Hadronic weak interaction

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Essential references

- [DDH]-Desplanques, Donoguhe, and Holstein, *Ann*. *Phys*. 124:449(1980)
- Adelberger and Haxton, *Ann. Rev. Nucl. Part. Sci.* 1985. 35:501
- Desplanques, Physics Reports 297(1988)1

DDH Theory

- Two-body Meson-exchange potential

$$V = \sum_{k=\pi,\rho,\omega} \sum_{\Delta I} h_{k,\Delta I}\, Y(m_k\, r)\, Q_k(p, r, \sigma, \tau)$$

- 6 free parameters $f_\pi, h_{\rho,0}, h_{\rho,1}, h_{\rho,2}, h_{\omega,0}$, and $h_{\omega,1}$
- DDH give reasonable ranges. reduce 6 to 4,

$$f_\pi, h_{\rho,0}, h_{\rho,2}, h_{\omega,0}$$

- Nuclear PV is determined by one-body potentials

$$X_N^{p\ or\ n} = \pm 5.5\, f_\pi - 1.13\, h_{\rho,0} - 0.91\, h_{\omega,0}$$

- The expressions for observables depend on the N-N PC potential used. (AV18 consistently used here.)

DDH ranges and best values

DDH limits and best

$f\pi$	0.	4.6	11.4
$f\rho 0$	−30.8	−11.4	11.4
$f\rho 1$	−0.38	−0.19	0.
$f\rho 2$	−11.	−9.5	7.6
$f\omega 0$	−10.3	−1.9	5.7
$f\omega 1$	−1.9	−1.1	−0.8

10 existing precise experiments and 4 constrained quantities

- p-p scattering at 15, 45 MeV
  - linear combination of $h_{\rho,0} + h_{\rho,2} \big/ \sqrt{6}$ and $h_{\omega,0}$
- p-p scattering at 220 MeV
  - $h_{\rho,0} + h_{\rho,2} \big/ \sqrt{6}$
- ^{18}F
  - f_{π}
- p-α, ^{19}F, ^{41}K, ^{175}Lu, ^{181}Ta asymmetries and ^{133}Cs anapole moment
  - X_N^p

p-p consistency check

- p-p at 15 and 45 MeV measure S-P interference and depend on the same linear combination of couplings
  - $f_{\rho,0} + f_{\rho,1} + f_{\rho,2} / \sqrt{6} + .92 (f_{\omega,0} + f_{\omega,1})$
- predicted ratio is .56 and measured ratio is .59±.27

One-body PV potential

- If the model-space of a nucleus consists of proton (or neutron) excitations then we are interested in matrix elements between these states, $\langle \psi_2 | V_{PNC} | \psi_1 \rangle$. Although V_{PNC} can change the state of two nucleons, the amplitudes where only 1 nucleon changes state add coherently and dominate the matrix element for large A.

Discussion of ^{18}F (^{19}F)

$$P_\gamma = \frac{2}{39\ \text{keV}}\left(\frac{\tau_- E_-^3}{\tau_+ E_+^3}\right)^{1/2} h_\pi \langle + | V_\pi | - \rangle$$

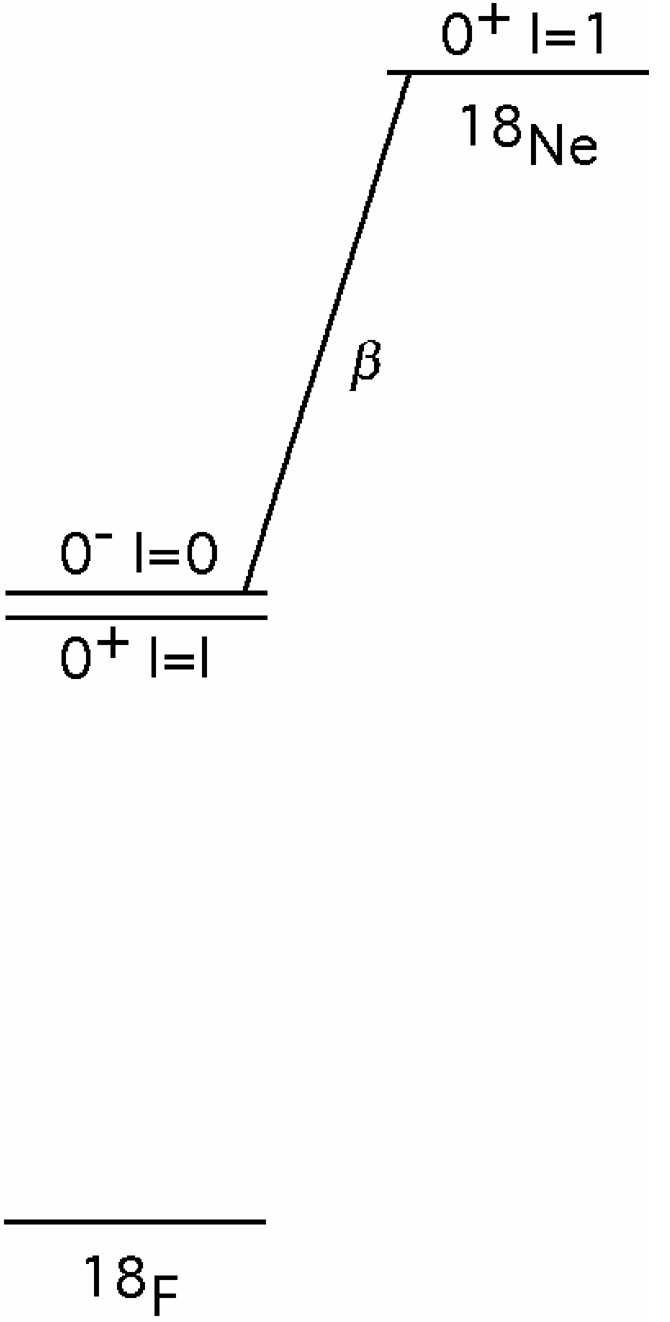
P_γ measured. $\langle + | V_\pi | - \rangle$ is needed.

^{18}Ne G. S. is the IAS of 0^+ $\mathrm{I} = 1$.

β decay amplitude $= aV_\pi(\tau_z \rightarrow \tau_\pm) +$

$b\, \sigma \cdot p\ \tau_\pm$

a and b from CVC and PCAC. The ratio of the matrix elements of the 1-body and 2-body matrix elements is independent of the details of the wave function. The measured lifetime determines $\langle + | V_\pi | - \rangle$.



Discussion of ^{21}Ne

- PV circular polarization of the 2789 keV γ in the odd-neutron nucleus ^{21}Ne is consistent with 0.
- One would expect a large asymmetry based on ^{18}F=0 and $X_{Np} \neq 0$.
- Both neutron and proton states are active in ^{21}Ne. PV asymmetries involve a theoretically unstable combination of X_{Np} and X_{Nn}. The combination depends on the residual interaction chosen. (A. Brown)
- Although some calculations have ^{21}Ne~ X_{Np},+X_{Nn}, ^{21}Ne can't be used to constrain the HWI.

- The repulsive short-range nucleon-nucleon potential reduces the contributions of the ρ and ω mesons. Deplanques has evaluated the linear combinations of couplings, X’s, that enter in PV in heavy nuclei using nuclear-matter theory for different nucleon-nucleon forces.

X_{Np} (for X_{Nn} change sign of $\Delta I=1$)

Force	f_π	$f_{\rho,0}$	$f_{\rho,1}$	$f_{\rho,2}$	$f_{\omega,0}$	$f_{\omega,1}$
AV18	5.5	-1.13	-.48	0	-.91	-.77
RSC	5.5	-.89	-.45	0	-.75	-.67
T-S	5.5	-1.98	-.81	0	-1.51	-1.26
Haxton	5.5	-1.91	-.58	0	-1.12	-.99

Consistency of 6 odd-proton nuclei

- p-α, ^{19}F, ^{41}K, ^{175}Lu, ^{181}Ta, and ^{133}Cs are all odd-proton nuclei. All are therefore ~ $X_{N,p}$.

Expt.	X_{Np}	
$p-\alpha$	6.1 ± 1.7	
^{19}F	7.8 ± 2.0	(coeffecient of f_π from experiment)
^{41}K	7.8 ± 1.6	
^{133}Cs	13.2 ± 2.3	
^{175}Lu	$5.9 \pm .5$	
^{181}Ta	$6.3 \pm .6$	

	Ave.	$\chi 2$/DoF	Pran
All 6	$6.4 \pm .4$	11.0/5	.05
X ^{133}Cs	$6.2 \pm .4$	2.1/4	.73

6 parameters and 4 constraints

- We need more independent experiments and/or additional theoretical information
- More theoretical information
  - Take DDH reasonable ranges at face value
  - $f_{\rho,1}$ and $f_{\omega,1}$ enter the expressions for observables with very small coefficients
- Fix $f_{\rho,1}$ and $f_{\omega,1}$ at DDH best values and add the DDH reasonable rang in quadrature to the experimental errors. Now 4 parameters and 4 constraints

Results of 4 parameter fit to 10 measurements

fitted parameters and DDH range

par	value	error	DDH		
$f\pi$	−0.456387	0.91383	0.	4.6	11.4
$f\rho0$	−43.3029	8.75909	−30.8	−11.4	11.4
$f\rho2$	37.0889	12.8566	−11.	−9.5	7.6
$f\omega0$	13.698	9.38951	−10.3	−1.9	5.7

$\chi2$/DOF= 7.48286/7

probability of random occurence= 0.380391

The AV18 potential was used.

10 Experiments consistently described by three couplings

Coupling	Value	DDH Range
f_π	$-.5 \pm .9$	$0 \rightarrow 11.4$
$h_{\rho,0}$	-33 ± 5	$-31 \rightarrow 11$
$h_{\rho,2}$	41 ± 13	$-11 \rightarrow 8$

3 parameter fit, $h_{\omega,0} = 0$, $\chi 2 / \mathrm{DOF} = 9.6 / 8$

Conclusions

- The fit is consistent with the data
- f_{π} is small (we already knew that from ^{18}F)
- $f_{\rho,0}$ is large (at the limit of the DDH range)
- $f_{\omega,0} \neq 0$ is not necessary to describe data
- $f_{\rho,2}$ may be large (2.2 σ outside the DDH range)
- Although ΔI=1 is Cabibbo allowed and ΔI=0 and 2 are Cabibbo suppressed, the fits show the opposite pattern
- It is desirable to determine more linear combinations of couplings

Future work

- Measure anapole moments in closed shell odd proton and odd neutron
  - Check theory of anapole moments - ^{133}Cs is a very complex nucleus
  - Check the one-body approximation. ^{209}Bi~X_{Np} and ^{207}Pb~X_{Nn}
- Measure γ circular polarization in $n+p \rightarrow d+\gamma$
  - Constrains $f_{\rho,2}$
- Measure PV observables in neutron reactions
  - Asymmetry in $n+p \rightarrow d+\gamma$, constrains f_π.
  - 2-body and few-body asymmetries
  - Use few-body methods to evaluate the asymmetries. Absolutely necessary to plan and interpret experiments!

Critique of DDH

- The possible spin-isospin structure of the PV interactions is fixed (Herczeg)
- DDH theory is a model. Assumes a particular momentum dependence for the interactions
- No demonstration that the model is complete or that the terms correspond to the physical light mesons
- 2-π exchange neglected
- Interpretation of many-body systems involves nuclear models (except for ^{18}F and ^{19}F)

EFT

- In principle couplings can be calculated using QCD
- A theory based on systematic expansion in low-energy constants. Early version had 10-12 constants
- C. P. Liu theory has f_{π} and 5 LEC's corresponding to S-P scattering amplitudes (Danilov parameters).
- Theory applies for energies < 40 MeV (can't us p-p 220 MeV)
- Liu has calculated all two-body PV observables
- Greens' function Monte Carlo method can reliably calculate PV matrix elements for few-body systems. Calculations are essential to plan and interpret experiments

Feasible two-body experiments

• p-p	$s_p \bullet k_p$	done
• $n+p \rightarrow d+\gamma$	$s_n \bullet k_\gamma$	phase 1 at LANL done
		phase 2 proposed at SNS
• $n+p \rightarrow d+\gamma$	γ CP	FEL or intense n source + improved CP polartimiter
• n+p	s_n rot.	next-generation

Feasible few-body experiments

• $p+\alpha$	$s_p \bullet k_p$	done
• $n+\alpha \rightarrow n+\alpha$	s_n rot.	preparing NIST
• $n+d \rightarrow t+\gamma$	$s_n \bullet k_\gamma$	consideration at SNS
• $n+d \rightarrow t+\gamma$	γ CP	see 2-body
• $n+{}^3He \rightarrow p+t$	$s_n \bullet k_n$	consideration at SNS
• $n+{}^3He \rightarrow p+t$	$s_3 \bullet k_n$	next-generation
• $n+d$	s_n rot.	preliminary expts. done

EFT

- Work out and publish spin-isospin content of EFT
  - Which couplings determine $\Delta I=0$, 1, and 2
- Work out one-body approximation for EFT in order to include nuclear PV constraints
  - Expect that $\Delta I=2$ is absent for nuclei
  - Expect that X's depend on nuclear force
    - Isospin and density dependence?
- Work out few-body observables in order to plan and interpret experiments

- EFT provides a rigorous framework for understanding HWI
  - 6 parameters
  - Valid for E Less that 40 MeV
- Two-body calculations done
- Need few-body calculations to design and interpret experiments
- Need existing and proposed 2 and few-body experiments to constrain f_{π} and 5 LEC's
- couplings reveal short-range structure of q-q correlations

Conclusions

- Experiments require small f_π and large $h_{\rho,0}$ and $h_{\rho,2}$. ΔI=1 is Cabbibo allowed and ΔI=0 and 2 are suppressed!
- The small ΔI=1 is solid. More assumptions are required for ΔI=0 and 2. ΔI=0 is large and ΔI=2 may be large.
- W and Z exchange are short-range. Above pattern is telling us something about the short-range behavior of q-q correlations in the non-perturbative regime.