“Extraordinary Conclusion”
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Lise Meitner

Jaideep Taggart Singh (he/him/his)

Facility for Rare Isotope Beams/MSU

EDMs 2026: Complementary Experiments and Theory Connections

École de Physique des Houches

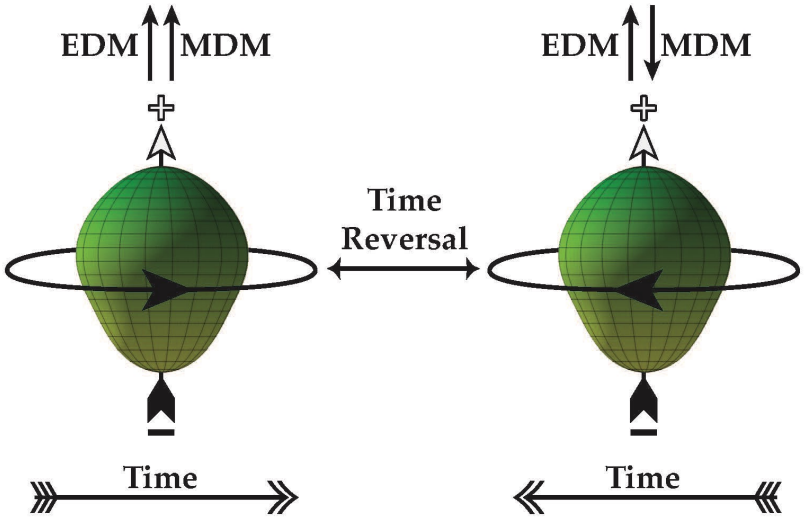
Yves Rocard Lecture Hall in the Cécile DeWitt Building

March 6, 2026 @ 11:45-12:15

FRIB

SCAN ME

~~"Extraordinary Conclusion"~~
Protactinium is the worst!



see talk by M. Tseng

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https://pollev.com/jaideepsingh305

For the early career researchers, let's play a game...

Note: only the first 40 responses will be recorded so please only students and postdocs!

91 $^{4}K_{11/2}$
Pa
Protactinium
231.04
$[Rn]5f^{2}6d7s^{2}$
5.89

Lise Meitner

SCAN ME

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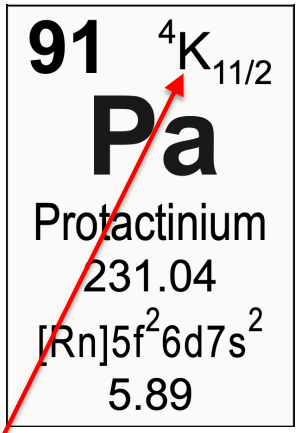
What is the numerical value (0,1,2,...) for orbital angular momentum that corresponds to the term symbol K?

https://en.wikipedia.org/wiki/Term_symbol



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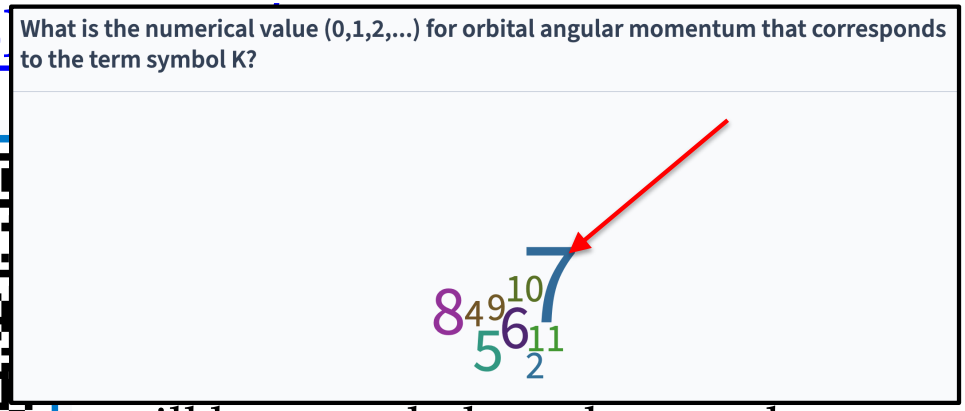

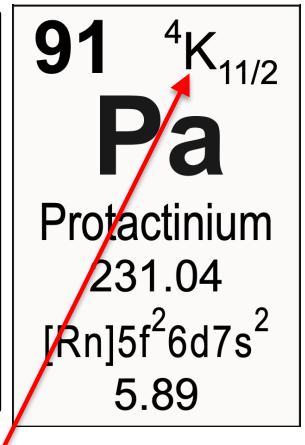

Lise Meitner

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SCAN ME

FRIB

~~"Extraordinary Conclusion"~~

Protactinium is the worst...but what if it weren't?

https://www.nobelprize.org/nomination/archive/show_people.php?id=6097

Year, Death: 1968

Nominee in 49 nominations:

- Physics 1937 by Werner Karl Heisenberg
- Physics 1937 by Max von Laue
- Physics 1940 by Arthur Compton
- Physics 1940 by James Franck
- Physics 1940 by Dirk Coster
- Physics 1941 by James Franck
- Physics 1943 by James Franck
- Physics 1945 by Oskar Benjamin Klein
- Physics 1946 by Max von Laue
- Physics 1946 by Niels Bohr
- Physics 1946 by Oskar Benjamin Klein
- Physics 1946 by Egil Hylleraas
- Physics 1946 by James Franck
- Physics 1947 by Arthur Compton
- Physics 1947 by Max Planck
- Physics 1947 by Maurice de Broglie
- Physics 1947 by Oskar Benjamin Klein
- Physics 1947 by Egil Hylleraas
- Physics 1947 by Prince Louis-Victor de Broglie
- Physics 1948 by Harald Wergeland
- Physics 1948 by Otto Hahn
- Physics 1949 by Georg Hettner
- Physics 1954 by Max Born
- Physics 1955 by Georg Hettner
- Physics 1956 by James Franck
- Physics 1959 by Joseph Rotblat
- Physics 1961 by Joseph Rotblat
- Physics 1964 by Max Born
- Physics 1965 by Max Born
- Physics 1967 by Aleksander Jabłoński
- Chemistry 1924 by Heinrich Goldschmidt
- Chemistry 1925 by Kasimir Fajans
- Chemistry 1925 by Heinrich Goldschmidt
- Chemistry 1929 by Max Planck
- Chemistry 1930 by Max Planck
- Chemistry 1933 by Max Planck
- Chemistry 1934 by Max Planck
- Chemistry 1936 by Adolf Deissmann
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- Chemistry 1939 by Theodor Svedberg
- Chemistry 1941 by Frans Jaeger
- Chemistry 1942 by Wilhelm Palmaer
- Chemistry 1946 by Kasimir Fajans
- Chemistry 1947 by Niels Bohr
- Chemistry 1947 by Nil Dhar
- Chemistry 1948 by Oskar Benjamin Klein
- Chemistry 1948 by Niels Bohr

Lise Meitner

SCAN ME

Ground Rules

1. **My audience are the Early Career Researchers - students and postdocs - at this workshop and, according to Sklyer (41 out of 70 = 59%), you are the majority and the future of the field!**

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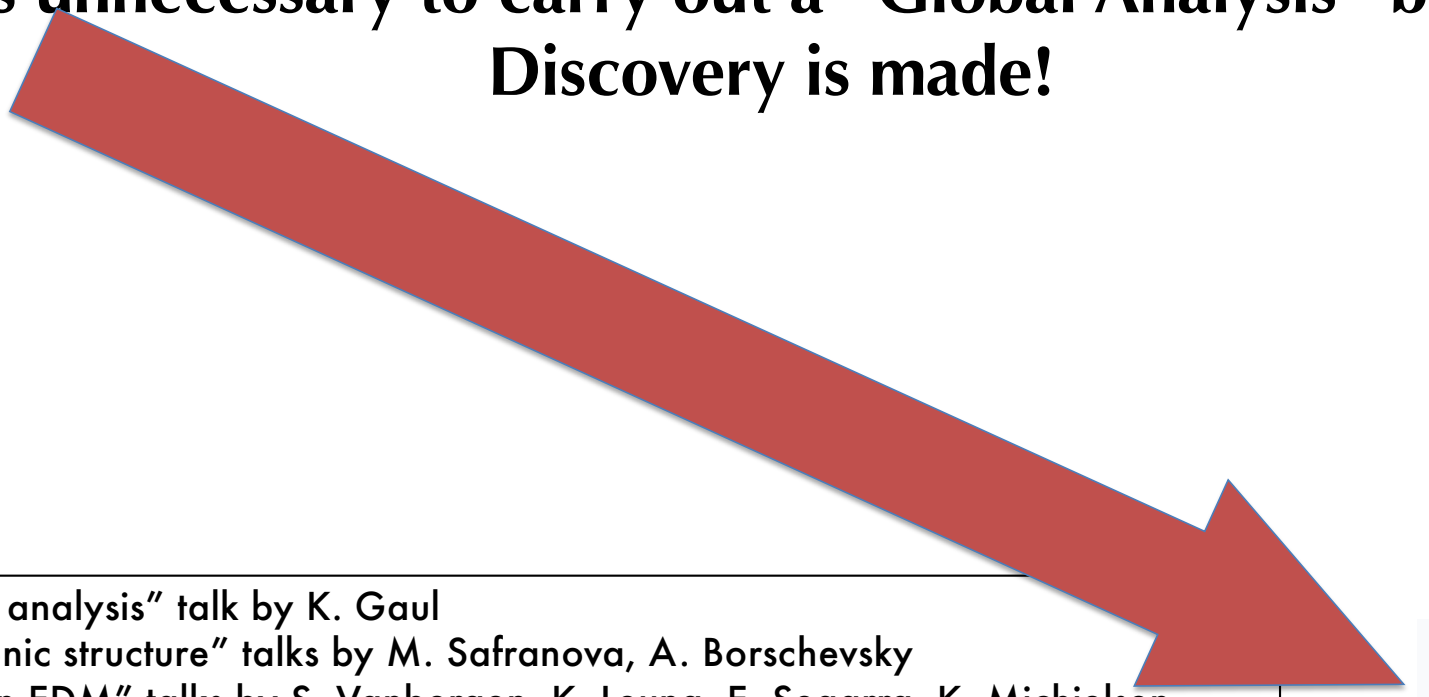
4. **My Very Modest Proposals are nothing more than just Humble Calls To Action for your consideration delivered with Great Humility...**

Students and Postdocs only please!

It is unnecessary to carry out a "Global Analysis" before a Discovery is made!



see "global analysis" talk by K. Gaul
see "electronic structure" talks by M. Safranova, A. Borschevsky
see "neutron EDM" talks by S. Vanbergen, K. Leung, E. Segarra, K. Michielsen
see "leptonic EDM" talks by E. Hessels, S. Y. Park, G. Carugno, D. Comparat, S. Hoekstra, E. Wursten, P. Schmidt-Wellenburg
see "nuclear hadronic CPV" talks by R. F. Garcia Ruiz, M. Au, C. Crawford, S. Samiei, F. M. Vidal, G. Tonani, A. Claessens
see "signature of CPV observable" talks by Y. Ema, H. Mulders, L. Gialdi

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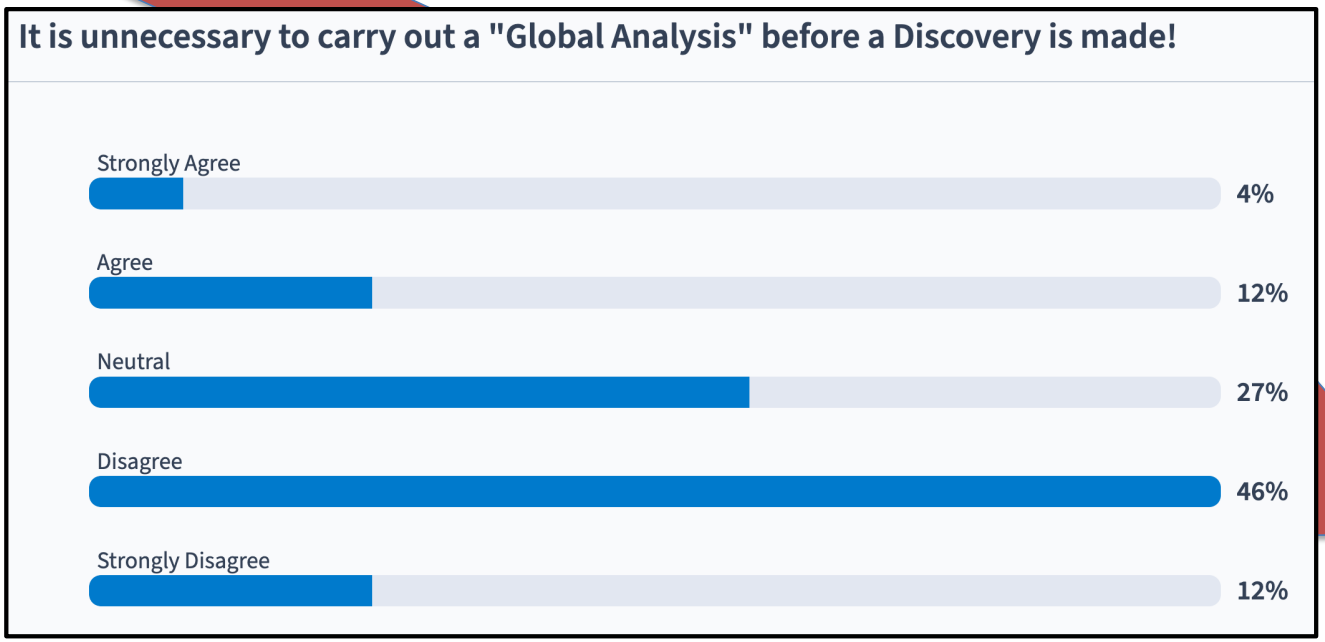

Students and Postdocs only please!

My View: It IS necessary to carry out a "Global Analysis" before a Discovery is made!

1. It is not obvious at all what the "best" system is. What does "best" even mean?
2. No one knows the source or sources of new CPV physics.
3. The Global Analysis Framework, pioneered by Tim Chupp and Michael Ramsey-Musolf, provide the only meaningful constraints on new CPV physics based on *both* experimental limits and reasonable (but not "Naturalness") theoretical arguments.

4. The Sole Source Framework should be a relic of the past that was only useful when we had just a handful of experimental limits and an unsophisticated understanding of how to connect high energy scale new CPV physics to low energy observables. We are now in the Golden Era of EDM experiment and theory!

5. As a more practical consideration, we all need to explain to funders and grant reviewers the impact of our work using a consistent and standard framework.

A Call To Action! (Part 1/4)

Our community needs a Global Analysis Framework "Fitter" that:

1. is open source so that we all know what is under the hood
2. is semi-crowd-sourced so that it can maintained and updated quickly
3. can be run from a web browser anywhere in the world
4. that provides evaluated / recommended default parameters and assumptions
5. but also allows the user to vary parameters and select assumptions
6. produces downloadable high resolution eps plots of uncertainty ellipses, etc.
7. produces downloadable LaTeX tables
8. is super easy to use to aid adoption – this is the most important one

Students and Postdocs only please!

Examples:

CKM Fitter Live

Dark Matter Limit Plotter

νDoBe — A Python tool for neutrinoless double beta decay

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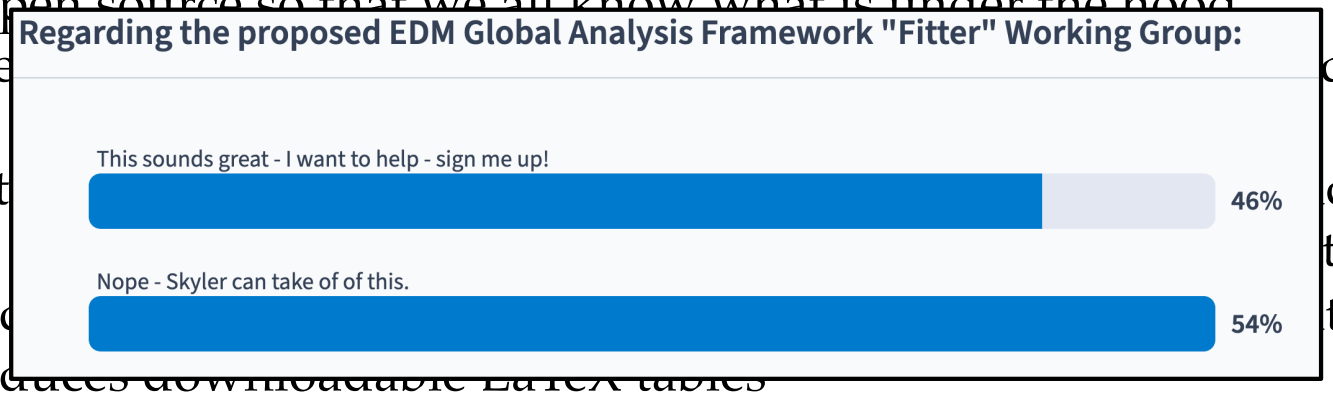

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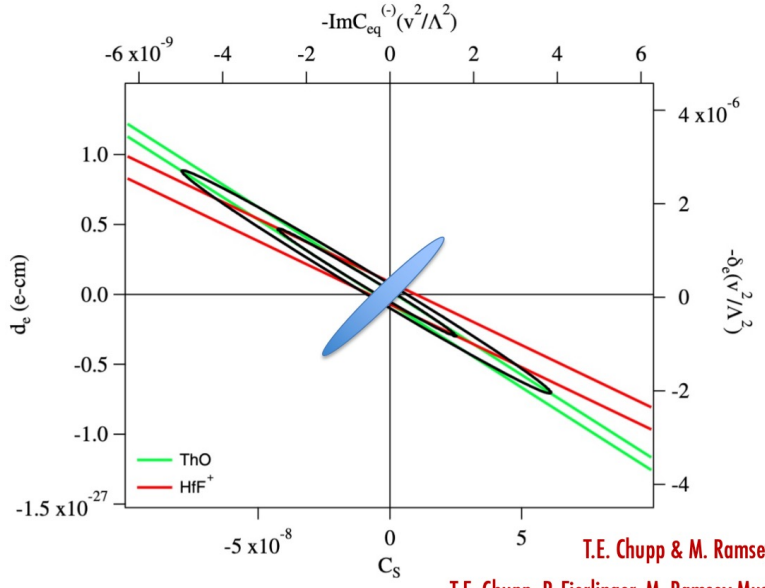
Examples:

[CKM Fitter Live]
[Dark Matter Limit Plotter]
[νDoBe — A Python tool for neutrinoless double beta decay]

Sign Conventions Are Hard – Let's Agree On This Convention, and definitely not the one below which is crucially wrong!

Global Analysis Framework: The Crucial Importance of Fr Electron EDM



Alkali Atom electron EDM Cs, Fr, ...

Orthogonal sensitivity!

C1.04 Yasuhiro Sakemi next talk!

T.E. Chupp & M. Ramsey-Musolf PRC 91:035502 (2015)

T.E. Chupp, P. Fierlinger, M. Ramsey-Musolf, JTS, RMP 91:015001 (2019)

2023-11-28 6th HAW C1.3 - Pears @ FRIB - JTS

see "electronic structure" talk by T. Fleig

A Call To Action! (Part 2/4)

Examples:
https://github.com/Jayich-Lab/EDM-Limits
https://www.psi.ch/en/nedm/edms-world-wide

Our community needs a repository of:

1. complete and archival experimental limits:
    1. stored in a simple text file as (central value +/- stat +/- syst)
    2. with the system, year of publication, and doi link or equivalent
    3. **For particles:** the central value should be:
        - **the EDM in units of 1 Py = 1 Pendlebury = 1.0E-32 e*cm**
          named in honor of John Michael Pendlebury (1936-12-01 to 2015-09-01)
    4. **For molecules:** the central value should be:
        - **the CPV frequency shift in units of 1 Sd = 1 Sandars = 1 rad-nanoHz (omega not nu)**
          named in honor of Patrick George Henry Sandars (1939-03-29 to 2013-04-26)
2. complete and archival calculated parameters:
    1. stored in a simple text file as (central value +/- uncertainty)
    2. with the parameter, system, year of publication, and doi link or equivalent
    3. with sign conventions, very carefully triple checked, following:
       https://arxiv.org/abs/2403.02052

Students and Postdocs only please!

A Call To Action! (Part 2/4)

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https://github.com/Jayich-Lab/EDM-Limits
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   2. [illegible]
   3. [illegible]
   4. [illegible]
2. complete and archival calculated parameters:
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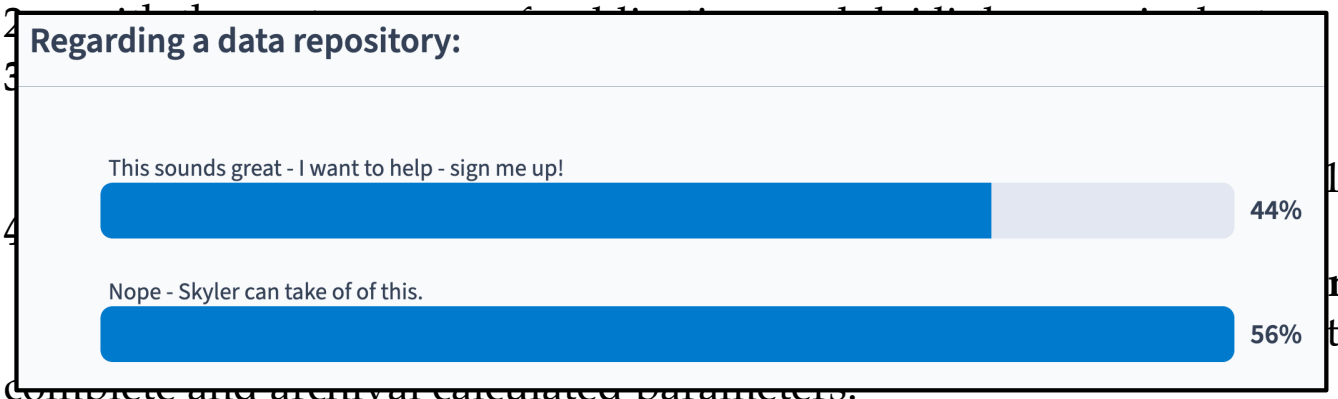

15-09-01)

nanoHz (omega not nu)

to 2013-04-26)

Students and Postdocs only please!

Towards A Common Language (Part 1/5)

For particles:
use unitless "kappa's" with descriptive subscripts, for example:

$$d_{\mathrm{a}} = \kappa_{\mathrm{e}} d_{\mathrm{e}} + \left[\kappa_S C_S + \kappa_{\mathrm{NSM}} \left(\frac{S\mathrm{n}}{e \cdot \mathrm{fm}^3} \right) - \frac{1}{3} \kappa_{\mathrm{MQM}} \left(\frac{M_{\mathrm{n}}}{e \cdot \mathrm{fm}^2} \right) + \kappa_T C_T \right] (1\ \mathrm{Py})$$

For molecules:
use unitless "W's" with descriptive subscripts, for example:

$$\Delta\omega_{\mathrm{CPV}} = \frac{4 d_{\mathrm{e}} E_{\mathrm{e,eff}}}{\hbar} + 4 \left[W_S C_S + W_{\mathrm{NSM}} \left(\frac{S_n}{e \cdot \mathrm{fm}^3} \right) - \frac{1}{3} W_{\mathrm{MQM}} \left(\frac{M_{\mathrm{n}}}{e \cdot \mathrm{fm}^2} \right) + W_T C_T \right] (1\ \mathrm{Sd})$$

Effective E-field @ nucleus in molecule:
to aid in comparing NSM in molecules to NSM in atoms...

$$E_{\mathrm{n,eff}} = \hbar \left(\frac{W_{\mathrm{NSM}}}{\kappa_{\mathrm{NSM}}} \right) \left(\frac{\mathrm{rad} \cdot \mathrm{Hz}}{e \cdot \mathrm{cm}} \right) \approx \frac{40\ \mathrm{MV}}{\mathrm{cm}}$$

Students and Postdocs only please!

Towards A Common Language (Part 1/5)

For particles:
use unitless "kappa's" with descriptive subscripts, for example:

$$d_{\mathrm{a}} = \kappa \left[\cdots + \kappa_T C_T \right] (1\ \mathrm{Py})$$

For mol
use unit

$$\Delta\omega_{\mathrm{CP}} \left(\cdots \right) + W_T C_T \Big] (1\ \mathrm{Sd})$$

These Kappas should be used for atomic/particle coefficients and these Ws should be used for molecular coeffecients.

Yes, I'll update my slides now! 70%

Nope, I'm happy with the convention that I've adopted. 30%

Effective E-field @ nucleus in molecule:
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Towards A Common Language (Part 2/5)

For Nuclear Schiff Moments:

$g_{\pi NN} = g_A m_p / f_\pi = 13$

use unitless "a's" with descriptive subscripts, for example:

$$S_{\rm n} = \left[a_p \left(\frac{d_p}{1\ {\rm Py}} \right) + a_n \left(\frac{d_n}{1\ {\rm Py}} \right) + g_{\pi NN} \left(a_0 \bar{g}_0 + a_1 \bar{g}_1 \right) \right] \left(e \cdot {\rm fm}^3 \right)$$

For nuclear Magnetic Quadrupole Moments: see "polyatomic" talk by L. Caldwell

use unitless "b's" with descriptive subscripts, for example:

$$M_{\rm n} = \left[b_p \left(\frac{d_p}{1\ {\rm Py}} \right) + b_n \left(\frac{d_n}{1\ {\rm Py}} \right) + g_{\pi NN} \left(b_0 \bar{g}_0 + b_1 \bar{g}_1 \right) \right] \left(e \cdot {\rm fm}^2 \right)$$

$$b_0 = -b_1/5 = -0.006 \left(m_p^0 + m_n^0 \right) \qquad \text{and} \qquad b_{p,n} = (3/14) m_{p,n}^0$$

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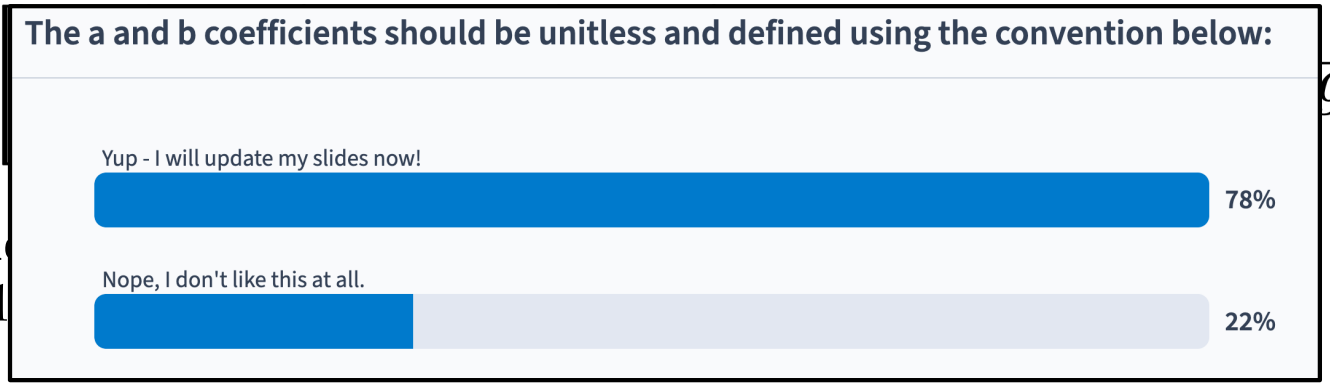
use unitl



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Towards A Common Language (Part 3/5)

- instead of “paramagnetic” for systems with unpaired electrons, say “open shell”
- instead of “diamagnetic” for systems with fully paired electrons, say “closed shell”
- Boltzmann constant is approximately equal to 0.1 neV per 1 microKelvin
- use 1 fT instead of 10 pG (SI!)
- use 1 pT instead of 10 nG (SI!)
- use 1 nT instead of 10 microG (SI!)
- use 1 microT instead of 10 mG (SI!)
- use 10 kV/cm instead of 1 MV/m (because of the Purcell “e*cm” convention)
- instead of “table-top” experiments (~3 m^2), let’s be more inclusive and just starting call it “room-sized” experiments (~300 m^3)

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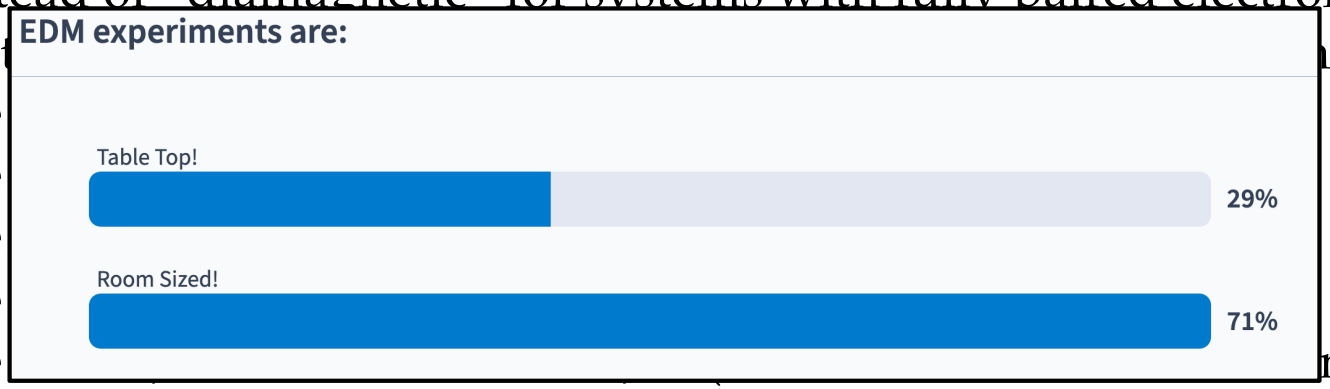
- instead of “diamagnetic” for systems with fully paired electrons, say “closed shell”
- Bolt… …icroKelvin
- use…
- use…
- use…
- use…
- use… …m” convention)
- instead of “table-top” experiments (~3 m^2), let’s be more inclusive and just starting call it “room-sized” experiments (~300 m^3)



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Towards A Common Language (Part 4/5)

PHYSICAL REVIEW A, VOLUME 65, 032113

Nuclear Schiff moment and time-invariance violation in atoms

V. V. Flambaum and J. S. M. Ginges
School of Physics, University of New South Wales, Sydney 2052, Australia
(Received 3 August 2001; published 20 February 2002)

V. V. FLAMBAUM AND J. S. M. GINGES

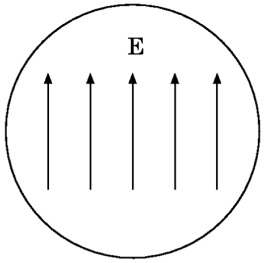

FIG. 1. Constant electric field **E** inside the nucleus produced by the Schiff moment. **E** is directed along the nuclear spin **I**.

Left: 2002

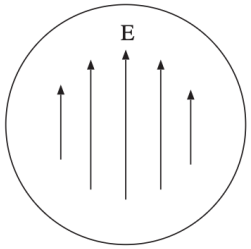

Fig. 24. Constant electric field **E** inside the nucleus produced by the P,T-odd interaction (Schiff moment field). **E** is directed along the nuclear spin **I**.

Right: 2004

see talk by J. Ginges

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Towards A Common Language (Part 4/5)

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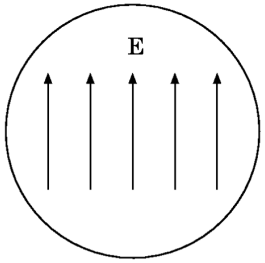

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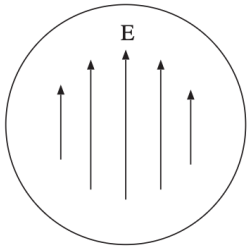
Left: 2002

Wrong – only the LEFT one is correct since each E-field vector has the same magnitude as it clearly states in BOTH captions!

Jacinda just told me that these are actually field lines so only the direction and density (line spacing) are relevant so the two diagrams are equivalent, but the right one is more pretty - JTS.



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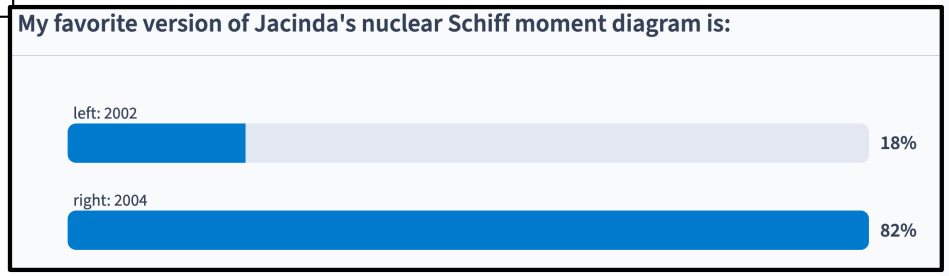

A Call To Action! (Part 3/4)

Nuclear physics (structure+QCD – my fields – sad face emoji!) is the severest limiting factor that restricts the constraining power of the exquisite and hard-earned experimental EDM limits – this is an opportunity!

- Lattice QCD is the only path towards towards a realistic connection between the QCD scale and the Hadronic scale. (Support Andrea Shindler and friends!)
- More nuclear theory and experiment in order to expand Schiff moment/Octupole moment correlation analysis to include Th-228, Th-230, and U-230 (Support Herlik Wibowo and friends!)
- Desperate need for nuclear theory calculations related to Nuclear Schiff Moments for (in order of importance): Hg-199, Yb-171, Xe-129, Eu-153, Fr-221, Fr-223, Pa-229
- More nuclear theory for Cs-133 for both nMQM and nuclear anapole moment
- Desperate need for nuclear experiment for Pa-229, Fr-221, Fr-223, Th-227, Th-229, Ac-227, Eu-153 (full ladder of nuclear transition strengths and level schemes, ground state and excited state spins, ground state and excited state parities, ground state magnetic moments)

see nuclear theory talks by H. Wibowo & A. Shindler
see "nuclear Schiff moment" talks by T. Xia, B. Nima, T. Chupp, U. Schmidt, D. Kawall, S. Stellmer

Two different groups studying the same system, using similar techniques, having common technical challenges probably should work independently. However, if there more than two groups, then we must work together to the extent possible given real-world constraints.

Rep. Prog. Phys. **60** (1997) 1351–1396. Printed in the UK PII: S0034-4885(97)07903-7

Parity violation in atoms

Marie-Anne Bouchiat† and Claude Bouchiat‡

† Laboratoire Kastler-Brossel§, 24 rue Lhomond, 75231 Paris Cedex 05, France
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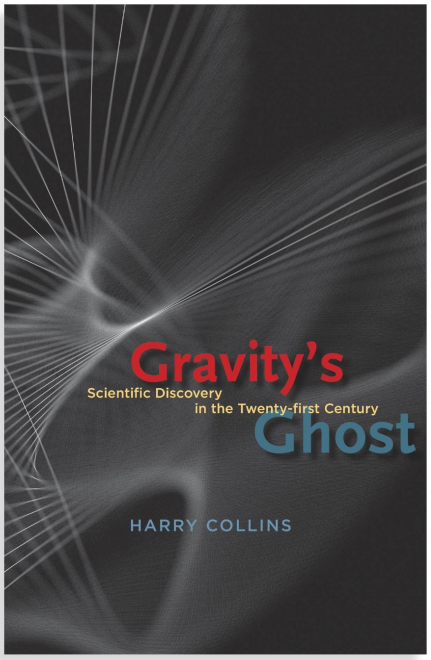
Received 1 August 1997

Parable 1: The complicated mess of the 1970's and 1980's APV experiments...

see talk by J. Ginges



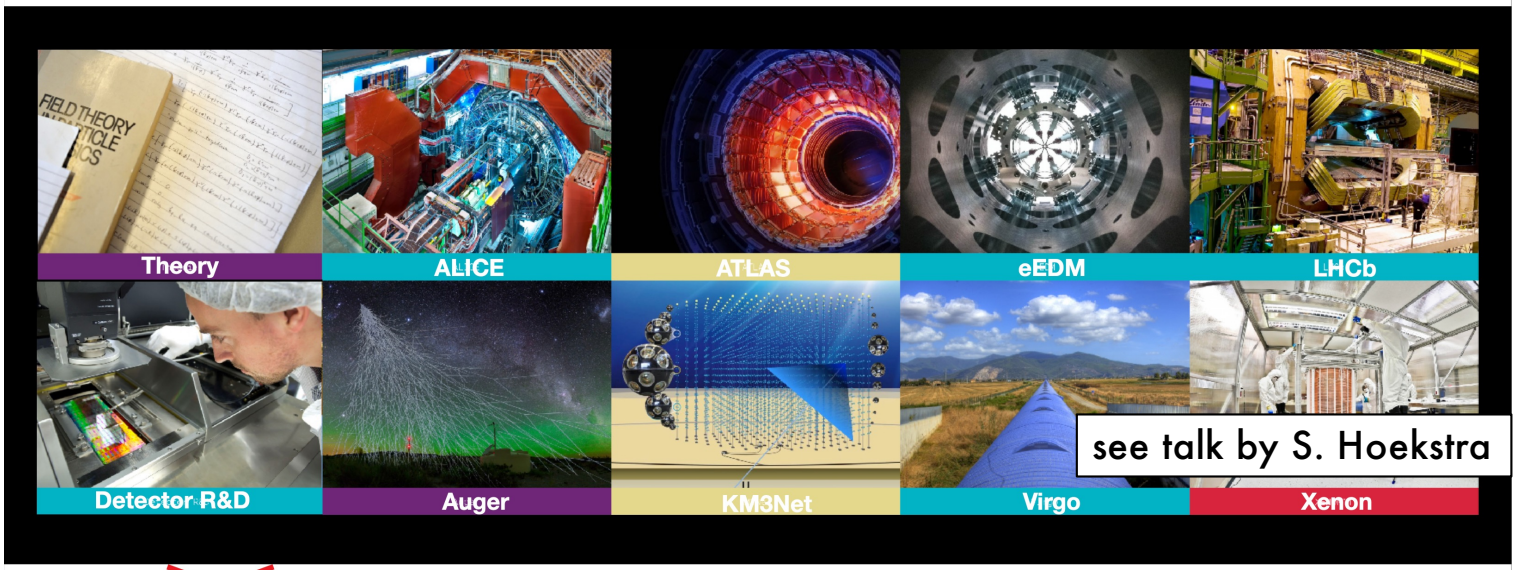
Parable 2: The several premature near-deaths of LIGO before their spectacular success!

Adopt the Italian Model!

A Call To Action! (Part 4/4)

1. Build a large team and attack the problem with overwhelming force from every angle in multiple ways – risk mitigation!
2. You must include theorists working at every length scale as well as chemists!
3. Shift your perspective from a single PI room-sized team to a multi-institution particle or nuclear physics collaboration! N.B. Relish the opportunity to learn patience and to improve your communication skills!

NL-eEDM: A Nikhef research programme started in 2017…



Nikhef
Dutch National Institute for (astro)Particle Physics

…using molecules and lasers

Data point 1: If the ACME collaboration can do this, then you can to!
Data point 2: Dave DeMille himself self-identifies as a particle physicist!

see intro talk by G. Pignol

From the past...

T I M E R E V E R S A L

Conférences données par le
Professur W. PAULI

à l'Ecole d'Eté de Physique Théorique

Les Houches, Haute-Savoie (France)
Eté 1952

https://www.houches-school-physics.com/books/

INTERACTION OF A NUCLEUS
with
ATOMIC AND MOLECULAR FIELDS

by

Norman F. RAMSEY
Harvard University

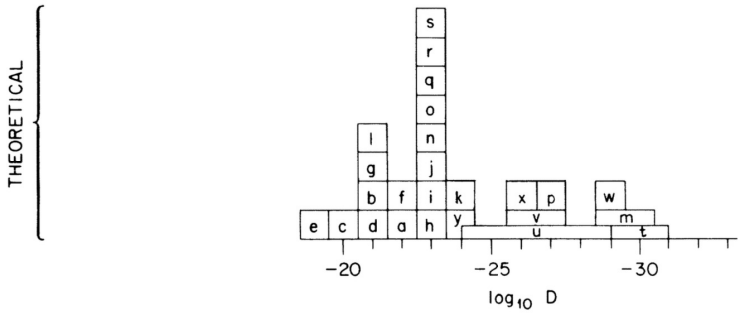
Université de Grenoble

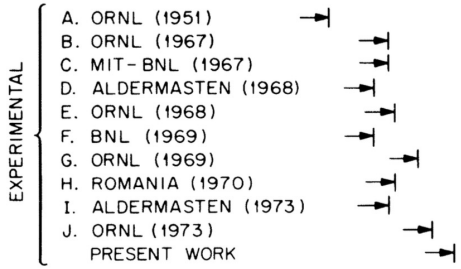
Cours professé à
L'ECOLE D'ETE DE PHYSIQUE THEORIQUE
Les Houches (Haute-Savoie) - France

Juillet 1955.

In atomic problems, exceptions to the above theorem sometimes arise due to degeneracy of states with different parity. On the other hand, the energy separations of different nuclear energy levels are so large compared to normal interaction energies with nuclear electric moments that such degeneracies are very unlikely. Purcell and Ramsey (PUR50) have pointed out that the above proof depends on the assumption that the electrical effects of a nucleus arise only from electrical charges or on a related parity assumption and that these assumptions are not necessarily self obvious in the case of little-understood particles like nucleons an nuclei. Therefore, in an experiment with J.Smith (SMI51a, SMI51b), they searched with high precision for a possible electric dipole moment of the neutron. They find, however, that if such a dipole moment exists its magnitude must be less than the charge of the electron multiplied by a distance D of 5×10^{-21} cm.

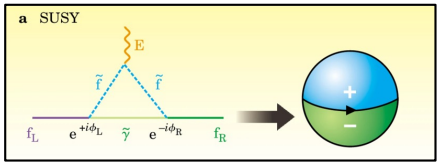
...towards the future! But let's think carefully about the appropriate way we motivate our EDM research...

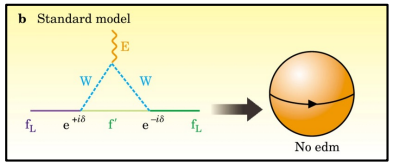




Phys. Rev. D 15, 9 (1977)

Physics Today, June 2003





CERN-TH-2025-161, Nikhef 2025-012

Bubble Trouble: a Review on Electroweak Baryogenesis

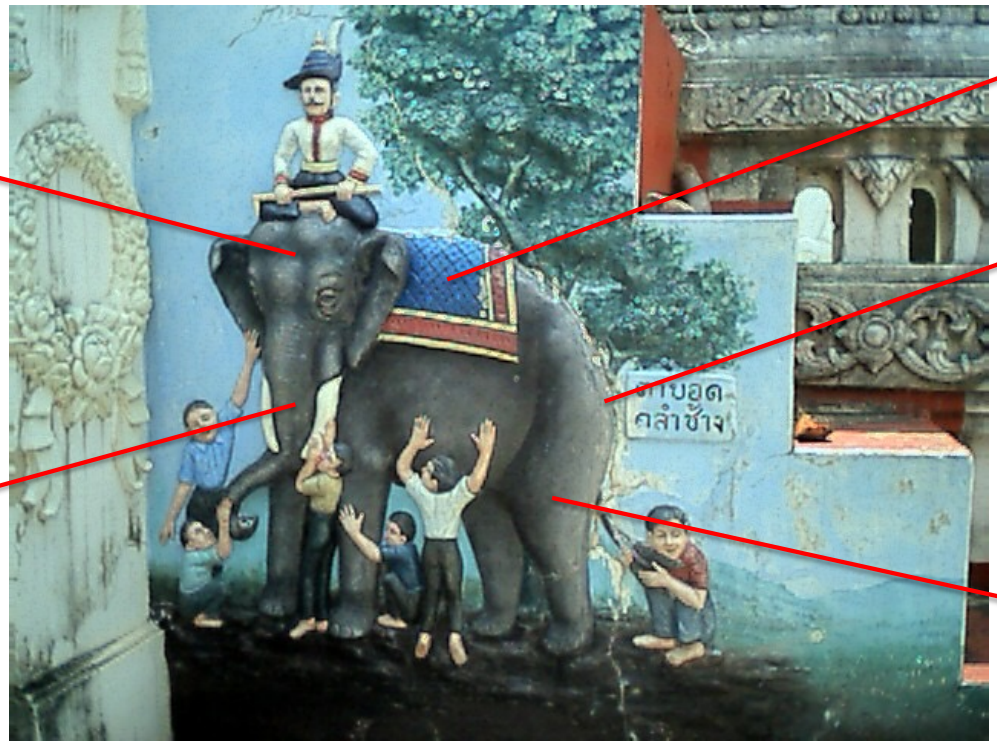
Jorinde van de Vis[a,*], Jordy de Vries[b,c], Marieke Postma[c,d]

[a] *Theoretical Physics Department, CERN, 1 Esplanade des Particules, CH-1211 Geneva 23, Switzerland*
[b] *Institute for Theoretical Physics, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, The Netherlands*
[c] *Nikhef, Science Park 105, 1098 XG Amsterdam, The Netherlands*
[d] *Institute for Mathematics, Astrophysics and Particle Physics, Radboud University, 6500 GL Nijmegen, The Netherlands*

https://arxiv.org/abs/2508.09989

see talks by J. v. de Vis and J. M. D. Illán

Complementarity: We are the Elephant Butt of New Physics Searches.



LHC Direct Searches

$\sigma_{\rm LHC} \propto |C_{ij}|^2$

Neutrino Oscillations

Particle Astrophysics

EDMs

$d_{\rm edm} \propto \mathtt{Im}\, C_{ij}$

see talk by M. Ardu

Neutrinoless Double Beta Decay

modified from Stéphanie Roccia's original concept

https://en.wikipedia.org/wiki/Blind_men_and_an_elephant

Towards a Common Language (Part 5/5): We are the Lobster Butt of New Physics Searches.

Particle Astrophysics

EDMs

$d_{\rm edm} \propto \mathrm{Im}\, C_{ij}$

see talks by M. Ardu and S. Y. Park

Neutrinoless Double Beta Decay

LHC Direct Searches

$\sigma_{\rm LHC} \propto |C_{ij}|^2$

Neutrino Oscillations

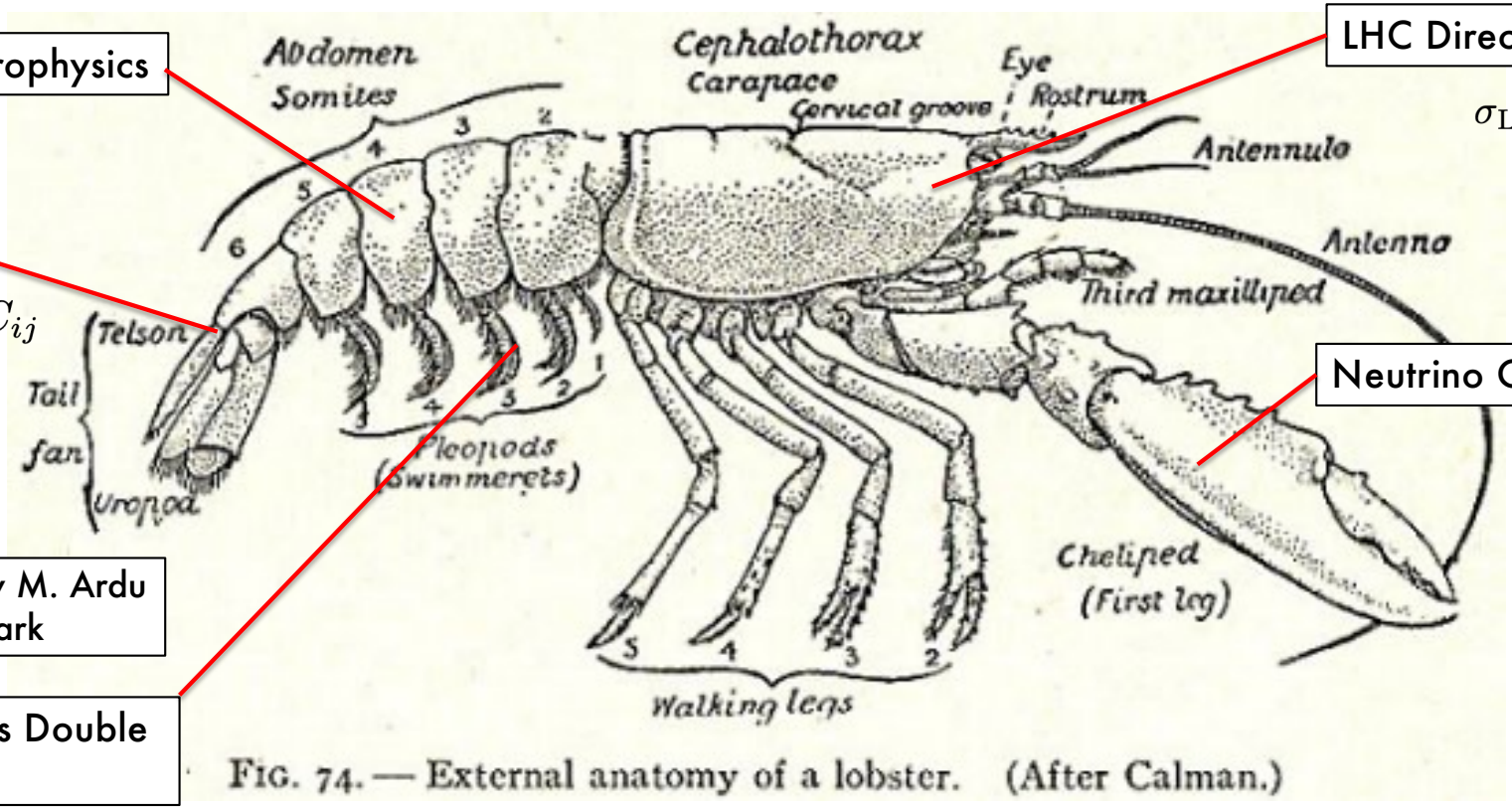
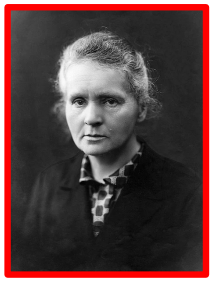


FIG. 74. — External anatomy of a lobster. (After Calman.)

https://thehaul.wordpress.com/terms-of-art/lobster-anatomy-diagrams/

We Are Following In The Footsteps Of Giants Towards A Transformational Discovery Within Our Lifetime!



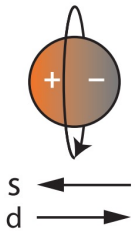
88 $^1S_0$
Ra
Radium
(226)
$[Rn]7s^2$
5.2784

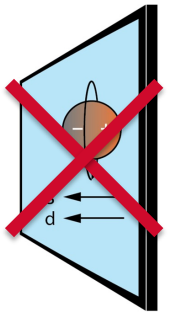
91 $^4K_{11/2}$
Pa
Protactinium
231.04
$[Rn]5f^26d7s^2$
5.89

87 $^2S_{1/2}$
Fr
Francium
(223)
[Rn]7s
4.0727

Chien-Shiung Wu (0/23)

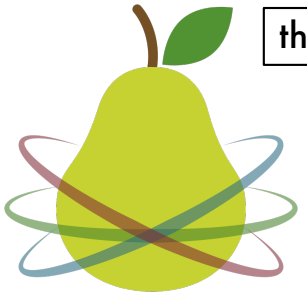
Marie-Anne Bouchiat (?/?)

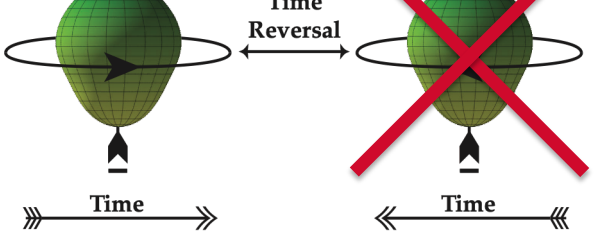




Wikipedia,
NIST
AIP Emilio Segre Visual Archives
M. Zolotrev

thanks Kent!





Marie Curie (2/5), Lise Meitner (0/49), & Marguerite Perey (0/5)

Thank You To Our Hosts and Sponsors!

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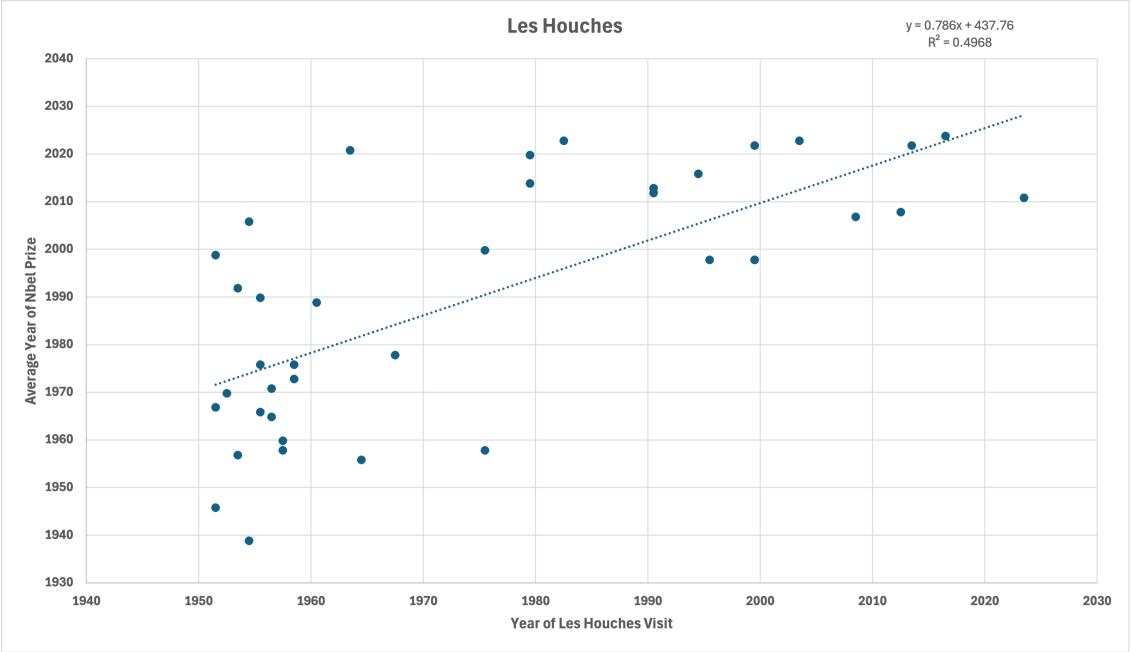
https://www.houches-school-physics.com/en/

WILHELM UND ELSE HERAEUS-STIFTUNG

https://www.we-heraeus-stiftung.de/english/

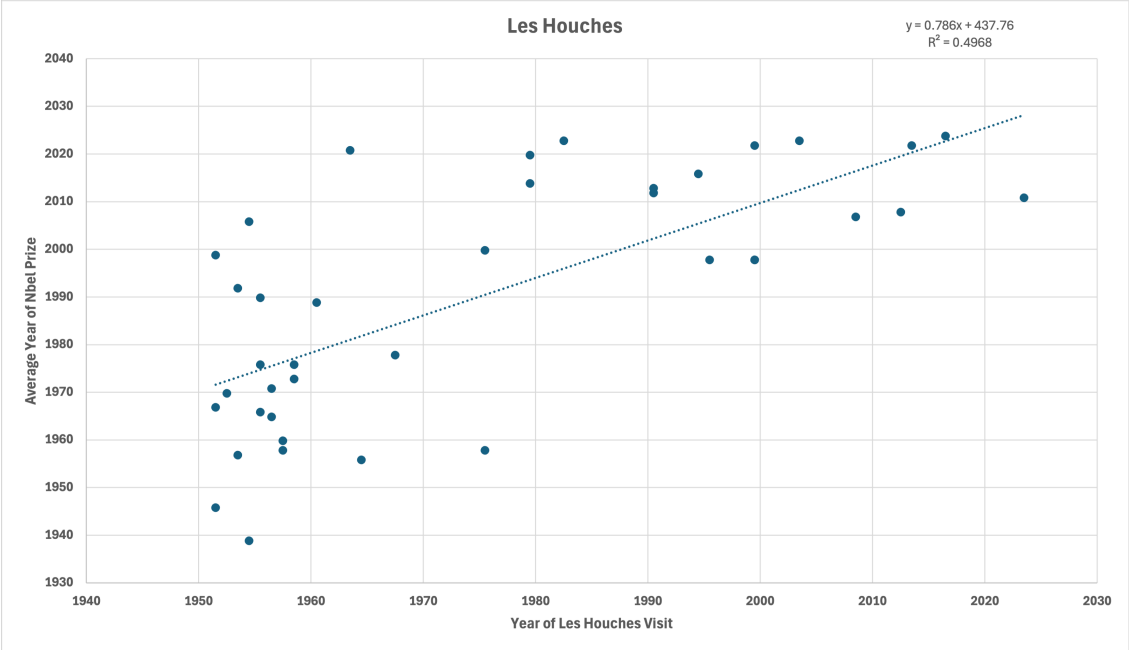
Thank You To Stephanie, Guillaume, and Skyler!

credit (above): Thomas Hepworth



Congratulations To Stephanie, Guillaume, and Skyler!

credit (above): Thomas Hepworth



Now: March 6, 2026 @ 12:25 PM
Nobel Prize Prediction: April 26, 2030 @ 06:11 AM
uncertainty is about 6 months

Thank You All!
See you next time if I am invited back after this!

credit (above): Thomas Hepworth

credit (right): Skyler Degenkolb