Finite nuclei based on quark meson coupling model

S. Karan[1],* P. K. Panda[1], A. Rabhi[2], and R. N. Mishra[3]
[1]*Deptartment of Physics, Utkal University, Bhubaneswar,Odisha, 752004, INDIA*
[2]*University of Carthage, Institut Preparatoire aux Etudes Scientifiques et Techniques, BP51, 2070 La Marsa, Tunisia and*
[3]*Department of Physics, Ravenshaw University, Cuttack,Odisha-753003, INDIA*

An accurate description of the properties of finite nuclei is one of the fundamental problems in theoretical nuclear physics. Several nuclear models have been proposed to overcome the problem as well as to describe nuclear matter properties. An entirely different model was proposed by Guichon which is based on a mean field description of nucleons, namely the quark meson coupling(QMC) model.

This model may be viewed as an extension of quantum hydrodynamics(QHD)[1]. However the mesons couple not to point like nucleons but to confined quarks. The quark meson coupling model describes nuclear matter as a system of nonoverlapping MIT bags in which quarks interact with the scalar (σ) and vector (ω, ρ) fields and those are treated as classical fields in the mean field approximation. The quark field ψ_q, inside the bag then satisfies the equation of motion:

$$i\partial\!\!\!/ - [(m_q^0 - g_\sigma^q) - g_\omega^q \omega \gamma^0 + \frac{1}{2} g_\rho^q \tau_3 \rho_{03} \gamma^0] \psi_q(x) = 0, \qquad q = u, d \tag{1}$$

where m_q^0 is the current quark mass and g_σ^q, g_ω^q, g_ρ^q denote quark meson coupling constants. The normalized ground state for a quark in the bag is given by

$$\psi_q(r,t) = \mathcal{N}_q \exp(-i\epsilon_q t/R) \times \begin{pmatrix} j_0(x_q r/R) \\ i\beta_q \vec{\sigma}.\hat{r} j_1(x_q r/R) \end{pmatrix} \frac{\chi_q}{\sqrt{4\pi}} \tag{2}$$

where

$$\epsilon_q = \Omega_q + R(g_\omega^q \omega + \frac{1}{2} g_\rho^q \tau_3 \rho_{03})$$

and

$$\beta_q = \sqrt{\frac{\Omega_q - R m_q^*}{\Omega_q + R m_q^*}}$$

with the normalization factor given by

$$\mathcal{N}_q^{-2} = 2R^3 j_0^2(x_q)[\Omega_q(\Omega_q - 1) + R m_q^*/2]/x_q^2$$

where $\Omega_q \equiv \sqrt{x_q^2 + (R m_q^*)^2}$ and $m_q^* = m_q^0 - g_\sigma^q \sigma$. The bag eigenvalue for nucleon N is determined by the boundary condition at the bag surface

$$j_0(x_q) = \beta_q j_1(x_q).$$

The energy of a static bag describing nucleon consisting of three quarks in ground state is expressed as:

$$E^{bag} = \sum_q n_q \frac{\Omega_q}{R} - \frac{Z}{R} + \frac{4}{3}\pi R^3 B \tag{3}$$

where Z is a parameter which accounts for the zero point motion of nucleon and B is a bag constant[2]. The term Z/R contains all the corrections such as center of mass and gluonic correction.

The effective mass of nucleon bag at rest is taken to be $M^* = E^{bag}$. The equilibrium condition for the bag is obtained by minimizing the effective mass, M^* with respect to bag radius.

$$\frac{dM^*}{dR^*} = 0, \tag{4}$$

By fixing the bag radius R=0.8 fm and bare nucleon mass M=939 MeV ,the unknowns Z=3.27320 and $B^{\frac{1}{4}}$=170.29493 MeV are obtained.The coupling parameters are

*Electronic address: supriyakaran555@gmail.com

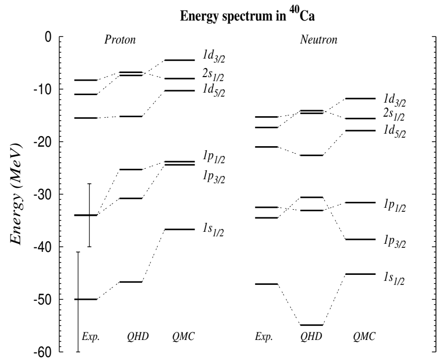

FIG. 1: Energy spectrum of ^{40}Ca

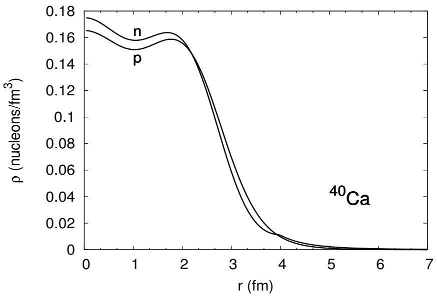

FIG. 2: Nucleon density distribution in ^{40}Ca (for $m_q = 0$ MeV and R=0.8 fm)

g_σ^q=5.73764, g_ω=8.18473, g_ρ=8.760155,where g_ω=3g_ω^q and g_ρ^q=g_ρ.The meson masses are m_σ=550 MeV, m_ω=783 MeV and m_ρ=770 MeV. For the effective nucleon mass as a non linear function of the σ meson

$$M^* = M - g_\sigma(\sigma)\sigma \tag{5}$$

with $g_\sigma(\sigma)$=$(1 + \frac{b}{2}\sigma)$, g_σ=$3g_\sigma^q S(0)$=8.25333, b=$-0.00378MeV^{-1}$ and

where

$$S(\sigma(r)) = \frac{\Omega/2 + m_q^* R^*(\Omega - 1)}{\Omega(\Omega - 1) + m_q^* R^*/2} \ ,$$

with $S(0)$=0.479484.

For static spherically symmetric nuclei the variation of corresponding Lagrangian results a set of coupled non liner differential equations, which may be solved by standard iteration procedure. The numerical calculation was carried out for the nucleons like ^{40}Ca, ^{16}O, ^{48}Ca, and binding energy and rms charge radius were obtained.

The calculated spectrum of ^{40}Ca is presented in Fig. 1. The charge density distribution for ^{40}Ca (for $m_q = 0$ and $R = 0.8fm$) is presented in Fig. 2. In table we have shown the binding energy and charge radius for different spherically symmetric nuclei, which fit well with experimental data. Calculation for heavier spherical nuclei is in progress.

TABLE I: Binding energy per nucleon E/A (in MeV), rms charge radius r_{ch} (in fm). $m_q = 0MeV$ and $R = 0.8fm$

Model	$-E/A$			r_{ch}		
	QMC	QHD	Exp.	QMC	QHD	Exp.
^{16}O	7.971	4.89	7.89	2.07	2.75	2.73
^{40}Ca	7.841	6.31	8.45	2.70	3.48	3.48
^{48}Ca	6.731	6.72	8.75	2.80	3.47	3.47

References

[1] C. J. Horowitz, B. D. serot, Nuclear Physics **A 609**, 503 (1981).

[2] G. Grams,A. M Santos, P.K. Panda, C. Providencia, D. P. Menezes, Phys. Rev. C **95**, 055807 (2017).