Neutron Matter and Drops

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- Neutron Matter
  - EOS
  - Computational Aspects
  - Pairing Gap and Dispersion
  - Other Quantities

- Neutron Drops
  - Energies and Saturation
  - Comparing ab-initio energies with Skyrme
  - Pairing and Single-Particle Energies

- Future
Neutron Matter EOS

Neutron Matter properties less well-known than Nuclear Matter near equilibrium density. Ab Initio calculations can provide guidance to the density functional.

Equation of State at Low Densities

Gezerlis & Carlson, PRC 2008
Dilute Neutron Matter
various simulations

Dean Lee (08)
Low Density Neutron Matter
Microscopic vs. Skyrme

- Bsk8
- Bsk9
- SIII
- Sly4
- Sly5
- Sly6
- Sly7
- SkM*
- Neutron Matter
- Cold Atoms
Computational Approach:

GFMC: sum over spin/isospin explicitly
Diffusion MC: spin-independent (s-wave interactions)
AFDMC: Monte-Carlo sums over spin/isospin

All algorithms are branching random walks:
Significant linear algebra at each step in the walk

Neutron Matter Diffusion Monte Carlo
~65 particles (scales like $N^3$)
Gap with even/odd staggering
Need $<< 1$ MeV accuracy

Each calculation (fixed $\rho,N,k$) takes of order $1/2$ day on 1000 processors
approximately 1 Tflop on Franklin
90% parallel efficiency up to 1000 processors
Neutron Matter Pairing Gap

\[ \Delta / E_F \]

BCS-atoms
QMC Unitarity

BCS-neutrons

Neutron Matter
Cold Atoms

Gezerlis and Carlson, PRC 08
Neutron Matter Pairing Gap

Analysis of cold atom experiments gives Gap/Ef = 0.45 (05).

Largest Gap/Ef in any system!
Carlson and Reddy, PRL 08

Calculations also agree; new AFDMC calculation much closer to DMC
New Calculations:
Dispersion of Single-Particle States

Can be a constraint to Skyrme models
weak reaction rates, spin susceptibility,...
of interest in neutron stars
Momentum Distributions

- $k_f a = -10$ ($k_f = 0.54 \text{ fm}^{-1}$)
- $k_f a = -5$
- $k_f a = -2.5$
Neutron Drops

Information beyond constant (local) density:
Adjustable External Potential
Woods-Saxon, Harmonic Oscillator
adjusts density, deformation, ...
Can compare microscopic theory and DF Energies
Density
Pairing
etc.
Neutron Drops

Present: Compare ab-initio with Skyrme Models
Future: Additional Constraints to Skyrme,...

GFMC calculations

AV18 + UIX (closed)
AV18 (open)
Shallow well comparison

$V_0 = -25$ MeV, $\sim 1$ MeV/N binding of sd shell

Overbinding, BSK8 and SIII give best agreement

Note: no pairing included in Skyrme
Deeper well comparison

Significant overbinding, particularly for N>8
Single-Particle Densities

8 Neutrons
Woods Saxon: $V_0 = -35.5, r_0 = 3.0, a = 1.1$

GFMC: AV18+UIX: $E = -103.3(1)$
GFMC: AV18 + UIX: $V_0 = -20: E = -35.71(0.04)$
GFMC: AV18: $V_0 = -20: E = -36.35(0.04)$
8 Neutrons

Woods Saxon: $V_0 = -35.5, r_0 = 3.0, a = 1.1$

- GFMC: AV18+UIX: $E = -103.3(1)$
- Skyrme SIII: $E = -112.915$
- Skyrme SLY4: $E = -119.05$
- Skyrme SLY6: $E = -119.436$
- Skyrme SLY7: $E = -118.53$
- Skyrme SkP: $E = -117.92$
- Skyrme SkM*: $E = -128.394$
- Skyrme Bsk8
- Skyrme Bsk9
- GFMC: AV18
Pairing and single-particle states

Just starting in Skyrme models

Both GFMC and Skyrme give 1s lower than 0d in N=9 Woods-Saxon wells
Note: 17O has opposite behavior

Magnitude of splitting; dependence on well being investigated
Plans: Remainder of year 2

Neutron Matter: finish s.p. excitations and comparisons w/ other results
Neutron Drops: finish first round of drops, including pairing and HO pot.
Nuclei: contribute to improving initial 12C

Plans: Year 3

Neutron Matter/Drops: Additional external potentials
  quadrupole, other fields in drops
  static density response in matter
Nuclear Scattering: Benchmark low-energy scattering in A<12
Light Nuclei: External Wells
  Improvements in 12C toward Hoyle state
Algorithms: AFDMC / AFMC methods
  promising initial results in (polarized) cold atoms Stetcu
(Preliminary) Plans: Years 4 and 5

Quantum Monte Carlo for largest computers (Roadrunner, BGP, ...)

Scattering/Reactions for Light Nuclei

\(^{12}\text{C}\) calculations, Hoyle state and transitions

Larger Nuclei and Matter w/ QMC methods (AFDMC and/or AFMC)