frontiers | Frontiers in Physics

TYPE Editorial
PUBLISHED 25 January 2024
DOI 10.3389/fphy.2024.1368771



OPEN ACCESS

EDITED AND REVIEWED BY
Jie Meng,
Peking University, China

*CORRESPONDENCE
N. G. Kelkar,
nkelkar@uniandes.edu.co

RECEIVED 11 January 2024
ACCEPTED 15 January 2024
PUBLISHED 25 January 2024

CITATION
Khemchandani KP, Martínez Torres A and Kelkar NG (2024), Editorial: Exotic aspects of hadrons and nuclei.
*Front. Phys.* 12:1368771.
doi: 10.3389/fphy.2024.1368771



# Editorial: Exotic aspects of hadrons and nuclei

K. P. Khemchandani[1], A. Martínez Torres[2] and N. G. Kelkar[3]*

[1]Departamento de Física, Universidade Federal de São Paulo, São Paulo, Brazil, [2]Universidade de São Paulo, Instituto de Física, São Paulo, Brazil, [3]Departamento de Física, Universidad de los Andes, Bogotá, Colombia

KEYWORDS

**exotic hadrons, kaon-nucleus interaction, finite temperature effective field theory, four-body bound states, Yakubovsky approach, charm-strange mesons, tetraquarks**

Editorial on the Research Topic
Exotic aspects of hadrons and nuclei

We confront a series of exciting findings in the area of hadron and nuclear physics in the present times. The novelties in the field are the discoveries of a series of exotic systems which can be used to understand the non-perturbative regime of the theory of strong interactions. Some such systems are clear examples of multiquark hadrons, those which cannot be explained within the traditional quark model. Other types of exotic systems being investigated currently are bound states of mesons and nuclei. The existence of tetraquarks and pentaquarks were just contemplations of theoretical models until about two decades ago. However, such states are continuously being detected in experimental data these days. The excitement caused by the recent, mind-boggling discovery of Tcc [1, 2] at the Large Hadron Collider beauty (LHCb) experiment, a doubly charmed meson ($cc\bar{q}\bar{q}$), is no less than that led by the discovery of $J/\Psi$ half a century ago. Astonishingly, the former state, Tcc, has half the decay width of $J/\Psi$. Such findings indicate that Tcc might be a clear example of a molecule of open charm mesons, like the atomic molecules. Interestingly a tetraquark (or a molecule of $D\bar{D}^*$) with doubly hidden charm content, $c\bar{c}q\bar{q}$, has also been discovered [3] and confirmed later [4–6]. It has been named $\chi_{c1}$ (3872) and though it´s spin-parity has been confirmed [7], it´s properties such as the precise pole position are still being studied [8]. This latter state is also as long-lived as the Tcc.

Many similar puzzling states have been found and there exists an enormous debate on the existence of tetraquarks involving different flavors of quarks. The present Research Topic consists of a work exploring the existence of a tetraquark with doubly hidden strange content, indicating that $f_2$ (2010) can be understood as a $ss\bar{s}\bar{s}$ state. Dong et al. construct correlation functions by writing both diquark-antidiquark and meson-meson type interpolating currents, as well as mixing of the two to calculate the mass of the tetraquark using QCD sum rules.

Strangeness is an extremely interesting property of the matter in many ways. For example, the interactions of kaons with nuclear matter are well known to be strongly attractive. The interaction of an anti-Kaon ($\bar{K}$) with a nucleon has long been associated with the formation of $\Lambda(1405)$. It is the attractive nature of $\bar{K}N$ which induces an anomalously lower mass of $\Lambda(1405)$ when compared to its nonstrange counterpart [$N^*(1535)$] with the same quantum number. A natural question which arises is if adding more nucleons to $\bar{K}N$ can form exotic nuclear matter containing strangeness. Taking a step forward then one would question if such a phenomenal flavor would be present in neutron stars. Finding an answer to the aforementioned questions is not easy. Even though the nature of the $\bar{K}N$ interaction is being continuously studied by the community, the properties of $\Lambda(1405)$ are still not well understood. One of the difficulties is that the lighter coupled systems, such as pion-hyperon, cannot be easily studied in a laboratory and most information must come from kaon beams. Indeed, such is the strategy of numerous experiments running at the DAFNE facility located at the National Laboratory in Frascati of the Instituto Nazionale di Fisica Nucleare (INFN), Italy. A summary of the studies of low energy interactions of anti-Kaon with light nuclei carried out at the DAFNE collider, by the AMADEUS Collaboration, is presented in the review by Skurzok et al.

To complement the experimental investigations of kaon-light nuclei, this edition provides a peek into the tools necessary to study such systems from the theoretical point of view in two different manuscripts: one treating a four-body system and another dealing with a larger one, thus, requiring a many body approach. Interactions of two hadrons are typically studied by solving the Bethe-Salpeter or Lippmann Schwinger equations. It is important to recall that very often several hadronic systems with the same quantum numbers have similar masses and, hence, should be treated as coupled channels. The situation gets more complex when bigger, but not much bigger, systems are to be studied. Interactions of three/four hadrons can be studied by solving Faddeev/Yakubovsky equations, which are far more complicated than the two-body scattering equations. The Faddeev/Yakubovsky equations are a set of three/four coupled equations and solving them for coupled systems can be quite challenging. It is customary to resort to some kind of approximations to solve such equations. A version of the coupled Yakubovsky equations for 4-body bound states that directly incorporates 2-body interactions in momentum space, thus avoiding the use of 2-body t-matrices is presented by Mohammadzadeh et al.

To study interactions involving larger number of hadrons, a different treatment is required and a detailed formalism is provided by Montaña et al. in a manuscript discussing the properties of open charm/bottom mesons in hot and dense media. In fact, production of heavy flavor hadrons in high energy collisions is a hot topic of research these days. The elevated interest on heavy flavor hadrons arises due to the discoveries of exotic structures in this particular sector. Besides the Tcc mentioned in the beginning of this text, several open charm mesons with anomalous nature have been discovered in recent times. A prominent case is the one of $D_s(2317)$, which can be understood as a $DK$ bound state, providing the state a mass much lower than that expected in the quark model. The manuscript by Montaña et al. considers several exotic mesons which can be understood as molecules of lighter mesons and studies their properties in hot, dense media using a thermal effective field theory developed in a series of works by the same authors. The information given in the manuscript is relevant for studies of high energy pA and AA collisions carried out at LHC and RHIC.

To summarize, the small collection of articles in the present edition clearly gives a hint of the challenges faced in the modern-day hadron-nuclear physics which is full of surprises and with regular appearances of extraordinary findings.

## Author contributions

KK: Writing–original draft, Writing–review and editing. AM: Writing–original draft, Writing–review and editing. NK: Writing–original draft, Writing–review and editing.

## Acknowledgments

AM and KK gratefully acknowledge the support from FAPESP grant numbers 2022/08347-9 and 2023/01182-7. NK thanks the Faculty of Sciences, Universidad de los Andes for support through grant number INV-2023-162-2841.

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