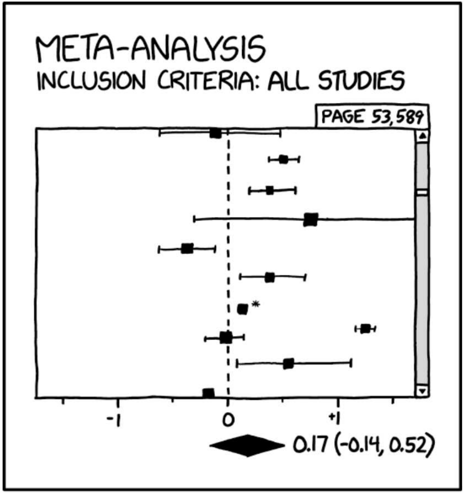
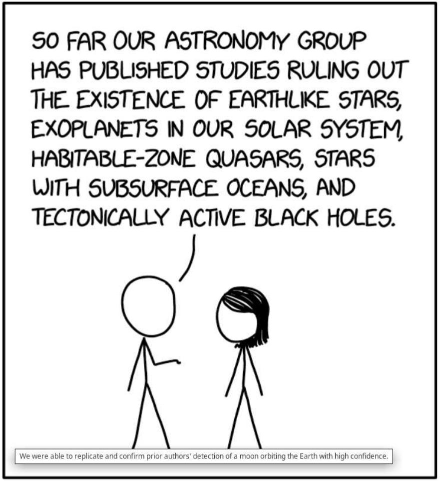
xkcd.com/2755/



BAD NEWS: THEY FINALLY DID A META-ANALYSIS OF ALL OF SCIENCE, AND IT TURNS OUT IT'S NOT SIGNIFICANT.

xkcd.com/2783/



SCIENCE GOT WAY EASIER WHEN WE REALIZED YOU WERE ALLOWED TO DO STUDIES JUST TO RULE STUFF OUT.

Laser Atom Traps at TRIUMF

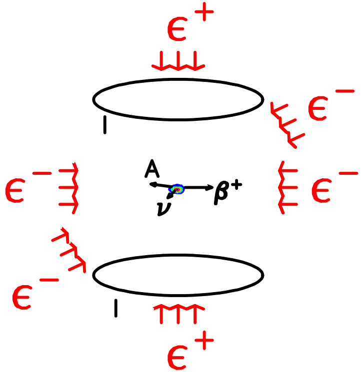
- How atoms traps don’t work, and how they do
- Intro to Parity:
  Its signatures in decays and in atoms
- TRIUMF Atom Trap for Beta Decay

Deduce ν momentum from the other products

Test standard model predictions for angular distributions: so far all ν’s are left-handed

- Francium Trapping Facility

Measuring the weak interaction in atoms by parity violation



Collaborations

TRIumf Neutral Atom Trap collaboration:

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TRIUMF
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J.A. Behr
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UNIVERSITY OF MANITOBA
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G. Gwinner

Support: NSERC, NRC through TRIUMF, U.S. DOE, State of Texas

FrPNC collaboration

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I. Halilovic
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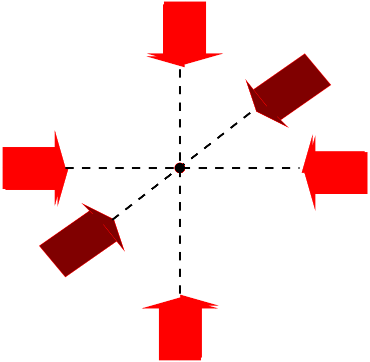
UNIVERSITY OF MARYLAND
L. Orozco

TRIUMF
J.A. Behr
A. Gorelov

Support: NSERC, NRC through TRIUMF, U.S. NSF

Magneto-optical trap: damping

For a trap, we want a damped harmonic oscillator
’Red-detuned’ beams provide the “damping”

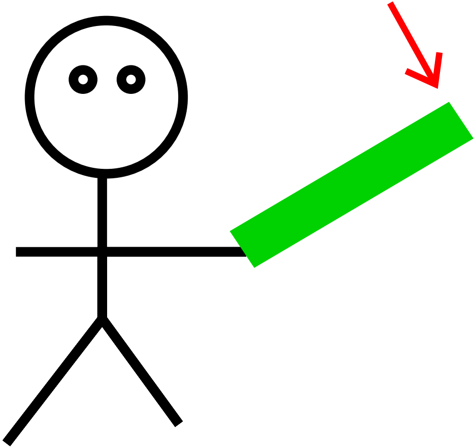


‘Optical molasses’

We still need a position-dependent force

“‘Light sabers’ would make atom traps easy” (H. Norton)

$$\vec{\nabla} \cdot \vec{S} \neq 0$$



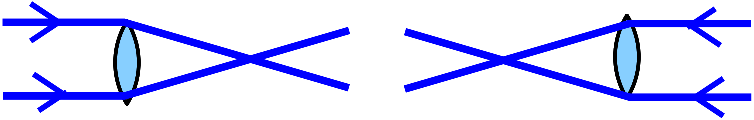
But light sabers violate Poynting’s theorem

“Why Optical Traps Can’t Work”

Earnshaw Theorem: $\vec{\nabla} \cdot \vec{E} = 0 \Rightarrow$

no electrostatic potential minimum for charge-free region

“Optical Earnshaw Theorem” (Ashkin + Gordon 1983):



$\Rightarrow$ no 3-D traps from spontaneous light forces with static light fields

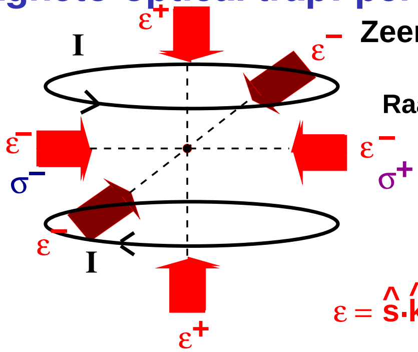
Using Poynting’s theorem:

$$\vec{\nabla} \cdot \vec{S} = \frac{c}{4\pi} \vec{\nabla} \cdot (\vec{E} \times \vec{B}) = -\vec{J} \cdot \vec{E} - \frac{\partial u}{\partial t} = 0$$

Dodges !

- Time-dependent forces (pulsed lasers)
- Dipole Force traps (“optical tweezers”)
- Modify internal structure of atom with external fields

Magneto-optical trap: perturb atoms

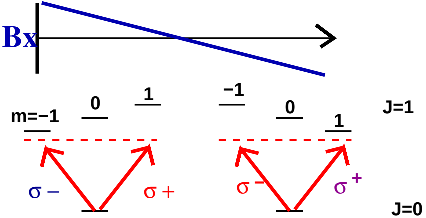


Zeeman Optical Trap (MOT)

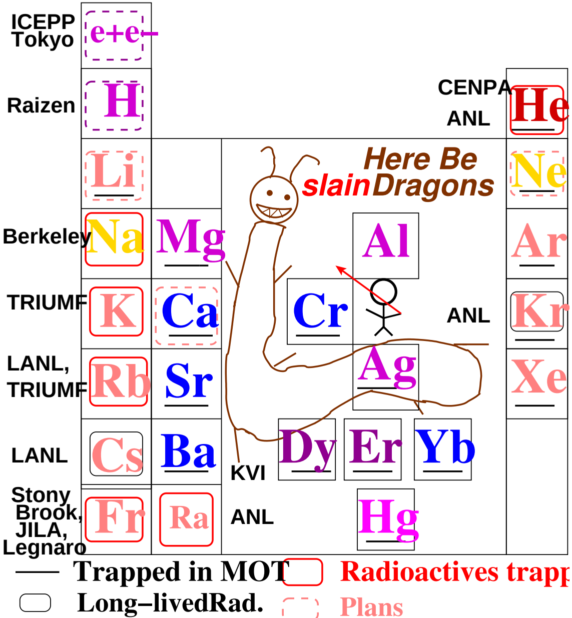
Raab et al. PRL 59 2631 (1987)

Damped harmonic oscillator

$\varepsilon = \hat{s} \cdot \hat{k}$



What elements can be laser cooled?

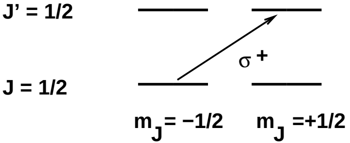


How to spin-polarize a nucleus with a laser

Polarization of nuclei by Optical Pumping

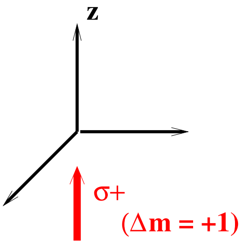
Biased random walk

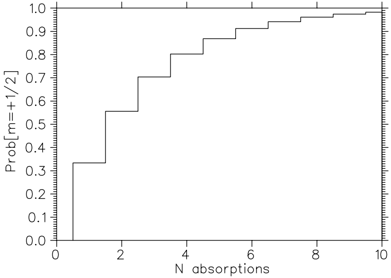
Simple example:



P(m=1/2) = 1 - $(2/3)^N$ after N steps

Need 12 cycles to get to 99% of maximum.





Parity (From A. Zee “Fearful Symmetry”)

As of 1956, we thought all interactions respected parity

Parity operator

$\boldsymbol{P}\,\psi(\vec{r}) \rightarrow \pm\,\psi(-\vec{r})$

$\boldsymbol{P}$  $=$ 

1957:

$\tau - \theta$ Puzzle

+ μ decay

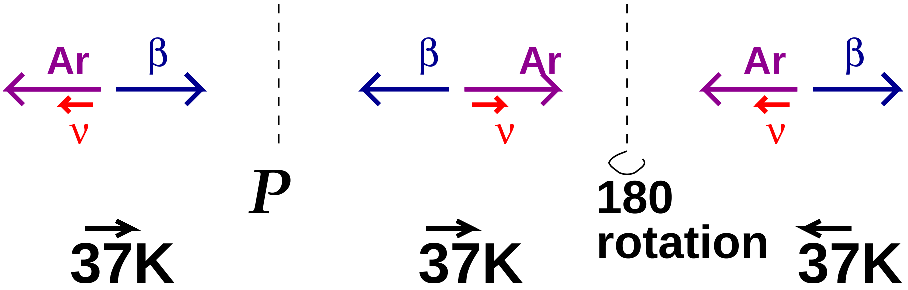
+ ^{60}Co decay $\Rightarrow$

$\boldsymbol{P}$  $\neq$ 

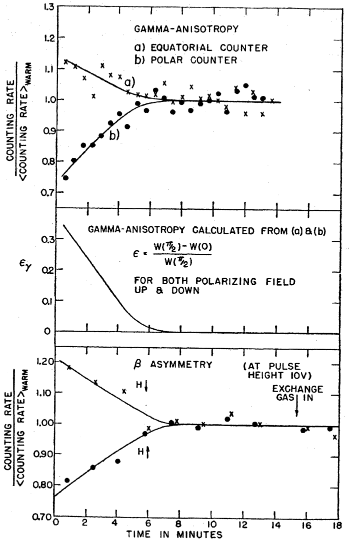
Decays: Parity Operation can be simulated by Spin Flip

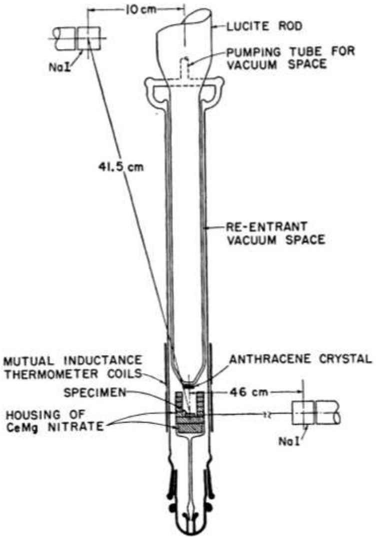
Under Parity operation *P*:

$\vec{r} \to -\vec{r}$ $\quad \vec{p} \sim \frac{d\vec{r}}{dt} \to -\vec{p}$ $\quad \vec{J} = \vec{r} \times \vec{p} \to +\vec{J}$



One experimental discovery of parity violation





Wu, Ambler, Hayward, Hopper, Hobson, PR 105 (1957) 1413

Dilution Refrigerator to spin-polarize

$$^{60}\mathrm{Co} \to {}^{60}\mathrm{Ni} + \beta^- + \bar{\nu}$$

$$W[\theta] = 1 + PA\hat{I} \cdot \frac{\vec{p}_\beta}{E_\beta}$$

$$= 1 + A\frac{v}{c}\cos[\theta]$$

$$A_{\beta-} \approx -1.0$$

Followup:

$$^{58}\mathrm{Co} \to {}^{58}\mathrm{Fe} + \beta^+ + \nu$$

$$A_{\beta+} > 0$$

$\not{P}$ in atoms is tiny

P  = 

Atoms are mostly chemistry,
i.e. electromagnetism, which respects Parity
Some $\not{P}$ effects are ppb

Consider 2 signatures:

Molecular enantiomer energies;

Controlled Stark-$\not{P}$ interference

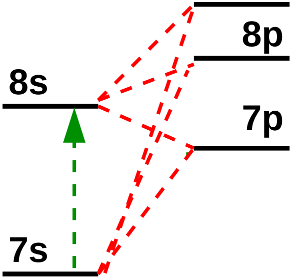
A "chargeless" weak interaction: the biggest Standard Model prediction

1973 ν scattering Gargamelle CERN

Stark - Weak interference: flip E field

This idea is credited to the Bouchiat's (theorist-experimentalist couple)
Wieman in Boulder made the best 'chargeless weak interaction" measurement in Cesium atoms in 1999.
Emulating Boulder Cs scheme in Fr:

$$|A_{7s\to 8s}|^2 = |E1_{\rm Stark} + E1_{\rm PNC}|^2$$
$$\approx |E1_{\rm stark}|^2 + 2E1_{\rm Stark}E1_{\rm PNC}$$

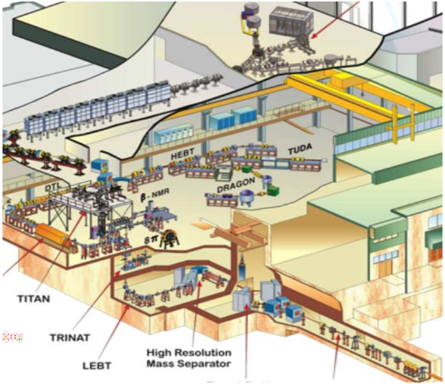


The interference term is $\sim 10^{-9}$ of an allowed E1 transition amplitude (rather than 10^{-18}).
By picking an E field one can make the asymmetry about 10^{-3}

- Then calculate (or, preferably, measure) $E1_{\rm Stark}$ to extract $E1_{\rm PNC}$

TRIUMF

TRIumf Neutral Atom trap at Isotope Separator + ACcelerator

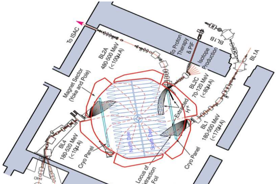


^{47}K 8x10^{6}/s

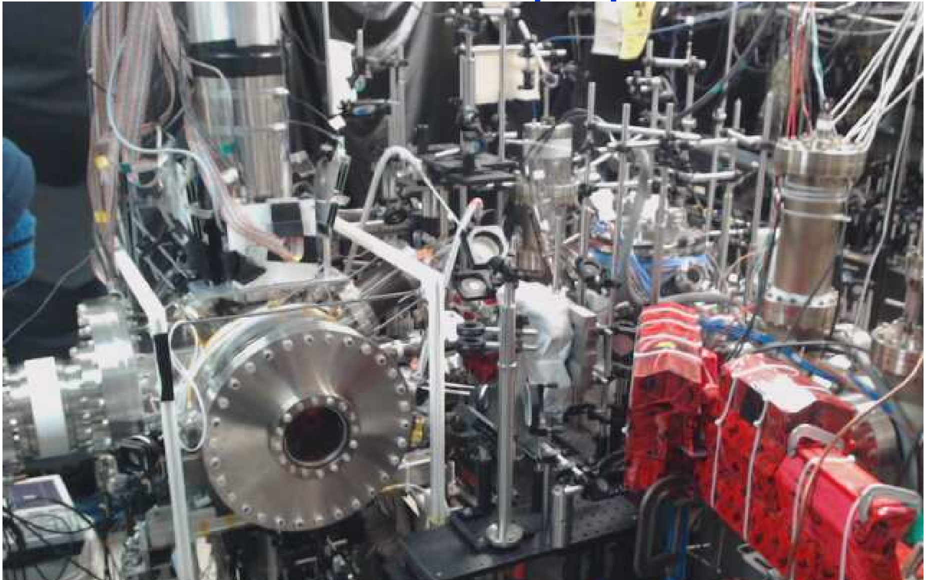
UC target
$\sim$ 2000^{o}C

20 μA
protons

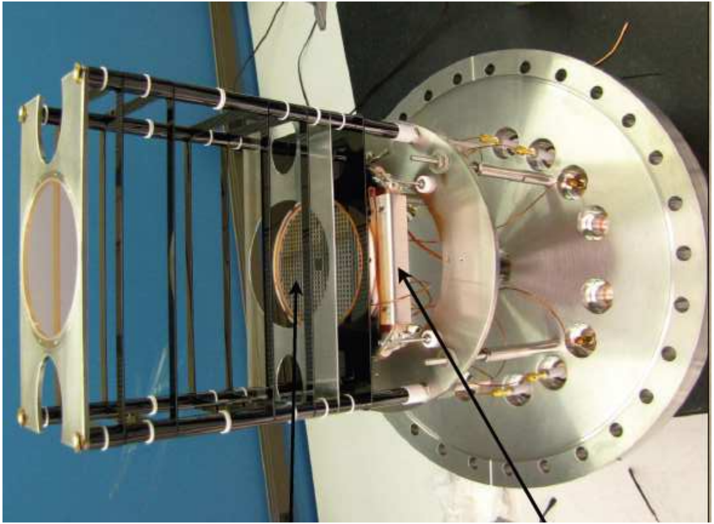
main TRIUMF cyclotron
‘world’s largest’
500 MeV H^{-} (0.5 Tesla)



TRINAT lab: “tabletop experiment”



ion MCP assembly



14 inch CF flange

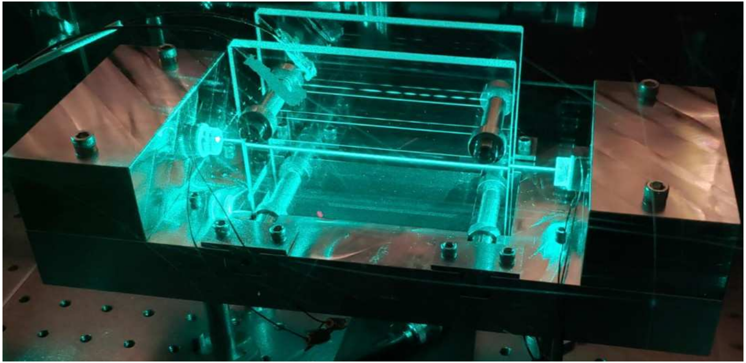
Electrostatic field

delay-line anode for position info

no stray wires

Low-Z (glassy carbon, titanium) to minimize β^+ scattering

Optical PowerBuildupCavity



To drive the weak transition

- 316LN SS + titanium +PEEK (no magnetism)
- Q $\approx$ 4,000

- Laser frequency-locked to UltraLowExpansion cavity (drifts $\sim$ MHz/month)
- PBC length is locked by PZT stack to keep integral number of λ's in cavity