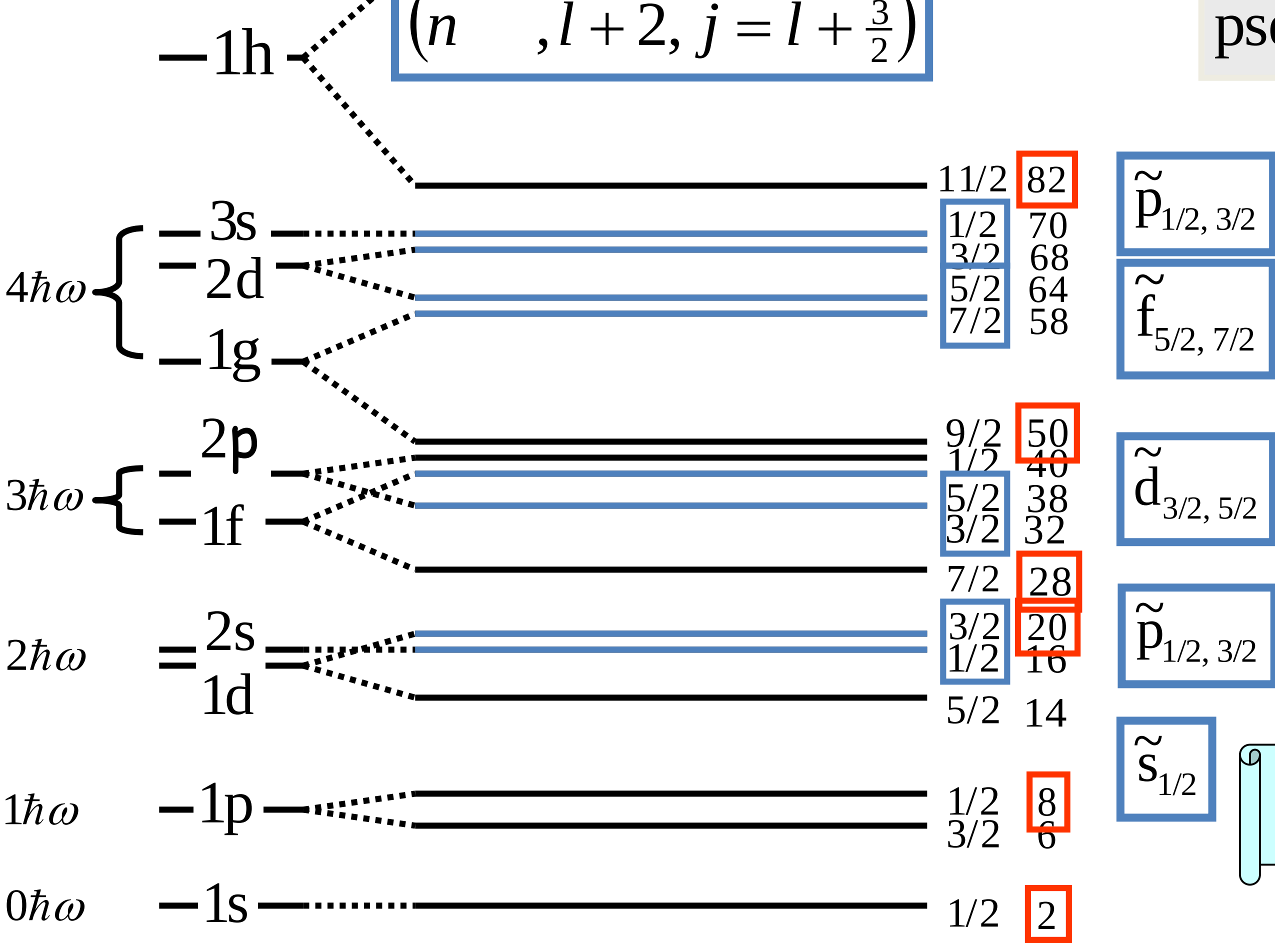
Pseudo-spin symmetry

Woods-Saxon

$\kappa \vec{l} \cdot \vec{s}$

$$\left(n+1, l, j = l + \tfrac{1}{2}\right)$$
$$\left(n, l+2, j = l + \tfrac{3}{2}\right)$$

$$\text{pseudo-orbit}: \ \tilde{l} = l + 1$$
$$\text{pseudo-spin}: \ \tilde{s} = 1/2$$



Hecht & Adler NPA137(1969)129

Arima, Harvey & Shimizu PLB30(1969)517

Origin: Ginocchio, PRL78(97)436.

Review：Liang, Meng, Zhou, Phys. Rep. 570 (2015) 1-84

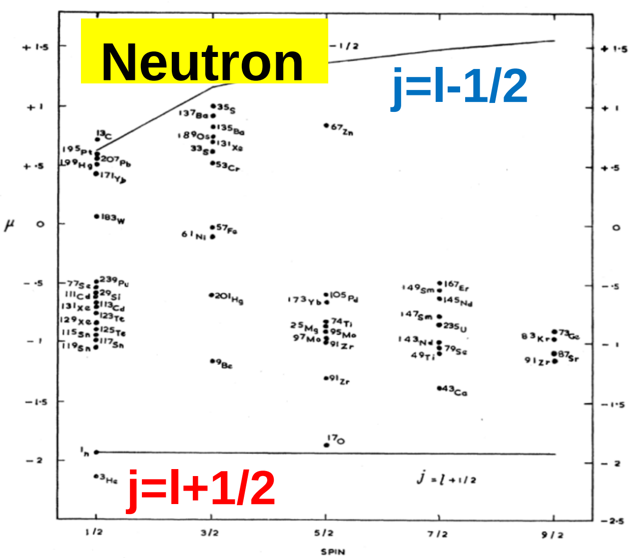
Schmidt magnetic moments

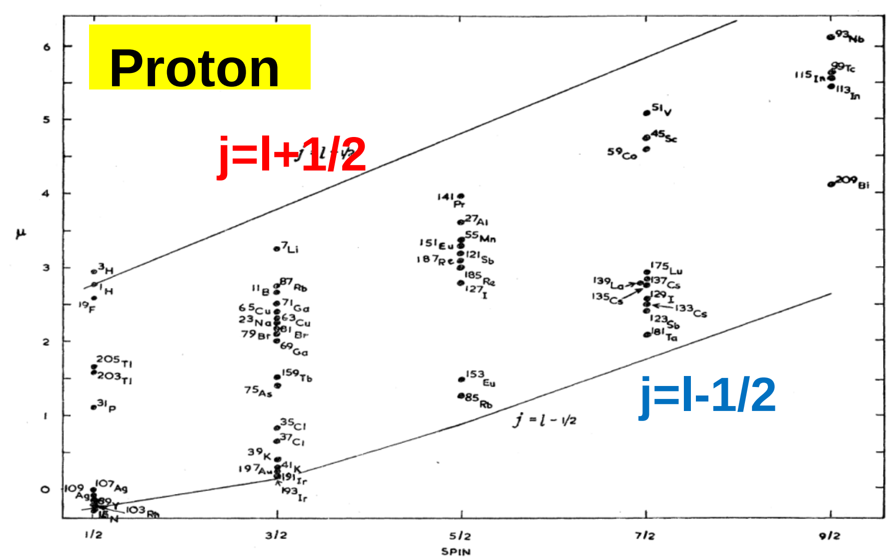
Magnetic moment of a nucleon in a orbital with *ljm*

$$\mu_S = \langle (nls)jm|\hat{\mu}_z|(nls)jm\rangle_{m=j} = \begin{cases} g_l l + \frac{1}{2} g_s, & j = l + 1/2 \\ \frac{j}{j+1}[g_l(l+1) - \frac{1}{2} g_s], & j = l - 1/2. \end{cases}$$

With orbital and spin g-factors of proton (neutron) $g_l = 1(0),\ g_s = 5.587(-3.826)$

The experimental nuclear magnetic moments are almost sandwiched between the Schmidt lines Blin-Stoyle, Rev. Mod. Phys. (1956).





Understanding the deviations from Schmidt lines

- **Non-relativistically, the deviations from Schmidt lines can be explained by:** **Arima, Shimizu, Bentz and Hyuga, Adv. Nucl. Phys. (1987), Towner, Phys. Rep. (1987).**

  ✓ **Meson exchange current (MEC): caused by the fact that the mesonic cloud surrounding the nucleons in the nuclear interior is no longer identical to that of a free nucleon.**

  M. Chemtob, Nucl. Phys. A 123 (1969) 449.

  K. Shimizu, M. Ichimura and A. Arima, Nucl. Phys. A 226 (1974) 282.

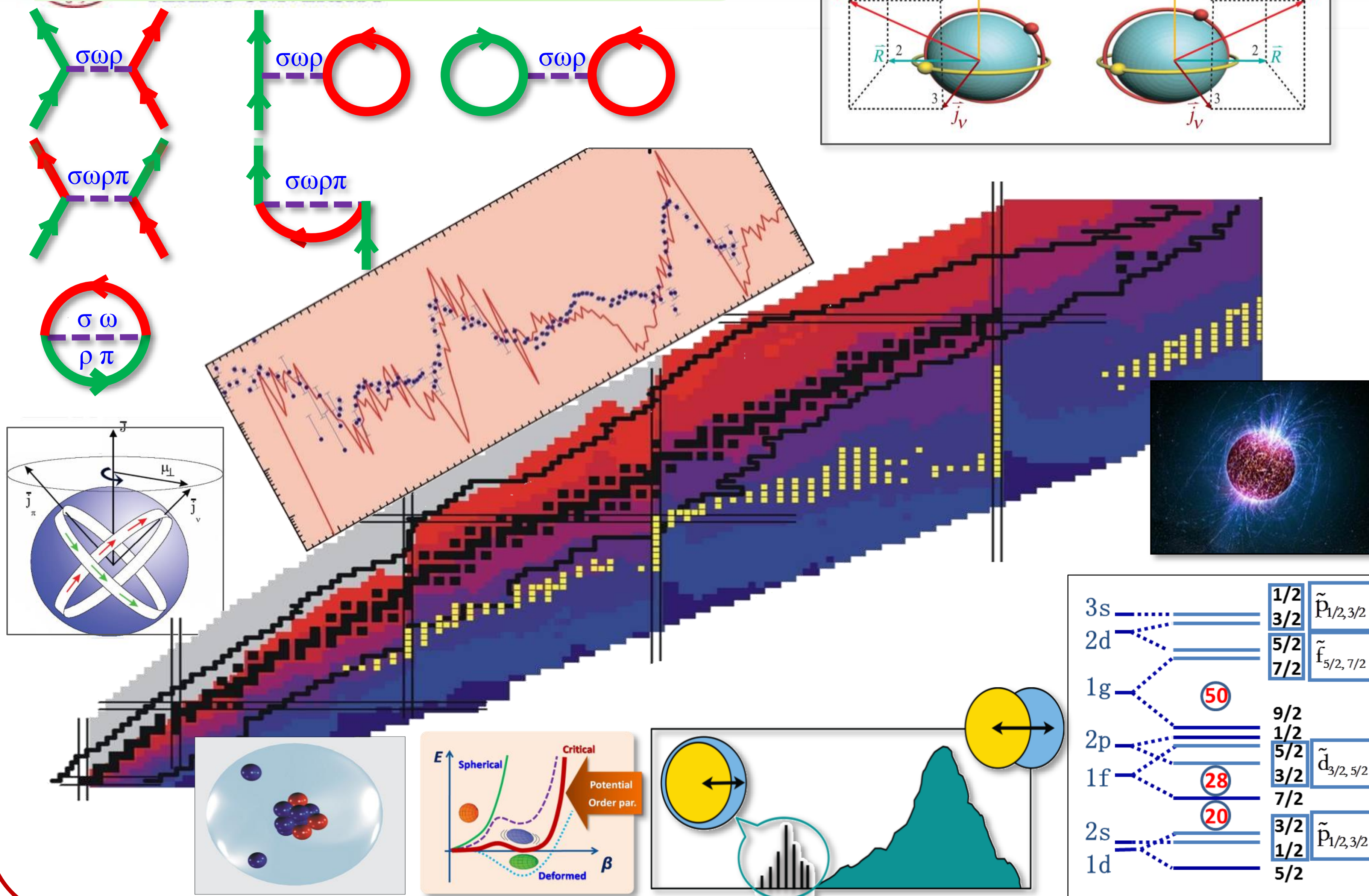
  I. S. Towner and F. C. Khanna, Nucl. Phys. A 399 (1983) 334.

  S. Ichii, W. Bentz, and A. Arima; Nucl. Phys. A404 (1987) 575

  ✓ **Arima–Horie effect / Configuration mixing (CM): correlations beyond the mean field, the first-order configuration mixing (core polarization): the single-particle state coupled to more complicated 2p-1h configurations, and the second-order core polarization.**

  A. Arima and H. Horie, Prog. Theor. Phys. 11 (1954) 509.

原子核协变密度泛函理论



Enhancement of magnetic moment in relativistic approach

- **From Gordon identity, the spatial part of the Dirac current**

$$\mathbf{j}_D = Q\bar{\psi}(\mathbf{r})\gamma\psi(\mathbf{r}) = \frac{Q}{M^*}\bar{\psi}(\mathbf{r})\mathbf{p}\,\psi(\mathbf{r}) + \frac{Q}{2M^*}\nabla\times[\psi^\dagger(\mathbf{r})\beta\mathbf{\Sigma}\,\psi(\mathbf{r})]$$

where the effective (scalar) mass: $M^* = M + S \approx 0.6M$

- **The corresponding nuclear magnetic moments,** $\mu = \frac{1}{2}\int d\vec{r}[\vec{r}\times\vec{j}]_z$

$$\boldsymbol{\mu} = \boldsymbol{\mu}_D + \boldsymbol{\mu}_A = \underbrace{Q\int d\mathbf{r}\frac{M}{M^*}\bar{\psi}[\mathbf{L}+\mathbf{\Sigma}]\psi}_{\mu_D} + \underbrace{\int d\mathbf{r}\kappa\bar{\psi}\mathbf{\Sigma}\psi}_{\mu_A}$$

- **Compared with the magnetic moment in non-relativistic theory**

$$\boldsymbol{\mu} = g_l\mathbf{l} + g_s\mathbf{s} = g_l\mathbf{l} + \frac{g_s}{2}\boldsymbol{\sigma} = \underbrace{g_l(\mathbf{l}+\boldsymbol{\sigma})}_{\mu_D} + \underbrace{(\frac{g_s}{2} - g_l)\boldsymbol{\sigma}}_{\mu_A}$$

- **Dirac magnetic moment in RMF theory is enhanced.**

Magnetic moments in relativistic approach

- **Therefore the straightforward applications of RMF theory fails to reproduce the experimental magnetic moments**

  Miller, Ann. Phys. (1975), Serot, PLB (1981)

- **Isoscalar magnetic moments in LS closed-shell plus or minus one nucleon can be reproduced well by either the renormalized current with RPA, or the Self-consistent deformed RMF calculations with time-odd fields because:**

  1) because of the LS-closure there are no spin-orbit partners on both sides of the Fermi surface and therefore the magnetic-moment operator cannot couple to magnetic resonances;

  2) the pion-exchange currents couple in first order only to the isovector part of the magnetic-moment operator and contributions of other processes to the isoscalar currents is small.

RPA:

McNeil , Amado, Horowitz, Oka, Shepard and Sparrow, PRC (1986), Ichii, Bentz, Arima and Suzuki, PLB (1987), Shepard, Rost, Cheung and Mc Neil PRC (1988),

Time-odd fields:

Hofmann and Ring PLB (1988), Furnstahl and Price PRC (1989), Yao, Chen and Meng PRC (2006).

Present Understanding

Magnetic moments in

- **Relativistic mean-field theory with time-odd fields**

Yao, Chen, and Meng, Phys. Rev. C **74** (2006) 024307

Consider

- **One pion exchange current**
- **CM(1st, 2nd)**

Demonstrated for

- **magnetic moments of *LS* closed shell nuclei ±1 nucleon**
- **magnetic moments of *jj* closed-shell nuclei ±1 nucleon**

Li, Yao, Meng, and Arima, Progress of Theoretical Physics **125** (2011) 1185

Li, Meng, Ring, Yao, and Arima, Sci. China Phys. Mech. Astron. 54 (2011) 204.

Magnetic moments with time-odd fields

Table: Isoscalar magnetic moments $\mu_s = [\mu_p + \mu_n]/2$. The time-odd fields are included in the deformed RMF calculations (Def.). The PC-F1 effective interaction is used.

		μ_s			
A	Orbit	Exp.	Sch.	Sph.	Def.
15	$1p_{1/2}^{-1}$	0.218	0.187	0.325	0.190
17	$1d_{5/2}$	1.414	1.440	1.566	1.440
39	$1d_{3/2}^{-1}$	0.706	0.636	0.954	0.728
41	$1f_{7/2}$	1.918	1.940	2.215	1.944

Table: Isovector magnetic moments $\mu_v = [\mu_p - \mu_n]/2$

		μ_v			
A	Orbit	Exp.	Sch.	Sph.	Def.
15	$1p_{1/2}^{-1}$	−0.501	−0.451	−0.340	−0.499
17	$1d_{5/2}$	3.308	3.353	3.471	3.448
39	$1d_{3/2}^{-1}$	−0.316	−0.512	−0.214	−0.292
41	$1f_{7/2}$	3.512	3.853	4.120	4.070

Isoscalar magnetic moments

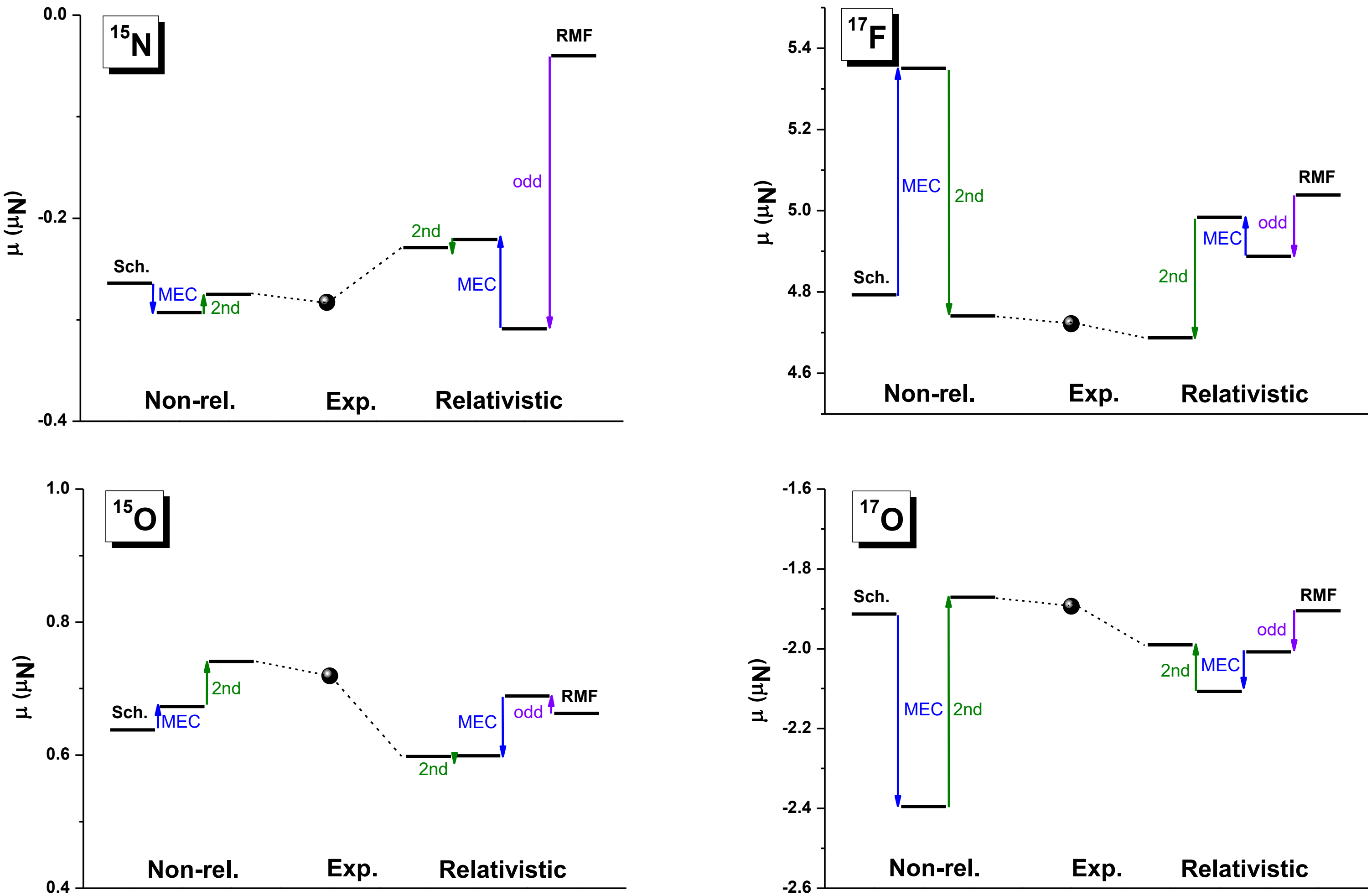
- **without time-odd fields:** much larger than Schmidt values.
- **with time-odd fields:** good agreement with Schmidt values

Isovector magnetic moments

- large discrepancy exists between the calculated results and the data.

Yao, Chen, and Meng, Phys. Rev. C **74** (2006) 024307

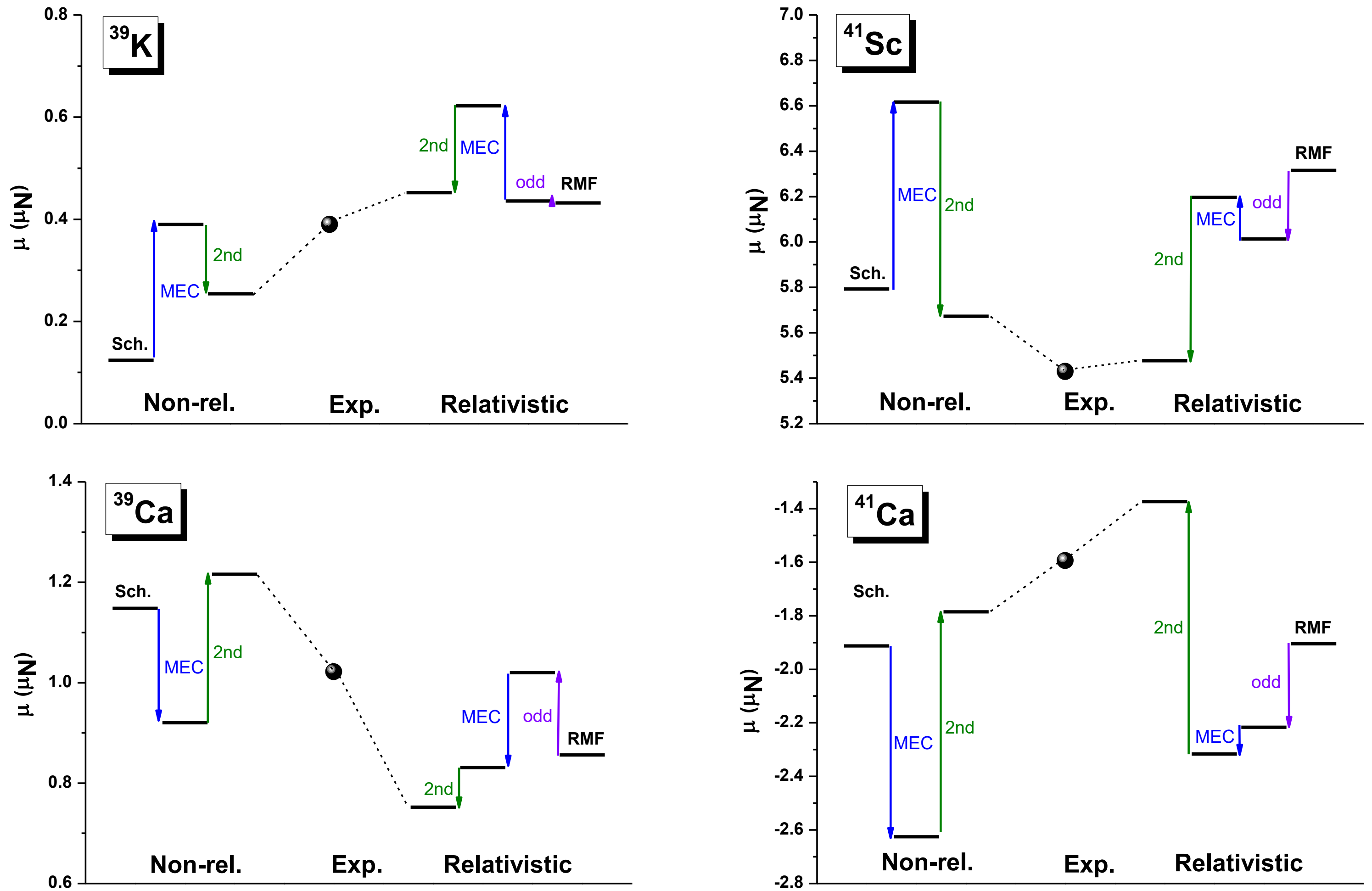
Magnetic moment with MEC and CM(2nd) for nuclei with *LS* closed-shell ±1



Li, Yao, Meng, and Arima, Progress of Theoretical Physics **125** (2011) 1185

Li, Meng, Ring, Yao, and Arima, Sci. China Phys. Mech. Astron. **54** (2011)204.

Magnetic moment with MEC and CM(2^{nd}) for nuclei with *LS* closed-shell ±1

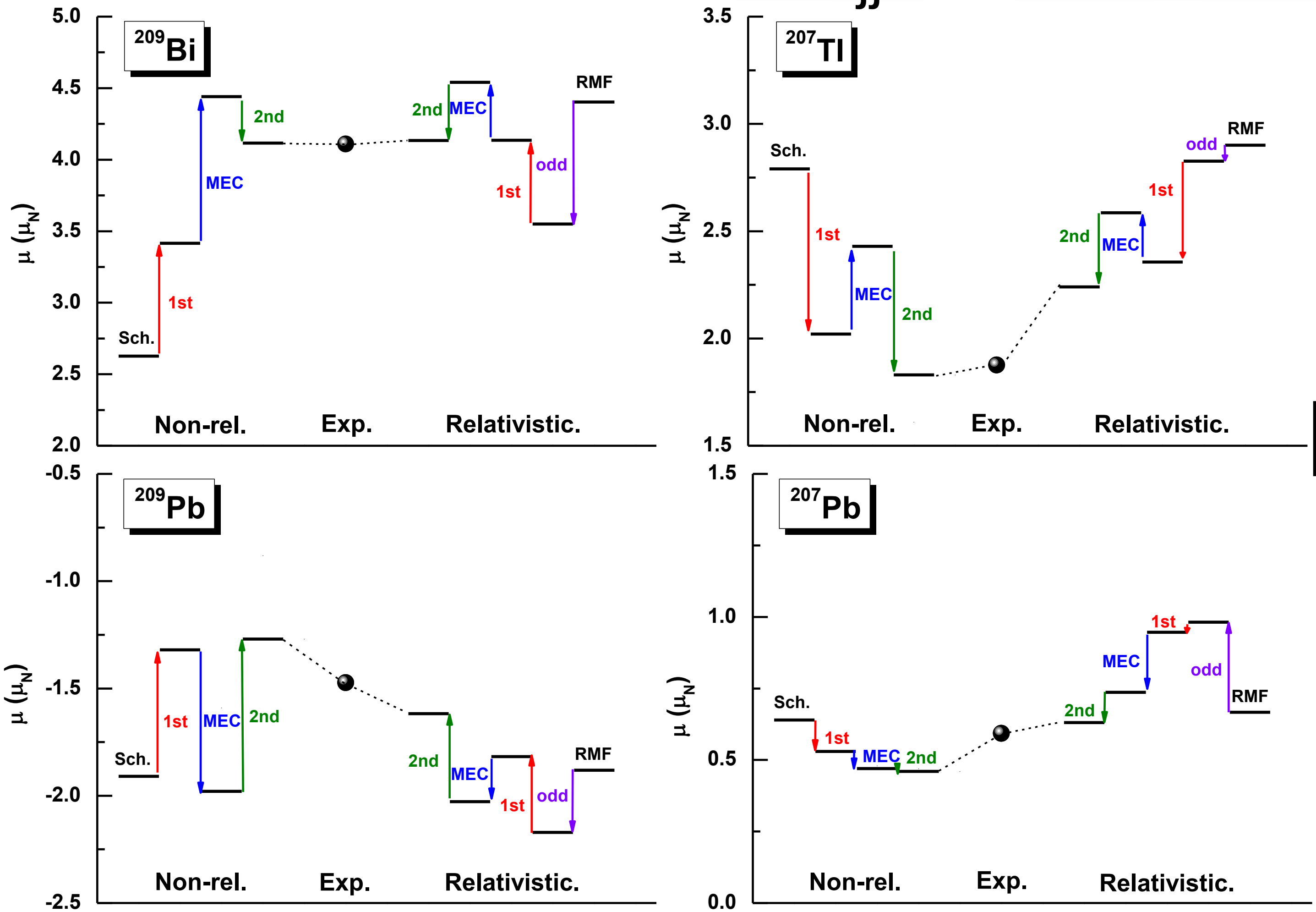


Li, Yao, Meng, and Arima, Progress of Theoretical Physics **125** (2011) 1185

Li, Meng, Ring, Yao, and Arima, Sci. China Phys. Mech. Astron. **54** (2011)204.

北京大學 PEKING UNIVERSITY

Magnetic moment with MEC and CM(1^{st} and 2^{nd}) for nuclei with jj closed-shell ±1



PC-F1

Magnetic moments in ^{209}Bi, ^{207}Tl, ^{209}Pb and ^{207}Pb are well described in relativistic way by including CM(1^{st} and 2^{nd}) and MEC, in agreement with non-relativistic results. In the CM(1^{st}, 2^{nd}), the residual interaction due to π is included

Summary and Perspectives

- **Magnetic moments are described in relativistic approach by including the time-odd fields, the meson exchange current and CM(1^{st} and 2^{nd}).**
- **The same quantitive description for magnetic moment as the non-relativistic one has been achieved.**
- **The important contribution of pion in as demonstrated in the meson exchange current and CM(1^{st} and 2^{nd}).**
- **Magnetic moments for *LS* closed shell nuclei, ^{16}O and ^{40}Ca, ±1 nucleon are well described by including CM(2^{nd}) and MEC.**
- **Magnetic moments for *jj* closed-shell nuclei ±1 nucleon ^{209}Bi, ^{207}Tl, ^{209}Pb and ^{207}Pb are well described by including CM(1^{st} and 2^{nd}) and MEC.**

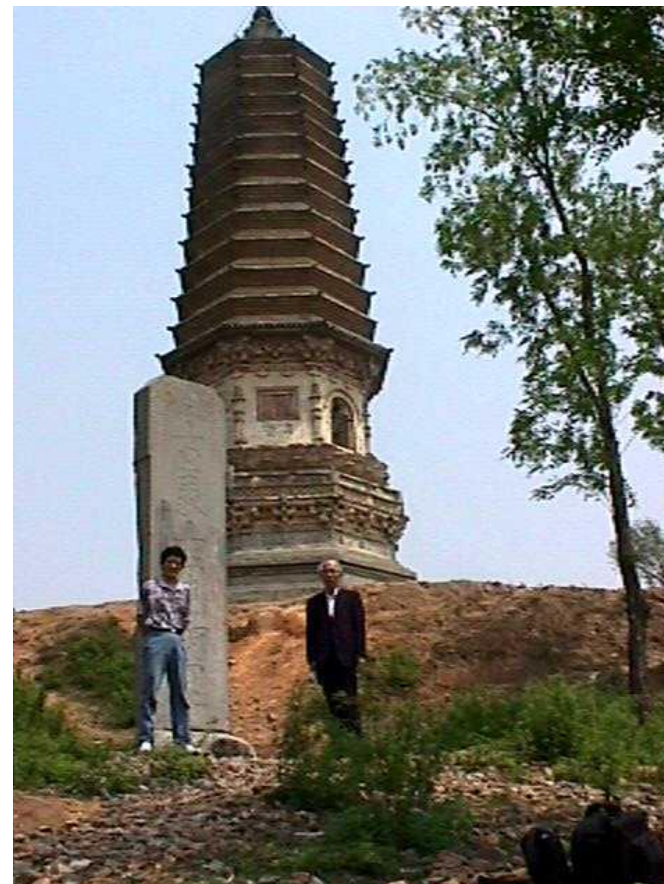
Thank you for your attentions!

"目光深邃，核界泰斗；倾心奉献，中日友好。"

陈佳洱

Peking University, China

1998年5月4日 被授予北京大学名誉教授



北京大学 / 河北易县 荆轲塔

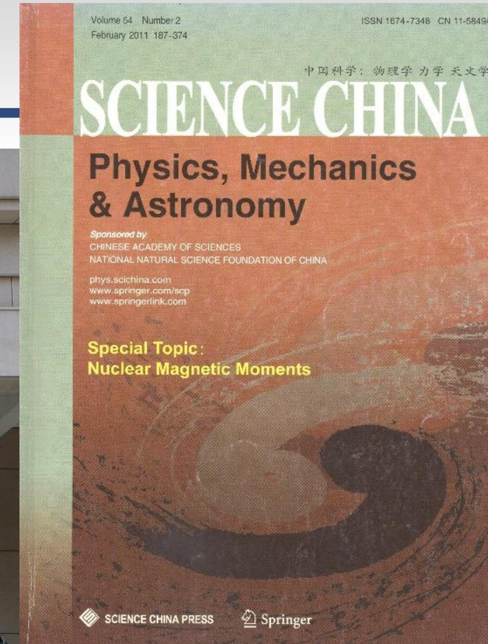
2003年11月10-15日
参加国家科技领导小组咨询委员会会议
会见老朋友 / 郭沫若故居

2009年11月9日 日本筑波 （感谢张焕乔先生）

2010年4月28日 被授予北京航空航天大学名誉教授

北京航空航天大学校长（现任中国科学技术协会党组书记、常务副主席）怀进鹏、副校长郑志明


原子核磁矩国际研讨会
International Workshop on Nuclear Magnetic Moments


Volume 54 Number 2
February 2011 187-374
ISSN 1674-7348 CN 11-5849/
中国科学：物理学 力学 天文学
SCIENCE CHINA
Physics, Mechanics & Astronomy
Sponsored by
CHINESE ACADEMY OF SCIENCES
NATIONAL NATURAL SCIENCE FOUNDATION OF CHINA
phys.scichina.com
www.springer.com/scp
www.springerlink.com
Special Topic: Nuclear Magnetic Moments
SCIENCE CHINA PRESS
Springer

Professor Akito Arima, Happy Rice Birthday！

恭贺 有马朗人 先生 米寿！祝健康快乐！

Looking forward 白寿 and 茶寿 celebration！