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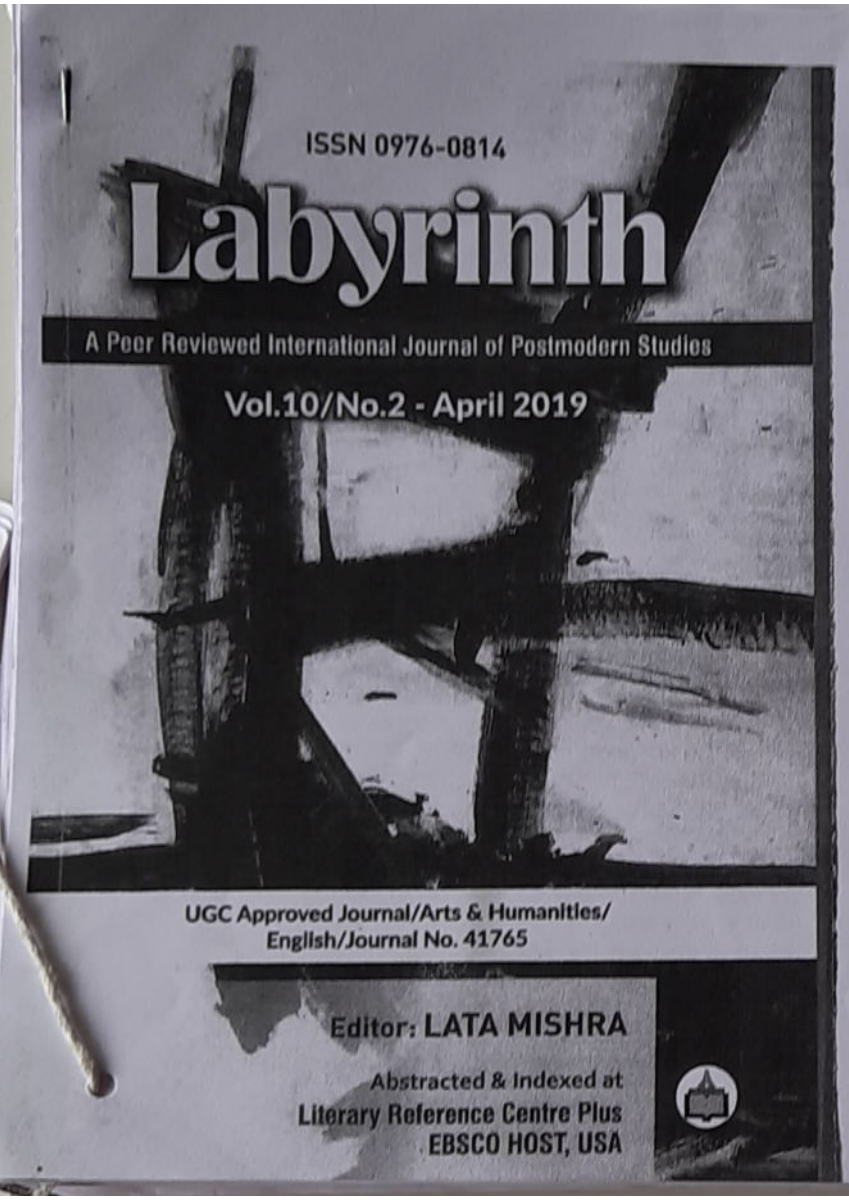

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# Labyrinth

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strength. Eco-feminism can be defined in many ways. According to McMillen, "the term was coined in the seventies by the French author Francoise d' Eaubonne. For d' Eaubonne the term was meant to counter the oppression of women and to defend Nature from the destruction by men" (Tollefsen 90). The ecological balance and the preservation of ecosystems is a prime objective of Eco-feminists. The late 20th century witnesses Eco-feminism as a movement speaking for women, nature and marginalised group.

Eco-feminist theory originated from the proposition that both woman and nature have been worst sufferers at the hands of Men in patriarchal society. This theory envisages that the harassment of both nature and women be eliminated. It promises a discourse that focuses a peaceful coexistence of woman and nature and both are equal sufferers and share the pains of each other very naturally. Feminist analysis covered the shared experiences of women and nature with a new vision. More specifically, Eco-feminists evaluate exploitation of women and nature by targeting the hierarchies created by culture, male, society, higher caste etc. The main focus of the theory is to reconceptualise the treatment of women and nature in non-hierarchical and non patriarchal ways. Peter Barry says that "eco-feminists re-read major literary works from an eco-centric perspective with particular attention to the representation of the natural world" (Barry 264). The emphasised on the preservation of ecosystems and advocated the principles of liberating women and nature from the ditches male-oriented society. Eco-feminists believe that human race can be saved by men and women with their revolutionary fervour to avoid such oppression which is harmful to nature. The present paper will be analysed through Eco-feministic framework.

In India, environmentalism began to be perceptible when the huge gamut of woman took part in the Chipko movement to protect forests from deforestation. These women dung to the

# 13

# Nature-Women Proximity: An Eco-feminist Reading of S.R. Harnot's *The Reddening Tree*

LEELA DHAR

ABSTRACT

In an era of ecological crisis, Eco-feminism is the only hope of retaining ecological balance in our modern world. The core thoughts of Eco-feminism are Mother-Earth, strength and integrity of every living thing. It also promises the discourse that cares for Mother Earth. It aims at exploring women-nature proximity. Women and nature have been two entities having calm nature fulfilling the required needs of men since the ancient times. However, culture is considered as superior to nature as men over women in our society. Defending nature and women, it has become the need of hour to save human civilisation. The present paper entitled "Nature-Woman Proximity: An Eco-feminist Reading of S.R. Harnot's 'The Reddening Tree'" is an attempt to have a disinterested view of hierarchical stratification of culture over nature and subsequently of men over women. It also explores how the human race can be saved by women and men collectively.

*Keywords:* Eco-feminism, Gender, Culture, Nature and Hierarchy of society.

Eco-feminism is a holistic belief that aims at focusing on care and concern for Mother Earth, love for the intrinsic value of all life and interdependence of living and non-living beings on this earth. It interrogates the difficulties that women and nature face on account of exploitation, suppression, destruction and indifference by hierarchal system or patriarchal structure of society. It motivates human beings to integrate their collective



strength. Eco-feminism can be defined in many ways. According to McMillen, "the term was coined in the seventies by the French author Francoise d' Eaubonne. For d' Eaubonne the term was meant to counter the oppression of women and to defend Nature from the destruction by men" (Tollefsen 90). The ecological balance and the preservation of ecosystems is a prime objective of Eco-feminists. The late 20th century witnesses Eco-feminism as a movement speaking for women, nature and marginalised group.

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# GABA (γ-aminobutyric acid), as a thermo-protectant, to improve the reproductive function of heat-stressed mungbean plants

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Manu Priya[1], Lomeshwar Sharma[1], Ramanpreet Kaur[1], H. Bindumadhava[2], Ramkrishnan M. Nair[2], K. H. M. Siddique[3] & Harsh Nayyar[1]

**Rising global temperatures are proving to be detrimental for the agriculture. Hence, strategies are needed to induce thermotolerance in food crops to sustain the food production. GABA (γ-aminobutyric acid), a non-protein amino acid, can partially protect plants from high-temperature stress. This study hypothesises that declining GABA concentrations in the cells of heat-stressed mungbean plants increases the heat-sensitivity of reproductive function. Mungbean plants were grown in a natural, outdoor environment (29.3/16.1 ± 1 °C as mean day/night temperature, 1350–1550 µmol $m^{-2}$ $s^{-1}$ light intensity, 60–65% as mean relative humidity) until the start of the reproductive stage. Subsequently, two temperature treatments were imposed in a controlled environment—control (35/23 °C) and heat stress (45/28 °C)—at about 800 µmol $m^{-2}$ $s^{-1}$ light intensity and 65–70% as mean relative humidity, until pod maturity. In heat-stressed (HS) plants, endogenous GABA concentrations in leaf and anther samples had declined by 49 and 60%, respectively, and to a much lesser degree in the plants, exogenously supplemented with 1 mM GABA. The reproductive function of GABA-treated heat-stressed plants improved significantly in terms of pollen germination, pollen viability, stigma receptivity and ovule viability, compared to untreated HS controls. In addition, GABA-treated heat-stressed plants had less damage to membranes, photosynthetic machinery (chlorophyll concentration, chlorophyll fluorescence, RuBisCO activity were functionally normal) and carbon assimilation (sucrose synthesis and its utilisation) than the untreated HS controls. Leaf water status improved significantly with GABA application, including enhanced accumulation of osmolytes such as proline and trehalose due to increase in the activities of their biosynthetic enzymes. GABA-treated heat-stressed plants produced more pods (28%) and seed weight (27%) $plant^{-1}$ than the untreated controls. This study is the first to report the involvement of GABA in protecting reproductive function in mungbean under heat stress, as a result of improved leaf turgor, carbon fixation and assimilation processes, through the augmentation of several enzymes related to these physiological processes.**

Considering the gradual rise in global and local temperatures, heat stress is becoming a major determinant affecting the production potential of various cool-season and summer-season crops[1,2]. Heat stress impairs plant growth and development with marked alterations in phenology, morphology, physiology, biochemistry and gene expression that eventually inhibit the production potential of affected crops[3]. The response of plants to heat stress is dependent on the growth stage; for example, heat stress during the vegetative stage can retard growth, accelerate phenology, and result in chlorophyll loss, scorching and necrosis. Plant cells show damaged membranes, denatured proteins and enzymes in cytosol and organelles, impaired synthesis of carbohydrates and proteins, synthesis of new heat stress-related proteins, oxidative damage, dehydration and loss of turgor-maintaining mechanisms[3]. Heat stress, at the time of reproductive stage, is more detrimental, which can result in flower and pod abortion, and impaired development and function of reproductive components, to severely affect the yield-contributing

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# Industrial Sector in Himachal Pradesh: Present Status and Future Perspectives

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## *ABSTRACT*

*Industrialization in Himachal Pradesh is a comparatively a recent phenomenon. From relatively backward and predominantly agriculture state at the time of attaining statehood in 1971, it has steadily progressed. The State Government right from the year 1971 has been providing many incentives and facilities for the promotion of industries. These facilities and incentives centered around cheap finance, subsidy at the time of installation of machinery, transport subsidies, income tax relief and concession with regard to central sales tax. In the present paper, an attempt has been made to analyze the performance of industrial sector in Himachal Pradesh during the last three decades in terms of some key parameters such as growth of units, investment and employment. The secondary data has been obtained from the website of the Directorate of Industries, Himachal Pradesh. The analysis is done in terms of simple percentages, however in order to evaluate the growth of industrial sector, annual compound growth rate is calculated. With a view to measure the extent of inter-district disparities, the co-efficient of variation has been calculated. It was concluded that, medium and large scale industries have achieved a higher growth during the reform period, but, still small scale industries plays an important role in the industrial scenario of the Himachal Pradesh. Due to geographical factors, the process of industrialization is concentrated in some borders areas of few districts such as Paonta Sahib and Kala Amb of Sirmaur district, Parwanoo, Barotiwala, Baddi, and Nalagrah of Solan district, whereas, other districts of the State has remained relatively unaffected by the process of industrial development. The Government of Himachal Pradesh should take an overall growth approach in order to attain balanced and inclusive development of the industrial sector.*

**Key Words:** ***Industrialization, Investment, Employment, Subsidy, Finance, Disparities, Inclusive, Industrial Package, and Growth.***

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REVIEW PAPER

# Plant growth-regulating molecules as thermoprotectants: functional relevance and prospects for improving heat tolerance in food crops

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## Abstract

**Among various abiotic stresses, heat stress is one of the most damaging, threatening plant productivity and survival all over the world. Warmer temperatures due to climatic anomalies above optimum growing temperatures have detrimental impacts on crop yield potential as well as plant distribution patterns. Heat stress affects overall plant metabolism in terms of physiology, biochemistry, and gene expression. Membrane damage, protein degradation, enzyme inactivation, and the accumulation of reactive oxygen species are some of the harmful effects of heat stress that cause injury to various cellular compartments. Although plants are equipped with various defense strategies to counteract these adversities, their defensive means are not sufficient to defend against the ever-rising temperatures. Hence, substantial yield losses have been observed in all crop species under heat stress. Here, we describe the involvement of various plant growth-regulators (PGRs) (hormones, polyamines, osmoprotectants, antioxidants, and other signaling molecules) in thermotolerance, through diverse cellular mechanisms that protect cells under heat stress. Several studies involving the exogenous application of PGRs to heat-stressed plants have demonstrated their role in imparting tolerance, suggesting the strong potential of these molecules in improving the performance of food crops grown under high temperature.**

**Keywords:** Antioxidants, crosstalk, GABA, high temperature, hormones, osmolytes.

## Introduction

Rising temperatures, as a result of changing climate, are a major concern to scientists and agriculturists worldwide (Hasanuzzaman *et al.*, 2013). The Inter-Governmental Panel on Climate Change (IPCC, 2014) reported that the world's temperature increased by 0.74 °C from 1906 to 2005 because of unabated emanation of greenhouse gases by anthropogenic exercises (IPCC, 2014). This trend is expected to persist, which will lead to catastrophic losses in crop productivity (Bita and Gerats, 2013; Sharma *et al.*, 2016). Estimated yield losses in India by 2100 range from

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Research article

# Securing reproductive function in mungbean grown under high temperature environment with exogenous application of proline

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ARTICLE INFO

*Keywords:*
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ABSTRACT

Escalating temperatures are adversely impacting the production potential of various cool- and warm-season crops, such as Mungbean, therefore effective strategies are required to improve heat tolerance of various crops. Mungbean, a summer season food legume, is seriously affected at temperatures more than 35/25 °C, especially at its reproductive stage, resulting in pollen infertility to induce loss of flowers and potential pods. Proline (Pro), a well-researched stress-related molecule, has been implicated in determining pollen fertility, but its involvement in affecting reproductive function under heat stress is not reported so far. In the present study, it was hypothesised that depletion of endogenous Pro in reproductive components of the flowers of heat-stressed Mungbean plants might impair the reproductive function. To test this hypothesis, Mungbean genotypes (heat tolerant and heat-sensitive), growing in outdoor environment (32.5/17.5 ± 1 °C mean day/night temperature), until on the onset of flowering (30 days after sowing) were subjected to mild heat stress (MS; 40/28 °C) and high heat stress (HS; 45/33 °C), in the absence or presence of 5 mM proline treatment, applied as soil drenching and foliar spray, 2 days before imposition of heat stress. In MS plants, the endogenous Pro showed a significant increase in leaves, anthers, pollen and ovules, while in SS plants, a marked reduction was noticed. In later case, the activity of proline synthesising enzymes (pyrolline-5-carboxylate synthase and pyrroline-5-carboxylate reductase) declined severely, along with a proline catabolism enzyme (proline dehydrogenase) suggesting disruption in proline metabolism in vegetative and reproductive components. This was associated with considerable decrease in pollen germination, stigma receptivity and ovule viability in heat-stressed plants. Simultaneously, leaf tissue showed high damage to cell membranes, leaf water status, stomatal conductance and cellular respiration. Photosynthetic ability (Chlorophyll, Photo system II function), carbon fixation (RuBisCo activity) and assimilation processes (sucrose synthesis and its hydrolysis) were significantly inhibited, in heat-stressed (HS) plants, which impacted the pod number, pod and seed weight per plant. Pro treatment, especially to HS plants resulted in appreciable increase in its endogenous concentration in vegetative and reproductive parts, which significantly improved the pollen fertility as well as stigma and ovule function. At the same time, stress damage to leaves was reduced significantly, leaf water status and chlorophyll were significantly higher, as a result the carbon fixation and assimilation capacity improved notably to increase the pod set, filled pod number, pod weight and seed weight per plants, suggesting a vital role of proline in enhancing the thermo-tolerance. The effects of Pro treatment were more pronounced in heat-sensitive genotype.

## 1. Introduction

Rising temperatures, globally as well as locally, are becoming a major alarm for agricultural crops cultivated in arid and semi-arid parts of the world (Wahid et al., 2007). Heat stress seriously inhibits the normal growth and development of the plants to severely impair their production potential (Kaushal et al., 2016). Heat stress accelerates the phenology, to hasten and shorten the reproductive growth, to eventually decrease the potential yields in several crops (Prasad and Jagadish, 2015; Kaushal et al., 2016). Reproductive stage has been

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# A study of charge radii and neutron skin thickness near nuclear drip lines

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**Abstract**

We studied the charge radius, rms radius and neutron skin thickness $\Delta r_{np}$ in even-even isotopes of Si, S, Ar and Ca and isotones of N = 20, 28, 50 and 82. The $\Delta r_{np}$ in doubly-magic $^{48}$Ca, $^{68}$Ni, $^{120,132}$Sn and $^{208}$Pb nuclei has also been calculated. Theoretical calculations are done with the Hartree-Fock-Bogoliubov theory with the effective Skyrme interactions. Calculated theoretical estimates are in good agreement with the recently available experimental data. The charge radii for Si, S, Ar and Ca isotopes is observed to be minimum at neutron number N = 14. The theoretically computed results with UNEDF0 model parameterization of functional are reasonably reproducing the experimental data for $\Delta r_{np}$ in $^{48}$Ca, $^{68}$Ni and $^{120,132}$Sn. The energy density functional of UNEDF1 model provides much improved result of $\Delta r_{np}$ for $^{208}$Pb.


*Keywords:* Hartree-Fock-Bogoliubov; Skyrme Energy Density Functional; Nuclear many-body theory; Charge distributions; Self-consistent mean field

## 1. Introduction

Appreciable experimental progress in producing and analyzing exotic nuclei [1,2] has brought renaissance of nuclear structure models. In recent years, the production of more and more new isotopes has revived the interest in nuclear structure models. In nuclear physics, understanding the structure of the atomic nucleus is one of the key challenges. The study of those nuclei

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## *Short communication*

# Climatic variability during different phenophases and its impact on temperate fruit crops

**PRATIMA VAIDYA*, SHUBHRA RANDHAWA, PANKAJ SHARMA, YASH PAL SHARMA, KUNAL SATYARTHI and SURJEET SINGH RANDHAWA**

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Evidences of climate change are being witnessed worldwide and Himalayas are no exception. Anthropogenic activities are acting as a precursor for enhanced greenhouse effect in the mighty Himalayas, thus exposing them to climate vagaries. Temperature and precipitation variations in the north-west Himalaya were reported by Bhutiyani *et al*. (2009). During last century, temperature in the north-west Himalayas has increased by 1.6 °C, which is higher than the global figure of 0.85 °C (IPCC, 2014). Any deviation of external optimal conditions in terms of rainfall and temperature affect the fruit plants (fruit bearing ability, vigour, quality and intensity of diseases and pests) through changes in mechanical and physiological activities (Bal and Minhas, 2017). For many fruit and nut species of the temperate and subtropical climates fulfilment of cultivar-specific chilling requirements is a prerequisite for producing economically satisfactory yields (Leudeling *et al*., 2015). There is very little evidence of impact of climate variability during phenophases on temperate fruit crops. Therefore, study was conceptualized to quantify the change in climatic variables during pre-flowering, flowering and fruit and development stages in Kullu district from 1990 to 2016 and to assess the impact of such changes on fruit productivity.

Studies were conducted in Kullu district located in mid hill to high hill wet temperate zone (30° 22' 40" N to 33° 12' 40" N latitude and 75°45'55" E to 79° 04' 20" E longitude) of Himachal Pradesh which is known for its contribution in horticulture sector (Map 1). Mean minimum, maximum, diurnal temperature and rainfall data of Kullu district was collected since 1990 to 2016 from India Meteorological Department (IMD), Shimla. Climatic parameters were arranged into pre flowering, flowering, and fruit setting and development stages from November to February, March to April and May to August respectively, depending upon various phenophases of the temperate fruit crops and seasonal trends were analyzed. Area and production data of apple, pear, plum, peach, apricot, cherry, pomegranate, walnut and almond crops was collected from Directorate of Horticulture, Shimla from 1990 to 2016 and productivity was worked out. Trend analysis was done by using Mann-Kendall test which was quantified by

**Table 1:** Climatic trends and Sen's slope during different phenophases

| | Mean | Sen's slope | p-value |
|---|---|---|---|
| **Pre Flowering (November-Feb)** | | | |
| Average max temp | 18.81 | + 0.04 | 0.04 |
| Average min. temp | 3.10 | + 0.01 | 0.52 |
| Total rainfall | 216.4 | - 2.58 | 0.20 |
| Diurnal temp | 15.7 | + 15.69 | 0.19 |
| **Flowering (March-April)** | | | |
| Average max. temp | 24.7 | + 0.12 | 0.01 |
| Average min. temp | 8.3 | + 0.04 | 0.00 |
| Total rainfall | 176.6 | -6.17 | 0.00 |
| Diurnal temp | 16.5 | + 0.07 | 0.06 |
| **Fruit-setting (May-August)** | | | |
| Average max. temp | 31.50 | + 0.03 | 0.23 |
| Average min. temp | 17.7 | + 0.02 | 0.29 |
| Total rainfall | 360.3 | + 0.98 | 0.76 |
| Diurnal temp | 13.8 | + 0.01 | 0.76 |

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# Plant Nanobionic Effect of Multi-walled Carbon Nanotubes on Growth, Anatomy, Yield and Grain Composition of Rice

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**Abstract**
Oxidized multi-walled carbon nanotubes (MWCNTs) having a diameter of 14–30 nm and length of 200–300 nm were used to the prime rice seeds with different concentrations of MWCNT (70, 80 and 90 μg/mL). The effects on germination, growth, anatomy, physiology, yield, quantitative seed components and toxicity (using human cell lines) were evaluated. The treatments, when extended to realistic field environments, resulted in significantly better yield and productivity of rice. The MWCNT-treated plants had denser stomata and larger root length, which resulted in faster growth and facilitated both water and mineral uptake, thus boosting the crop yield. Increased vascular tissues enhanced the chlorophyll content and photosynthetic activity. No toxic effects of MWCNT were observed in the DNA of the CNT-treated plants, and in the human cell lines, treated with harvested grain extract of MWCNT-primed plants. This study provides some new insights into the use of nanomaterials in plants and their potential benefits in agriculture thus ushering in a new organic-inorganic interface.

**Keywords** MWCNT · Cell viability · FESEM · Rice · Seed yield · Confocal microscope · Seed composition

## 1 Introduction

Plant nano-bionics is a futuristic field of technology wherein synthetic nanomaterials will be utilized to empower plants with newer and faster functions. Carbon nanotubes (CNT) are one of the favorite nanomaterials in plant nano-bionics, which have the potential to interact with plant tissue to enhance biological activities; this also promotes the light-related reactions inside plant cells (chloroplast) and contributes towards light harvesting and influences the properties like biochemical detection of different solutes [1, 2]. CNTs are thin rolled-up sheets of graphene, having $sp^2$ hybridization, existing both as single-walled carbon nanotubes (SWCNT) and multi-walled carbon nanotubes (MWCNT) [1]. There are certain properties of carbon nanotubes, which show extraordinary interaction with plants because of their unique physicochemical property such that it enhances their growth significantly [2–8]. CNT have the ability to gather more light energy through plant chloroplast while augmenting the electron transport rate, and ultimately the photosynthesis rate [2]. They also absorb the broad range of light wavelength (UV, visible and near infrared), better than plant chloroplast pigments and SWCNT—chloroplast converts this absorbed light into excitons and increases the rate of photosynthetic function by transferring large amount of electrons. [2, 3] MWCNT also improves the water uptake capacity, total biomass, flowering, and yield of plants [6, 7, 9].

Rice (*Oryza sativa* L.) is a major crop, which is a staple diet of greater than 50% of the world population, hence needs attention to enhance its yield potential. Previous studies, conducted on rice, under lab environment, showed improvement in leaf growth and development with low concentration (20 mg/L) with both SWCNT and MWCNT, accompanied by increased chlorophyll content and net photosynthetic rate [10, 11], it also shows degradation effect at higher concentration, i.e., 500 mg/L [12, 13]. In another study on rice, both types of CNTs result in

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Physica Scripta

PAPER

# Microscopic study of shape evolution and ground-state properties of Iodine isotopes

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**Keywords:** Hartree–Fock-Bogoliubov theory, quadrupole deformation, charge radii, binding energy, neutron skin thickness, nuclear electric quadrupole moment, single-particle energy levels

## Abstract

In this paper, we investigated the shape evolution and ground-state properties of $^{108-144}$I isotopes using Hartree–Fock-Bogoliubov Model while employing the axially deformed single-particle harmonic oscillator basis for the expansion of quasiparticle wave functions. We have used SKP and UNEDF2 models to perform the theoretical calculations. We have presented the shape evolution and final values of the quadrupole deformation parameter $\beta_2$ of iodine isotopes. We have used the final values of the $\beta_2$ for studying the ground-state properties of the iodine isotopic chain. The investigated ground-state properties are the nuclear electric quadrupole moment, single-particle energy levels, the binding energy per nucleon, pairing energy, one-neutron separation energy, two-neutron separation energy, nuclear charge radius, neutron rms radius, proton rms radius, and neutron skin thickness. After using the SKP parameterization on $^{109}$I, we have observed the shape coexistence of prolate and oblate shape. Similarly, after using the UNEDF2 parameterization on $^{110}$I, $^{112}$I, $^{114}$I, $^{115}$I, $^{116}$I, $^{117}$I, $^{118}$I, and $^{119}$I, we discover the shape coexistence of prolate and oblate shape.

## 1. Introduction

The experimental and theoretical studies of exotic nuclei having a large number of neutron or protons are the most operational areas of research. The most prominent part in the enhancement of our understanding of nuclear physics away from the $\beta$-stability line goes to the radioactive ion beam (RIB) facilities and sensitive detection technologies. In the pursuit of a better understanding of the atomic nuclear structure, physicists observed a variety of nuclear shapes and structural phenomena. The study of nuclear shape evolution in an atomic nucleus is one of the fundamental quests in nuclear physics. As the number of nucleons increases after the shell closure, the additional nucleons create the polarizing effect that raises the deformation. From the theoretical studies of mean-field theories [1–8] and droplet-type models [9–12], we concluded that the neutron skin thickness $\Delta r_{np}$ provides us with an adequate probe for nuclear symmetry energy $E_{sym}(\rho)$ [13]. These studies aim to address all these properties, which are: shape evolution, shape coexistence, quadrupole deformation parameter $\beta_2$, single-particle energy levels, the binding energy per nucleon, pairing energy, one-neutron separation energy, two-neutron separation energy, nuclear charge radius, neutron rms radius, proton rms radius, and neutron skin thickness. In our previous paper [14], we have done microscopic studies of the nuclear structure of $^{128-138}$I nuclei within the framework of the projected shell model. Iodine is a potential candidate after shell closure $Z = 50$, having an atomic number of $Z = 53$. During our survey of experimental data of Iodine isotopes, we found the experimental data for binding energy [15], one-neutron separation energy [15], two-neutron separation energy [15], nuclear electric quadrupole moment [16], and charge radius $R_{ch}(fm)$(Only available for $^{127}$I [17]). The experimental data is not available for all isotopes. The right way to test any nuclear theory is to consistently calculate all isotopes from the proton drip line to the neutron drip line. So we propose to study all these nuclear properties of Iodine isotopes throughout the isotopic chain.

The Schrodinger equation is not beneficial to find the exact solution of many-body problems even if the number of the particle is not large. After reducing the problem to a one-particle problem, new methods make it

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THE EUROPEAN PHYSICAL JOURNAL A

Regular Article - Theoretical Physics

# Nuclear shape evolution and shape coexistence in Zr and Mo isotopes

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**Abstract** The phenomena of shape evolution and shape coexistence in even–even $^{88-114}$Zr and $^{90-116}$Mo isotopes are studied by employing covariant density functional theory (CDFT) with density-dependent point-coupling parameter set, DD-PCX, and with separable pairing interaction. The results for the rms deviation in binding energies, two-neutron separation energy, the differential variation of two-neutron separation energy, and rms charge radii, as a function of neutron number, are presented and compared with available experimental data. In addition to the oblate–prolate shape coexistence in $^{96-110}$Zr isotopes, the correlations between shape transition and discontinuity in the observables are also examined. A smooth trend of charge radii in Mo isotopes is found to be due to the manifestation of triaxiality softness. The observed oblate and prolate minima are related to the low single-particle energy level density around the Fermi level of neutron and proton, respectively. The rapid shape transition in Zr isotopes near $N \approx 60$ is identified to be caused by the evolution of the shell structure associated with massive proton excitations to $1\pi g_{9/2}$ orbit. The present calculations also predict a deformed semi-bubble structure in the $^{100}$Zr isotope.

## 1 Introduction

In nuclear physics, the study of exotic nuclei with large numbers of protons or neutrons is one of the most active areas of research, both theoretically and experimentally. The radioactive ion beam (RIB) facilities and sensitive detection technologies have extended our knowledge of nuclear physics far away from the $\beta$-stability line. The study of the evolution of the nuclear shape in atomic nuclei is one of the fundamental quests in nuclear physics. The polarizing effect of added nucleons leads to a gradual increase of deformation in the nuclei away from spherical shell closures. However, an abrupt shape transition is seen in neutron-rich nuclei around the A $\approx$ 100 mass region. In the case of Zr isotopes, the ground states from $N = 50$ up to $N = 58$ are weakly deformed and a sudden shape transition is observed as $N = 60$ is approached. The nuclei located at the onset of deformation are of considerable interest and this onset of deformation, from a theoretical point of view, can be described as a quantum phase transition (QPT) [1]. The QPT takes place when the nucleus changes its ground-state shape when going from one atomic nucleus to the next. The sudden shape transition in Zr isotopes is evident from the irregularities in the two neutron separation energies [2], mean-square charge radii [3,4], and excitation energies of $2_1^+$ states and $B(E2)$ values [5,6]. On the other hand, the shape transition is rather gradual in Mo isotopes [2,7] showing the characteristic signatures of triaxiality. This dramatic behavior makes the mass region A $\approx$ 100 of special interest to test various theoretical models.

Nuclei at and near closed subshells are known to exhibit shape coexistence [8,9]. Neutron-rich zirconium ($Z = 40$) and molybdenum ($Z = 42$) isotopes are good examples of shape coexisting bands [10]. The appearance of low-lying $0_2^+$ states is a feature of shape coexistence and shape transition in this mass region. Many experimental observations for shape transition and shape coexistence have been made in this mass region. The shape coexistence is seen in closed-subshell $^{94}$Zr nuclei where the role of subshells for nuclear collectivity is suggested to be important [11]. The possibility of shape coexistence has been suggested in $^{98}$Zr and $^{100}$Zr nuclei by the analysis of the yrast structure from the rotational band and transition strength through lifetime measurements [9,12–14]. The shape coexistence in Mo isotopic chain was studied experimentally by using the Coulomb excitation technique [15–17]. Very recently, Ha et al. [18] have studied the shape evolution of $^{106}$Mo, $^{108}$Mo, and $^{110}$Mo isotopes through the energies and lifetimes of $2_1^+$ states. The quadrupole defor-

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# Microscopic study of the shell structure evolution in isotopes of light to middle mass range nuclides

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**Abstract**

Shell structure evolution in isotopes (even Z and even N) of Silicon (Si), Sulphur (S), Argon (Ar) and Calcium (Ca) has been analysed. We have used both Relativistic Hartree-Bogoliubov theory and Non-Relativistic Hartree-Fock-Bogoliubov theory for the theoretical calculations of the physical observables of interest. We have employed the model based on Relativistic Hartree-Bogoliubov theory with the density dependent effective interactions of meson exchange and point coupling types. Calculations based on Hartree-Fock-Bogoliubov theory are carried out with different skyrme forces and their sensitivity has been tested. Physical observables of interest include binding energies, single neutron separation energies, two-neutron separation energies, shell closure parameter $D_n$(Z, N) and differential variation $dS_{2n}$(Z, N) based on two neutron separation energy. Our theoretical results gives indication of shell closure at neutron number N =14 and neutron number N = 20 for the nuclei of Silicon (Si). Shell closures at neutron numbers N = 14, 20 and neutron number N = 28 are observed for Sulphur (S) nuclides. Argon (Ar) and Calcium (Ca) isotopes also provides the signature of shell closures at neutron numbers N = 20 and neutron number N = 28.



*Keywords:* Binding energy; Relativistic mean field; Energy density functional; Hartree-Fock-Bogoliubov; Nuclear many-body theory; Relativistic Hartree-Bogoliubov (RHB)

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THE EUROPEAN PHYSICAL JOURNAL A

Regular Article - Theoretical Physics

# Structural properties of rotating hybrid compact stars with color-flavor-locked quark matter core and their tidal deformability

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**Abstract** We investigate the hybrid compact stars consisting of nucleons, hyperons and three flavor color-flavor-locked quark phase under global neutrality and chemical equilibrium conditions. The hadronic equations of state are computed within the framework of energy density functionals based on the relativistic mean field theory by employing two different model. The quark matter phase of equation of state is computed by using Quark Quasiparticle model derived from a non-relativistic energy density-functional approach. A set of hybrid equations of state for superdense hadron-quark matter is obtained and, employed to investigate the structural properties of non-rotating and rotating compact stars. The internal structure of rotating star with observed spin down frequencies, exhibiting shrinkage of soft quark core of compact stars are discussed for constant baryonic mass. We present the theoretically computed limits of radii for the spin down configurations of hybrid stars corresponding to the recently observed millisecond pulsars. The various EOSs considered in the present work are well within the recent astrophysical constraints on mass and radius measurements (Riley et al. in Astrophys J Lett 918(2):L27, 2021; Millet et al. in http://arxiv.org/abs/2105.06979, 2021) and dimensionless tidal deformability ($\Lambda_{1.4}$) (Abbott et al. in Phys Rev Lett 121(16):161101, 2018; Li et al. in Eur Phys J A 57(1):1–10, 2021).

## 1 Introduction

The theory of strong interactions, quantum chromodynamics (QCD) and ultrarelativitics heavy ion collisions - predicts that at high energy densities the hadronic matter may under go deconfinement phase consisting of quarks and gluons as fundamental degree of freedom. Therefore, recently, it is an open question whether the inner core of compact stars (CS) consists of quark matter [5–9]. However, this has been suggested currently that the dense nuclear matter in the interior of stable compact stars with maximum gravitational masses M$\approx 2.0$M$_\odot$ may exhibits the evidence for the presence of sizable quark matter cores [10]. Therefore, the hybrid stars phenomenology offers a unique tool to address the challenge of understanding the phase transition in the dense quantum chromodynamics. The nuclear theory studies [11–13] are mainly focusing for the understanding dense matter of compact stars (CS). The recent observations with LIGO and Virgo of GW170817 event [3,14] of Binary Neutron Stars merger and the discovery of CS with masses around $2M_\odot$ [15–20] have intensified the interest in these intriguing objects. The analysis of GW170817 has demonstrated the potential of gravitational wave (GW) observations to yield new information relating to the limits on CS tidal deformability. In addition to these astrophysical observations [21–25], the measurements of rotational frequencies of the pulsar can be employed to constraints the particle composition and behavior of Equations of State (EOS) of the dense nuclear matter. However, the direct measurement of radius and quark matter interior core of CS are still a great challenge from astrophysical interests. The upcoming high-precision x-ray space missions, such as the ongoing NICER (Neutron Star Interior Composition Explorer) [17–20,24] and the future eXTP (Enhanced X-ray Timing and Polarimetry Mission) [26] have aimed to improve the situation by simultaneous measurements of CS masses and radii with higher accuracy [18–20,27,28]. It is also expected that the limits on CS radii are to be improved by new detection of gravitational wave signals from neutron star mergers.

In fact, the precise gravitational mass and radius measurements of the neutron stars are the effective ways to constraints the EOS of high dense matter in its interiors. The quite reliable mass measurement of MSP J0740+6620 [29]

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# RMF-BASED MICROSCOPIC STUDY OF GROUND-STATE PROPERTIES AND NUCLEAR SHAPE TRANSITIONS IN EVEN–EVEN Po ISOTOPES

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Ground-state properties of even–even isotopes of polonium (Po) have been studied. The physical observables of our interest include quadrupole deformation and shape transitions, binding energies, charge radii, and neutron skin thickness. Theoretical results for the differential variation $\mathrm{d}S_{2n}(Z,N)$ based on two-neutron separation energy are also presented. Theoretical calculations are carried out by employing covariant density functional theory with density-dependent meson exchange (DD-ME2) and point coupling (DD-PC1) interactions. The presented ground state properties with the RMF (Relativistic Mean Field) model are in good agreement with recently available experimental data. The theoretical estimates calculated by the covariant density functional theory predict shape transition from oblate to spherical and spherical to prolate along the isotopic chain of even–even Po nuclei ranging from mass number of 186 to 218.

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## 1. Introduction

A new phase of the research has begun with the development of experimental facilities like radioactive ion beams and other technological advancements [1–6]. The modern facilities make it possible to study a variety of the nuclides which are unexplored till now. One of the key problems in nuclear physics is the understanding of atomic nucleus due to the complexity of the many-body system. The study of neutron-rich nuclei is a wide-open area of the research in the nuclear structure field. The nuclei far away from the line of $\beta$ stability is a matter of deep investigation and it is yet to be explored. The nuclei which are away from the $\beta$-stability line play an important role in the understanding of nuclear physics. The production of the new isotopes

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# EVOLUTION OF NUCLEAR SHAPES IN LIGHT NUCLEI FROM PROTON- TO NEUTRON-RICH SIDE

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The relativistic Hartree–Bogoliubov (RHB) model with density-dependent meson-exchange interaction and separable pairing is employed to study the shape evolution and shape coexistence in Mg ($Z = 12$), Si ($Z = 14$), S ($Z = 16$), and Ar ($Z = 18$) isotopes from proton-rich side to neutron-rich side. A sudden shape transition is observed in these isotopic chains. A reasonable agreement of quadrupole deformation is found with the finite range droplet model (FRDM). Our findings of binding energies, quadrupole deformation parameter, charge radii, and isotope shifts are also in good agreement with the results of Hartree–Fock–Bogoliubov calculations based on the D1S-Gogny force. In addition to shape evolution, the disappearance of $N = 28$ shell closure and onset of deformation is also observed towards the neutron-rich side. The modification of $N = 28$ shell gap is related to the quadrupole excitations across it. The present calculations infer the neutron drip line at $^{40}$Mg.

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## 1. Intoduction

The study of nuclei far from the $\beta$-stability line (exotic nuclei) is a devoted part of modern nuclear-structure studies. The limit of nuclear existence is reached while going away from the stability line. Nuclear drip lines form the edges of the nuclear chart and are defined as limits beyond which a single nucleon becomes unbound in the nuclear ground state. The advancement in Radioactive Ion Beam (RIB) facilities and sensitive detection technologies has made it accessible to study the structure and properties of these nuclei.

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# Microscopic study of shape evolution and some important ground state properties of $^{190-210}$Au isotopes

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In this paper, we have examined the nuclear structural properties of $^{190-210}$Au isotopes within the framework of the Hartree–Fock–Bogoliubov Model. For the theoretical calculations, we have used the UNEDF2 and SKP interactions. The studies include the shape evolution, quadrupole deformation parameter $\beta_2$, nuclear electric quadrupole moment Q(b), single-particle energy levels, the binding energy per nucleon, nuclear charge radius, neutron rms radius, proton rms radius and neutron skin thickness. To analyze the accuracy of our theoretical results, we have presented the comparative analysis with experimental data and finite-range droplet model calculations. The adequate resemblance with experimental data is supporting our studies. We observe the oblate-prolate shape coexistence for $^{190}$Au, $^{193}$Au and $^{195}$Au using the UNEDF2 interaction.

*Keywords*: Hartree–Fock–Bogoliubov theory; quadrupole deformation; nuclear electric quadrupole moment; single-particle energy levels; binding energy per nucleon; charge radius; neutron skin thickness.

PACS Number(s): 21.10.Gv, 21.10.Dr, 21.10.Ft

## 1. Introduction

Theoretical and experimental studies of nuclear properties of exotic nuclei are currently one of the most vibrant and beneficial research routes in nuclear physics. The investigation of these exotic nuclei having a large number of neutrons or protons is the most operational area of research. The sensitive detection technologies and radioactive ion beam (RIB) facilities are most beneficial for a better understanding of nuclear physics away from the $\beta$-stability line. Research on different structural phenomena and nuclear shapes hold an influential place in the better understanding of the nuclear structure. An investigation regarding shape evolution is also

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# NUCLEAR SHAPE EVOLUTION IN PALLADIUM ISOTOPES

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The phenomena of shape evolution and shape coexistence are studied in even–even $^{86-134}$Pd isotopes by employing the relativistic Hartree–Bogoliubov (RHB) model by employing density-dependent point-coupling parameter sets DD-PC1 and DD-PCX with separable pairing interaction. Our findings of binding energies, quadrupole deformation parameter, charge radii, and two-neutron separation energies as a function of neutron number $N$ are compared with available experimental data and various theoretical models. Our theoretical results predict prolate–oblate shape coexistence in $^{108}$Pd isotope.

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## 1. Intoduction

It is known that nuclei lying near shell closure $Z = 50$ exhibit shape transitions and shape coexistence [1, 2] with the increase in neutron number. Radioactive Ion Beam (RIB) facilities and sensitive detection technologies have opened new possibilities to study the structure and properties of various exotic nuclei. The nuclei in this mass region exhibit a rapid change of nuclear shapes with competing spherical, axially symmetric prolate and oblate, and triaxial shapes, resulting in shape instabilities and coexistence of nuclear shape transitions in isotopic chains [3]. In addition to structural richness, another interesting characteristics of this region is its involvement in the astrophysical rapid neutron capture process (also called r-process), one of the main nucleosynthesis mechanisms which leads to the production of heavy neutron-rich nuclei in the universe [4, 5].

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# Shape transitions and shell structure study in zirconium, molybdenum and ruthenium

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**Abstract**

In the present work we have studied the shape evolution and ground state properties like binding energies, shell closure parameter, neutron separation energies, nuclear size and neutron skin thickness in the even-even isotopes of Zirconium, Molybdenum and Ruthenium. Our theoretical results are compared with the available experimental data as well as theoretical extractions. The theoretical calculations are done by using the well known density dependent meson exchange model DD-ME2 and density dependent point coupling models DD-PC1 and DD-PCX.


*Keywords:* Nuclear density functional theory; Binding energy and masses; Nucleon-nucleon interactions; Charge distributions; Nuclear many-body theory

## 1. Introduction

The ground states of Zr, Mo and Ru isotopes are weakly deformed for neutron number ranging from N = 50 - 60, but as N = 60 is approached and crossed they undergo strong shape transitions from nearly spherical to well deformed prolate or oblate deformations. The evidence for these shape variation includes the $2^+$ lifetime measurements [1] and the presence of triaxiality in Mo isotopes have also been identified [2] from spectroscopic studies of high-spin states. The heavier

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THE EUROPEAN PHYSICAL JOURNAL PLUS

Regular Article

# Possibility of deformed dual bubble-like structure in light nuclei

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**Abstract** The nuclei with a depressed central nucleonic density (bubble nuclei) are studied. The relativistic Hartree-Bogoliubov model with density-dependent meson-exchange interaction has been used to explore the possibility of deformed dual bubble-like structures in light nuclei, which are experimentally accessible. In dual bubble nuclei, the central densities for both proton and neutron deplete simultaneously. The unoccupancy of low angular momentum states for proton and neutron orbitals plays a vital role in the formation of bubble structures. We find favorable candidates around $N$ or/and $Z = 14$ exhibiting a deformed dual bubble-like structure.

## 1 Introduction

Most of the nuclei, in general, exhibits maximum nucleonic density at the center and smoothly decay to zero at the surface. However, this trend of nucleon density distribution shows different behavior in some cases. In some distributions, the density at the center is depressed with a hump nearby it, followed by a smooth decrease towards the surface region. This type of density distribution is known as "bubble" structure. The bubble structure is characterized by the central depression of nucleonic density and is currently a hot topic in nuclear physics.

The concept of reduction of density in the nuclear interior was first considered by Wilson [1] where he explains the equally spaced nuclear levels by considering the nucleus to be a thin spherical shell. The first quantitative calculations for the possibility of spherical bubble nuclei were performed in the 1970s [2,3]. By now, there exists appreciable literature to understand the occurrence of bubble-like structures in different mass regions [4–13]. In the superheavy region, the occurrence of bubble structure has been ascribed to Coulomb repulsion [14–18]. Interestingly, the phenomenon of bubble structure is found in all mass regions from light, medium, heavy to superheavy nuclei.

Generally, the maximal density at the center of the nucleus is offered by the nonzero wavefunction of $s$-state with the radial distribution peaked in the nuclear interior. The orbitals with nonzero angular momenta do not contribute to the nuclear density at the center, as they are excluded by centrifugal force. The only contribution to the nuclear density at the center is from $s$-state. The depopulation of $s$-state leads to a depressed nuclear density at the center of

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THE EUROPEAN PHYSICAL JOURNAL A

Regular Article - Theoretical Physics

# Effect of nuclear deformation on proton bubble structure in $Z = 14$ isotopes

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**Abstract** We have studied the density distribution in some "bubble" nuclei. The bubble nuclei are characterized by the depletion of nucleonic density at the center of the nucleus. We have explored the effect of nuclear deformation on proton bubble structure in the Si isotopic chain. The Covariant Density Functional Theory (CDFT) with density-dependent meson-exchange (DD-ME2) interaction has been employed. Triaxially constrained calculations are performed to investigate the deformed bubble structure. Deformation causes the mixing of shells hence reducing the bubble effect in the nuclei. The role of nuclear deformation in nuclear density profiles is explored and compared with the spherical limits.

## 1 Introduction

The nuclear forces have the property of saturation, i.e., most of the nuclei exhibit an approximately constant nucleonic density ($\rho_o \approx 0.16\text{fm}^{-3}$) in the central parts and smoothly decay towards the surface region. In case of bubble nucleus, the density at the center of the nucleus is depleted with a hump nearby it. Although, it is somewhat unexpected for a nuclear system where the density in the center is significantly lower than saturation density. This phenomenon of central depression of nucleonic density has been discussed for many decades. In recent years there has been a growing interest in searching for bubble nuclei.

The possibility of bubble nuclei was firstly proposed and investigated by Wilson in the 1940s [1], who studied the low energy excitations by considering the nucleus to be a thin spherical shell. The first microscopic calculations for the spherical bubble structure in $^{36}$Ar and $^{200}$Hg were performed by Campi and Sprung in the 1970s [2]. An appreciable literature exists to understand the occurrence of bubble structure in different mass regions [3–12]. The existence of bubble or semi-bubble structures in light, medium, and superheavy nuclei has been investigated by Khan et al. [4]. Their study suggested that the shell effects cause central density depletion in light nuclei. Many studies have explored the presence of proton bubble in $^{34}$Si [5,8–10]. The phenomenon of bubble structure is predicted in all mass regions from light, medium, heavy to superheavy nuclei.

In the absence of centrifugal barrier, the wave function of $s$-orbit has a radial distribution peaked in the nuclear interior, with their corresponding wave function extending further into the surface. This non-zero part of the wave function contributes to the central density. The orbitals with non-zero angular momenta, the wavefunction peaks are suppressed in the interior of nuclei and do not contribute to central density. Thus, only $s$-orbit contributes to the nuclear density at the center. The depopulation of $s$-state leads to a depleted central density in the nucleus, and a bubble may form. The shape of interior $3s$ wavefunction was measured on $^{206}$Pb and $^{205}$Tl using electron scattering [3]. Differences in the charge density between $^{206}$Pb and $^{205}$Tl revealed that about 80% of the proton removal strength came from the $3s$ state, leading to a depletion of the proton density in the nuclear interior. The strength of the spin-orbit (SO) force is proportional to the gradient of the nuclear density. For a bubble nucleus, the negative value of this gradient leads to a reduced SO splitting for low $l$-orbitals [13]. The SO coupling play a crucial role in the occurrence of shell closure and a strong SO coupling exists in stable and near stable nuclei [14]. The bubble-like structure have a significant consequence on nuclear structure. A study of new magicity for $N = 32$ and $N = 34$ in Ca isotopes is carried out by using RHF model with PKA1 Lagrangian [15]. In this study, the central depression in neutron density profile for $^{54}$Ca leads to the reduction of $\nu 2p_{3/2} - -\nu 2p_{1/2}$

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# The microscopic studies of the even-even $^{12-28}$O, $^{34-60}$Ca, $^{48-80}$Ni, and $^{100-134}$Sn using covariant density functional theory

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**Abstract**

The current research intends to investigate the shape evolution and ground-state properties of even-even isotopic chains of Oxygen (Z = 8, N = 12 − 28), Calcium (Z = 20, N = 34 − 60), Nickel (Z = 28, N = 48 − 80), and Tin (Z = 50, N = 100 − 134) by using the DD-PCX parameterization based on covariant density functional theory. The covariant density functional theory is a popular theoretical tool for the description of nuclear structure phenomena. The nuclear properties of interest are potential energy surfaces, the binding energy per nucleon, two-neutron separation energy, differential variation of two-neutron separation energy, neutron rms radius, protons rms radius, and neutron skin thickness. The Covariant mass data and Skyrme mass data were very helpful to provide a comparative ground for better comparison of our data and testing the efficiency of DD-PCX parameterization. The effective interaction DD-PCX was designed to accurately calculate the neutron-skin thickness, and the comparative analysis present in the result section demonstrates that. We have observed the shape transition from spherical to oblate and oblate to spherical for $^{60}$Ni(Z=28, N=32) and $^{66}$Ni(Z=28, N=38) in our studies. We have observed the oblate shape in $^{60}$Ni, $^{62}$Ni, and $^{64}$Ni.


*Keywords:* Covariant density functional theory; Shape evolution; Binding energy per nucleon; Charge radius; Two neutron separation energy; Differential variation of two neutron separation energy; Neutron rms radius; Proton rms radius; Neutron skin thickness

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# Relativistic mean field model parametrizations in the light of GW170817, GW190814, and PSR J0740 + 6620

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Three parametrizations DOPS1, DOPS2, and DOPS3 (named after the Department of Physics Shimla) of the relativistic mean field model have been proposed with the inclusion of all possible self and mixed interactions between the scalar-isoscalar ($\sigma$), vector-isoscalar ($\omega$), and vector-isovector ($\rho$) mesons up to quartic order. The generated parameter sets are in harmony with the finite and bulk nuclear matter properties. A set of equations of state (EOSs) composed of pure hadronic (nucleonic) matter and nucleonic with quark matter (hybrid EOSs) for superdense hadron-quark matter in $\beta$ equilibrium is obtained. The quark matter phase is calculated by using the three-flavor Nambu-Jona-Lasinio (NJL) model. The maximum mass of a nonrotating neutron star with DOPS1 parametrization is found to be around $2.6M\odot$ for the pure nucleonic matter, which satisfies the recent gravitational wave analysis of GW190814 [Abbott *et al.*, Astrophys. J. Lett. **896**, L44 (2020)] with possible maximum mass constraint indicating that the secondary component of GW190814 could be a nonrotating heaviest neutron star composed of pure nucleonic matter. EOSs computed with the DOPS2 and DOPS3 parametrizations satisfy the x-ray observational data [Steiner *et al.*, Astrophys. J. **722**, 33 (2010)] and the recent observations of GW170817 maximum mass constraint of a stable nonrotating neutron star in the range $2.01 \pm 0.04$–$2.16 \pm 0.03M\odot$ [Rezzolla *et al.*, Astrophys. J. Lett. **852**, L25 (2018)] and also in good agreement with constraints on mass and radius measurement for PSR J0740 + 6620 (NICER) [Riley *et al.*, Astrophys. J. Lett. **918**, L27 (2021); Miller *et al.*, Astrophys. J. Lett. **918**, L28 (2021)]. The hybrid EOSs obtained with the NJL model also satisfy astrophysical constraints on the maximum mass of a neutron star from PSR J1614-2230 [Demorest *et al.*, Nature (London) **467**, 1081 (2010)]. We also present the results for dimensionless tidal deformability, $\Lambda$ which are consistent with the waveform models analysis of GW170817.

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## I. INTRODUCTION

The knowledge of neutron star properties is necessary to probe the high-density behavior of the equations of state (EOSs) for the baryonic matter in the $\beta$ equilibrium. Neutron stars are the densest manifestations of massive objects in the observable universe and sound knowledge of EOSs of dense matter is required to understand the properties of neutron stars. The precise gravitational mass and radius measurements of the neutron stars are effective ways to constrain the EOSs of high dense matter in its interiors. The mass measurement of MSP J0740 + 6620 [1] with $2.14^{+0.10}_{-0.09}M_\odot$, is likely to be the most massive neutron star yet observed. Recently, the simultaneous measurements of gravitational mass $M$ and equatorial circumferential radius $R_{eq}$ of PSR J0030 + 0451 from NICER data by Miller *et al.* [2] and Riley *et al.* [3] by using independent methods to actually map of the hot region of pulsar, have inferred [$M = 1.44^{+0.15}_{-0.14}M_\odot$, $R_{eq} = 13.02^{+1.24}_{-1.06}$ km] and [$M = 1.34^{+0.15}_{-0.16}M_\odot$, $R_{eq} = 12.71^{+1.14}_{-1.19}$ km], respectively.

Theoretically, the investigations of the observed masses and radii of compact stars (CS) reveals the particle composition and phase transition of dense nuclear matter at high densities. Several attempts [4–7] have been made to construct the EOSs comprising of nucleons, hyperons, and quarks under the constraint of global $\beta$ equilibrium. The inclusion of hyperons and/or quarks in EOSs softens the high-density behavior, leading to the reduction of maximum gravitational masses of CS. Recently, there are many EOS models that include hyperons as well as quark matter [6,8] and maximum gravitational mass calculated from them is compatible with $\approx 2M_\odot$.

The theory of strong interactions, quantum chromodynamics (QCD), and ultrarelativistic heavy-ion collisions predict that at high densities, the hadronic matter may undergo a deconfinement phase consisting of quarks and gluons. Therefore, recently, it is an open question whether the inner core of compact stars (CS) consists of quark matter [9–13]. However, it has been suggested currently that the dense nuclear matter in the interior of stable compact stars with maximum gravitational masses $M \approx 2.0M_\odot$ may exhibit evidence for

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# Effects of an isovector scalar meson on the equation of state of dense matter within a relativistic mean field model

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The effects of the isovector scalar $\delta$-meson field on the properties of finite nuclei, infinite nuclear matter, and neutron stars are investigated within a relativistic mean field (RMF) model which includes nonlinear couplings. Several parameter sets (SRVs) are generated to asses the influence of the $\delta$ meson on the properties of neutron stars. These parametrizations correspond to different values of the coupling constant of the $\delta$ meson to nucleons, with remaining ones calibrated to yield finite nuclei and infinite nuclear matter properties consistent with the available experimental data. It is observed that, to fit the properties of finite nuclei and infinite nuclear matter, a stronger coupling between the isovector vector $\rho$ meson and nucleons is required in the presence of a $\delta$ field. Furthermore, the $\delta$ meson is found to affect the radius of the canonical neutron star significantly. The value of dimensionless tidal deformability, $\Lambda$, for the canonical neutron star also satisfies the constraints from the waveform model analysis of the GW170817 binary neutron star merger event. A covariance analysis is performed to estimate the statistical uncertainties of the model parameters as well as correlations among the model parameters and different observables of interest.

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## I. INTRODUCTION

Neutron stars are the densest objects in the observable universe and deep knowledge of the equation of state (EoS) of dense matter in beta equilibrium is thus required to understand their behavior. It has been shown that the dense matter EoS must be treated relativistically [1,2]. For this reason, relativistic mean field (RMF) models have been widely used to obtain a realistic description of the properties of finite nuclei, bulk nuclear matter, and neutron stars. Currently, many different variants of RMF models with various couplings are in use to study finite nuclei and neutron star properties [3–5]. Accurate constraints are necessary to understand the limits of these different types of models. During the last decade, a wide range of astrophysical observations—such as the precise measurement of massive millisecond pulsars using the Shapiro delay technique [6,7], detection of gravitational waves generated by binary neutron stars in the GW170817 event by the LIGO-Virgo Collaboration [8,9], and the joint mass radius measurement of neutron stars using the x-ray timing technique by the NICER Collaboration [10–13]—have started to provide unprecedented new constraints on the dense matter EoS. They have triggered plethora of theoretical studies to look at the dense matter EoS from very different perspectives; see Ref. [14] and references therein. First-of-its-kind model independent measurement of neutron skin thickness $\Delta r_{np}$ of $^{208}$Pb [15] and $^{48}$Ca [16] at the Jefferesen laboratory also inspired theoretical studies to take a fresher look at the isovector channel of the nuclear interaction [17–21].

The effective mass of a nucleon quantifies the momentum dependence of the nuclear force in the medium. It can be quoted for infinite nuclear matter at the Fermi surface. It is, however, necessary to realize that the concept of effective mass is different in nonrelativistic [22,23] and relativistic formalisms [24]. Nevertheless, it plays some crucial roles in determining various finite nuclear properties, e.g., isoscalar giant quadrupole resonance (ISGQR) [25] and nucleon nucleon scattering in optical potentials [26], or even in realizing various properties of nuclear matter and neutron stars [27,28]. Recently, a systematic study was performed using RMF models which assessed the impact of relativistic (Dirac) effective mass ($M^*$) on the properties of neutron stars [29]. The isovector splitting of the effective mass, which measures the difference between neutron ($M_n^*$) and proton ($M_p^*$) effective mass, can also influence greatly the physical properties of finite nuclei, such as locating the drip lines [30] or nucleon-nucleus scattering of asymmetric systems [26]. Its impact increases manifold in high density environments

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# MDS Block Hankel-like Rhotrices using Conjugate Elements and Self-Dual Bases of Finite Fields

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## ABSTRACT

Maximum Distance Separable (MDS) matrices offer ideal diffusion properties and are of great importance in design of block ciphers and hash functions. A rhotrix as defined by Sani, is a coupled matrix which when used in a cryptosystem provides double security. Many authors constructed MDS Rhotrices over finite fields using matrices which are cryptographically significant. Hankel matrices have wide range of applications in engineering, coding theory and cryptography. In the present paper, we define block rhotrix and block Hankel- like rhotrix. Further, we construct MDS block Hankel-like rhotrices using self-dual basis and conjugate elements of $F_{p^n}$.

**KEYWORDS:** Finite Fields, MDS Rhotrix, Block Rhotrix, Hankel matrix, Hankel Rhotrix, Block Hankel- like Rhotrix.

## 1. Introduction

Rhotrix is a rhomboidal structure introduced by Ajibade [1] in 2006. A rhotrix is an extension of matrix tertions and matrix noitrets given by Attanassov and Shannon [3]. A 3–dimensional rhotrix as given by Ajibade is

$$R_3 = \left\langle \begin{matrix} & a & \\ b & c & d \\ & e & \end{matrix} \right\rangle,$$

where $a, b, c, d, e$ are real numbers and $c$ is called the heart of rhotrix $R_3$. He has also shown that there are many similarities in the operations of rhotrices and matrices. He introduced operations of addition and scalar multiplication.

In the literature of rhotrix theory, two methods of multiplication of rhotrices are defined. First method of multiplication of rhotrices is known as heart-oriented multiplication, which was discussed by Ajibade and further its

# CREX- and PREX-II-motivated relativistic interactions and their implications for the bulk properties of nuclear matter and neutron stars

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We investigate the implications of parity-violating electron scattering experiment on neutron skin thickness of $^{48}$Ca [calcium radius experiment (CREX)] and $^{208}$Pb [lead radius experiment (PREX-II)] data on the bulk properties of finite nuclei, nuclear matter, and neutron stars. The neutron skin thickness from the CREX and PREX-II data is employed to constrain the parameters of relativistic mean-field models which includes different nonlinear, self- and cross-couplings among isoscalar-scalar $\sigma$, isoscalar-vector $\omega$, isovector-scalar $\delta$, and isovector-vector $\rho$ meson fields up to the quartic order. Three parametrizations of RMF model are proposed by fitting CREX, PREX-II, and both CREX as well as PREX-II data to assess their implications. A covariance analysis is performed to assess the theoretical uncertainties of model parameters and nuclear matter observables along with correlations among them. The RMF model parametrization obtained with the CREX data acquires much smaller value of symmetry energy ($J = 28.97 \pm 0.99$ MeV) and its slope parameter ($L = 30.61 \pm 6.74$ MeV) in comparison to those obtained with PREX-II data. The neutron star properties are studied by employing the equations of state composed of nucleons and leptons in $\beta$ equilibrium.

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## I. INTRODUCTION

The nuclear equation of state (EoS) plays a vital role for understanding the properties of strongly interacting many-body systems like atomic nuclei and neutron stars [1–3]. The nuclear symmetry energy and its density dependence are key features of nuclear EoS. Constraining the density dependence of symmetry energy represents a long-standing and unresolved question in nuclear physics and astrophysics [3]. The density dependence of the symmetry energy has implications in a variety of phenomena such as heavy-ion collisions, core-collapse supernovas, and neutron-star structures. Although important, this quantity cannot be directly measured in the laboratory, it can only be derived from theories and thus to constrain their values it is necessary to identify and use relevant observables on finite nuclei. A neutron star is a highly dense and asymmetric nuclear system that has a central density of about five to six times the nuclear saturation density [4]. The study of the neutron star proclaims that its internal structure is more complex as new degrees of freedom like hyperons and quarks appear in the core. The properties of the neutron star like mass, radius, and tidal deformability can be explained by taking into account the interaction between nucleons and the mesonic degree of freedom in the form of Lagrangian. This provides an EoS which is the main input for the calculation of neutron star properties. The several relativistic mean-field (RMF) models having effective Lagrangian density consisting of nonlinear $\sigma$, $\omega$, $\rho$, and $\delta$ terms and cross terms have been analyzed for nucleonic matter and nucleonic along with hyperonic matter and accosted with the constraints of nuclear matter properties and astrophysical observations of compact star masses [5–7]. The nuclear theory studies [8–10] are mainly focusing on understanding the dense matter in compact stars (CS). The constraints on EoS at high density are imposed with accurate information of a neutron star's maximum mass and radius [1,11,12]. The precise measurement of masses of millisecond pulsars such as PSR J1614-2230 [13] and PSR J0348+0432 [14] show that the maximum mass of the neutron star should be around 2 $M_{\odot}$. The recent observations with LIGO and Virgo of GW170817 event [15,16] of Binary Neutron Stars merger and the discovery of CS with masses around $2M_{\odot}$ [13,14,17–20] have intensified the interest in these intriguing objects. The analysis of GW170817 has demonstrated the potential of gravitational wave (GW) observations to yield new information relating to the limits on CS tidal deformability.

The recent precise parity-violating electron scattering experiments on $^{48}$Ca [calcium radius experiment (CREX)] [21] and $^{208}$Pb [lead radius experiment (PREX-II)] [22] provide new insights into the neutron skin thickness of nuclei. These experiments are helpful in determining the nuclear weak charge form factor by measuring the parity-violating asymmetry. The weak charge form factor has a strong correlation with the density dependence of symmetry energy and neutron skin thickness of nuclei and plays an important role in

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# Observational constraint from the heaviest pulsar PSR J0952-0607 on the equation of state of dense matter in relativistic mean field model

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In the present work, we constrain the equation of state of dense matter in the context of heaviest observed neutron-star mass $M_{\rm max} = (2.35 \pm 0.17)M_\odot$ for the black widow pulsar PSR J0952-0607. We propose three interactions HPU1, HPU2 and HPU3 (named after Himachal Pradesh University) for the relativistic mean-field model, which include different combinations of nonlinear, self-couplings, and cross couplings among isoscalar-scalar $\sigma$, and isoscalar-vector $\omega$ and isovector-vector $\rho$ meson fields up to the quartic order. These interactions are in harmony with the finite nuclei and bulk nuclear matter properties. The equations of state computed by using newly generated interactions for the $\beta$-equilibrated nucleonic matter satisfy the heaviest observed neutron-star mass $M_{\rm max} = (2.35 \pm 0.17)M_\odot$ for the black widow pulsar PSR J0952-0607. The results for the radius $R_{1.4}$ and dimensionless tidal deformability $\Lambda_{1.4}$ corresponding to the canonical mass are also presented and agree well with the GW170817 event and astrophysical observations. The radius of $2.08M_\odot$ neutron-star mass is predicted to be in the range $R_{2.08} = 12.98$–$13.09$ km which also satisfy the NICER observations by Miller *et al.* [Astrophys. J. Lett. **918**, L28 (2021)] and Riley *et al.* [Astrophys. J. Lett. **918**, L27 (2021)]. A covariance analysis is also performed to assess the theoretical uncertainties of model parameters and to determine their correlations with nuclear matter observables.

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## I. INTRODUCTION

Neutron stars are stellar objects made of highly dense asymmetric matter and have extreme properties. The dense core of the neutron star enables us to study nuclear matter beyond saturation density. The composition of the matter at such high density is not known exactly to the date, but the thermodynamic state of the matter is theorized by the equation of state (EoS). In recent years, many advances in astrophysical experiments have probed new constraints on EoS by studying properties like mass, radius, and tidal deformability of neutron stars. Constraints from terrestrial experiments have been obtained by studying matter at supra-saturation density in heavy ion collisions and determining the neutron skin thickness. The possibility to detect gravitational waves from merging binary systems by the LIGO and VIRGO collaborations [1,2] and NICER measurements [3,4] on mass radius have major contributions to probe the behavior of the EoS from the low- to the high-density regime. The neutron stars are highly dense asymmetric nuclear systems having a central density about five to six times the nuclear saturation density. In recent years, new measurements of masses from radio pulsars timing [5–7], tidal deformabilities from gravitational wave analyses [1,8] and radii from x-ray pulse profiling [3,4,9,10] have attracted a great deal of attention, as these measurements have started to clarify about the possible existence of the novel state of matter in the dense inner core of the heaviest neutron stars and the EoS of dense matter [11–13]. The nuclear theory studies [14–16] are mainly focusing on understanding the dense matter in a neutron star. The constraints on the EoS at high density are imposed with currently available lower bound on a neutron star's maximum mass and radius [17–19]. The precise measurement of masses of millisecond pulsars such as PSR J1614-2230 [5] and PSR J0348+0432 [6] show that the maximum mass of the neutron star (NS) should be around $2M_\odot$. The recent observations with LIGO and Virgo of GW170817 event [1,2] of binary neutron stars merger and the discovery of neutron star with masses around $2M_\odot$ [5,6,9,10,20,21] have intensified the interest in these fascinating objects. The analysis of GW170817 has demonstrated the potential of gravitational wave (GW) observations to yield new information related to the limits on neutron-star tidal deformability.

The PSRJ1748-2446ad discovered by Hessels *et al.*, [22] is the fastest spinning pulsar having frequency 716 Hz ($P_s =$ 1.3959 ms) and mass $\leqslant 2M_\odot$. But, pulsar PSR J0952-0607 was discovered by Bassa *et al.* (2017) [23] with a spin period of $P_s = 1.41$ ms, making it the fastest and heaviest [$M_{\rm max} = (2.35 \pm 0.17)M_\odot$] known galactic neutron star in the disk of the Milky Way. It is a black widow pulsar with a low mass

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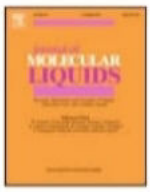

# A comparative analysis of volumetric, viscometric and conductometric properties of Triethylmethylammonium Tetrafluoroborate ($TEMABF_4$) and Tetraethylammonium Tetrafluoroborate ($TEABF_4$) in pure propylene carbonate (PC) and binary aqueous propylene carbonate solvents

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ABSTRACT

Electrolytes play a major role in electrochemical energy storage devices and specifically organic electrolytes are used predominantly over aqueous electrolytes due to wide electrochemical window, high energy density and efficiency. However, aqueous electrolytic systems for energy storage applications still need to be explored as these are non-flammable, environment friendly, non-toxic, carrying high ionic conductivity and low cost as compared to organic counterparts. In this study, an effort has been made in doing a comparative analysis of the physicochemical properties of Triethylmethylammonium Tetrafluoroborate ($TEMABF_4$) and Tetraethylammonium Tetrafluoroborate ($TEABF_4$) in pure propylene carbonate (PC) and binary aqueous mixtures of PC (0.01 &0.02 m) at different temperatures and concentrations. From this data, various volumetric, viscometric, and conductometric parameters have been calculated and the results obtained are analysed and compared in terms of solute–solute and solute–solvent interactions. From the analysis of thermo physical parameters, we have found that both the salts act as structure breaker in PC whereas structure maker in binary aqueous mixtures of PC (0.01 & 0.02 m). FTIR studies have also been done to see the intermolecular interactions and structural alterations. Furthermore, results from Cyclic Voltammetry (CV) studies suggested that a binary aqueous organic electrolytic system can also be a potential electrolytic system as its electrochemical window is comparable to that of pure electrolytic organic solvents.



## 1. Introduction

The increasing population and changing lifestyle of the people have been attributed to the increasing need for energy storage. Since fossil fuels are limited, so it is the responsibility of the present generation to reduce the dependency on non-renewable resources and evolve new ways for generation and storage of energy from renewable resources [1–3].There is a strong need for the methods to efficiently convert, store, transport and access this energy in many ways. However, it is also very important that the energy storage methods must be cleaner than the traditional methods as the devices used for the energy storage applications should not pose any threat to the environment by emerging as new chemical pollutants [4–5]. Electrical energy comes under the category of cleaner forms of energy which can be reserved in the form of chemical energy mostly in batteries, super capacitors, flow batteries, etc [6–8]. Batteries have the potential to provide fuel flexibility and come under a cleaner approach to protect the environment as they neither result in the emission of harmful gases nor create much noise [9]. The conductivity of the electrolytic solution plays an efficient role in improving the performance of batteries [10–11]. Usually, the ideal electrolytes should comprise features like a wide electrochemical window, large temperature range, high ionic conductivity, environment friendly, and low cost [12]. Based on the solvent used, electrolytes can be broadly categorized as aqueous-based and organic based [13]. It is difficult to find all the required features in either of the two types of electrolytes mentioned above [14]. The organic electrolytes have a wide electrochemical window giving rise to high energy density and high efficiency [15–17] and are prioritized over their aqueous counterparts [18–19]. On the other hand, the narrow electrochemical window limits the use of aqueous electrolytic systems as it results in low energy density

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# An overview of deep eutectic solvents: Alternative for organic electrolytes, aqueous systems & ionic liquids for electrochemical energy storage

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Aqueous electrolyte

ABSTRACT

As the demand for sustainable energy sources continues to rise, the need for efficient and reliable energy storage systems becomes crucial. In order to effectively store and distribute renewable energy, new and innovative solutions must be explored. This review examines the deep eutectic solvents (DESs) as a green, safe, and affordable solution for the electrochemical energy storage and conversion field, offering tremendous opportunities and a promising future. DESs are a class of environment-friendly solvents known for their low toxicity and unique properties, such as their good conductivity, high thermal stability, and non-flammability. This review explores the fundamentals, preparations, and various interactions that often predominate in the formation of DESs, the properties of DESs, and how DESs are better than traditional solvents involving cost-ineffective and unsafe organic electrolytes and ionic liquids as well as inefficient aqueous systems due to low energy density for electrochemical energy storage applications. Then, a particular focus is placed on the various electrochemical applications of DESs, including their role in the electrolytes in batteries/supercapacitors, electropolishing and electrodeposition of metals, synthesis of electrode materials, recycling of electrodes, and their potential for use in $CO_2$ capture. The review concludes by exploring the challenges, research gaps, and future potential of DESs in electrochemical applications, providing a comprehensive overview, and highlighting key considerations for their design and use.



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# Relativistic approach for the determination of nuclear and neutron star properties in consideration of PREX-II results

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The bulk properties of nuclear matter and neutron stars with the newly generated relativistic interaction Dev Bhoomi Himachal Pradesh (DBHP) are investigated, which provides an opportunity to modify the coupling parameters keeping in view the finite nuclei, nuclear matter, PREX-II data for neutron skin thickness in $^{208}$Pb, and astrophysical constraints. The relativistic interaction has been generated by including all possible self and mixed interactions among $\sigma$, $\omega$, and $\rho$ mesons up to the quartic order satisfying the naturalness behavior of parameters. A covariance analysis is performed to assess the statistical uncertainties of the model parameters and observables of interest along with correlations amongst them. We obtained a value of neutron skin thickness for the $^{208}$Pb nucleus of $\Delta r_{\rm np} = 0.24 \pm 0.02$ fm. The maximum gravitational mass of a neutron star and the radius corresponding to the canonical mass ($R_{1.4}$) come out to be $2.03 \pm 0.04\ M_\odot$ and $13.39 \pm 0.41$ km, respectively. The dimensionless tidal deformability $\Lambda$ for a neutron star is also analyzed.

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## I. INTRODUCTION

Neutron stars (NSs) are highly dense and asymmetric nuclear systems having a central density about 5-6 times the nuclear saturation density [1]. The studies of the NSs proclaim that their internal structures are quite complex as new degrees of freedom like hyperons and quarks may appear in the core. The NS properties like mass, radius, and tidal deformability can be estimated using equations of state (EOSs) obtained within various theoretical models [2–4]. One of such models is based on the relativistic interaction, which describes the interaction between nucleons through $\sigma$, $\omega$, and $\rho$ mesons. There are several models of relativistic mean-field (RMF) effective Lagrangian density consisting of nonlinear $\sigma$, $\omega$, and $\rho$ terms and cross terms that have been analyzed for nucleonic and hyperonic matter and confronted with the constraints of nuclear matter properties and astrophysical observations of NS masses [5–9].

The nuclear theory studies [10–12] are mainly focusing on understanding the dense matter in NS. The constraints on EOS at high density are imposed with currently available lower bounds on a neutron star's maximum mass and radius [13–15]. The precise measurement of masses of millisecond pulsars such as PSR J1614-2230 [16] and PSR $J0348 + 0432$ [17] show that the maximum mass of a NS should be around $2\ M_\odot$. The recent observations with LIGO and Virgo of GW170817 event [18,19] of Binary Neutron Stars merger and the discovery of NS with masses around $2\ M_\odot$ [16,17,20–23] have intensified the interest in these intriguing objects. The analysis of GW170817 has demonstrated the potential of gravitational wave (GW) observations to yield new information relating to the limits on NS tidal deformability. The Lead Radius Experiment (PREX-II) has recently provided a model-independent extraction of neutron skin thickness of $^{208}$Pb as $\Delta r_{\rm np} = 0.283 \pm 0.071$ fm [24]. The $\Delta r_{\rm np}$ has been identified as an ideal probe for the density dependence of symmetry energy—a key but poorly known quantity that describes the isospin dependence of the EOS of asymmetric nuclear matter and plays a critical role in various issues in nuclear physics and astrophysics. The neutron skin thickness of the lead nucleus exhibits a strong positive linear correlation with the slope of the symmetry energy parameter ($L$) at saturation density. The parameter $L$ that determines the density dependence of the symmetry energy strongly affects the mass-radius relation and tidal deformability ($\Lambda$) of a neutron star and provides a unique bridge between atomic nuclei and neutron stars [25]. The large value of $\Delta r_{\rm np} = 0.283 \pm 0.071$ fm suggests a large value of $L$, which yields a very stiff EOS. This generally gives rise to a large value of neutron star radius and the tidal deformability [3]. The upper limit on $\Lambda_{1.4} \leqslant 580$

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# Investigating the Solvation Behavior of Some Lithium Salts in Binary Aqueous Mixtures of 1-Ethyl-3-methylimidazolium Tetrafluoroborate ([EMIM][$BF_4$]) at Equidistant Temperatures ($T$ = 298.15, 303.15, 308.15, 313.15, 318.15) K

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**ABSTRACT:** In the current work, measurements of density, as well as speed of sound, were made to analyze the solvation behavior of some lithium salts in binary aqueous mixtures of 1-ethyl-3-methylimidazolium tetrafluoroborate ([EMIM][$BF_4$]) at equidistant temperatures ($T$ = 298.15, 303.15, 308.15, 313.15, 318.15) K and a pressure of 0.1 MPa. Various thermo-physical parameters like apparent and partial molar volumes ($V_\Phi$ and $V_\Phi^0$), apparent and partial molar isentropic compressions ($K_{\Phi,S}$ and $K_{\Phi,S}^0$), partial molar volume, and partial molar isentropic compression of transfer ($\Delta V_\Phi^0$ and $\Delta K_{\Phi,S}^0$) were calculated from the experimental data. McMillan−Mayer theory was used to calculate pairwise (AB) and triplet interactions (ABB) from the calculated coefficients. Based on the calculated parameters, the presence and paramountcy of solute-solvent synergy particularly hydrophilic interactions over hydrophobic interactions have been found for both $LiClO_4$ and LiI in binary aqueous mixtures of [EMIM][$BF_4$]. Furthermore, Hepler's criterion has been employed to examine the potential of these salts as a structure maker/breaker.