$\boxed{\text{March 29}}$

Equation of state of matter of nucleons at baryon density $n_B$ and proton fraction $x$

$T \simeq 0$ : reasonable @ density such that $k_F^2/2m \gg T$

@ $\rho_B = \rho_0 = 0.16\ fm^{-3}$

$$k_F \propto (3\pi^2 \rho_B)^{1/3}$$

$$\frac{k_F^2}{2m} \approx 20\ MeV \cong 10^{11}\ K$$

#

$$\frac{E(n_B)}{N_B} = e(n_B), \quad P = -\left(\frac{\partial E}{\partial V}\right)_N = n_B^2 \frac{\partial e}{\partial n_B}$$

Basic quantity $e(n_B)$ from a dynamical model

What do we know: <u>phenomenology</u>

Yukawa: nucleons are Dirac's spinors

exchange of boson

$$m \sim 1\,\mathrm{fm}^{-1} \sim 200\ \mathrm{MeV}$$

$$\cancel{\pi}$$

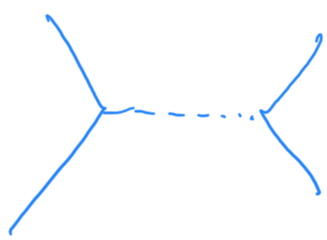
$$\mathcal{L} = \bar{\psi}(i\not{\partial} - m)\psi + \mathcal{L}_I$$

$$\psi_N = \begin{pmatrix} p \\ n \end{pmatrix}$$

$\pi$-meson $\quad m_\pi \sim 140\ \mathrm{MeV} \quad J^\pi = 0^-$

$$\mathcal{L}_I = g\bar{\psi}\gamma^5\psi\,\pi \qquad \pi = \begin{pmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \end{pmatrix}$$

$$\pi^\pm = \frac{1}{\sqrt{2}}(\pi_1 \pm i\pi_2) \qquad \pi^0 = \pi_3$$



non relativistic limit → potential

$$V_\pi \propto \frac{e^{-m_\pi r}}{r}$$

strongly spin-isospin dependent
and non central

$$S = \frac{(\vec{r}\cdot\vec{\sigma}_1)(\vec{r}\cdot\vec{\sigma}_2)}{r^2} - \vec{\sigma}_1 \cdot \vec{\sigma}_2$$

~ magnetic dipole.

How does it work?

Short answer: it only works
@ short distance.

How do we know? Phase
shift analysis

Fit partial waves @ large
angular momentum

$\boxed{\text{Fig. from Marco's thesis}}$

Realistic potentials that
fit all partial waves

... ... ... ...
up to pion-production
threshold.

$$V_{ij} = \sum_{n=1}^{6} v^{(n)}(r_{ij})\, O_{ij}^{(n)}$$

$$O^{(n)} = [\mathbb{1}, (\vec{\tau}_i\cdot\vec{\tau}_j)] \times [\mathbb{1}, (\vec{\sigma}_i\cdot\vec{\sigma}_j), S_{ij}]$$

Excellent fit: ~ 40 params
to reproduce thousands of
data points $\chi^2/\#\text{dof} \sim 1$

phase shifts from
Bob's webpage.

Bound state properties also
ok.

$$H\Psi_D = E_D\Psi_D$$

$\Rightarrow E_D$

$\Rightarrow Q_D$

$\Rightarrow \mu_D$

Three-body force

...

Predictive power of phenomenological hamiltonian

$$H = T + \sum_{j>i} v_{ij} + \sum_{k>j>i} V_{ijk}$$

$v_6$ deuteron + S-wave phase shifts

$v_8$ $(\vec{l}\cdot\vec{S})$ $(\vec{l}\,\vec{S})(\vec{\tau}_1\vec{\tau}_2)$

P-wave phase shifts

additional contributions

$[(\vec{l}\,\vec{S})^2, \; L^2][\mathbb{1}, (\vec{\tau}_1\vec{\tau}_2)]$

+ charge-symmetry breaking terms

Nearly exact calculations possible for $A \le 12$

$\boxed{\text{Note on chiral potentials } (*)}$

Approximations needed for larger A.

However in the $A \to \infty$, $V \to \infty$ limit with $\frac{A}{V}$ finite translation invariance can be exploited to greatly simplify calculations

Fundamental problem interactions cannot be treated in perturbation theory: recall $g_\pi^2/4\pi \sim 14$ needed to explain (at least qualitatively) the D-wave phase shifts.

Possible solution

- Extension of stochastic methods

- Renormalisation of the NN interaction

G-matrix perturbation theory

Variational approach.