My Research & Activities

@ the ASRC, JAEA

Hyun-Chul Kim
(金鉉哲: キムヒュンチュル)
Inha University (仁荷大學校)
&
ASRC, JAEA (日本原子力研究開發機構)

ASRC@東海村, February 25, 2019
Summary & Introduction

- I wrote 8 papers, among which three were published and five are now under review. Three papers are in preparation.

- I prepared 8 contributions to the Proceedings (FB22, QNP2018), of which 4 of them will appear in Few-Body Systems.

- I have collaborated with A. Hosaka, E. Hiyama, M. Oka, T. Sekihara during my stay at ASRC.

In this talk, I will report mainly what I have done while I was staying at the ASRC, JAEA.
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富山
2018. 12.8（土）～
2019. 2.24（日）
富山市ガラス美術館 展示室1・2・3
開館時間：9:30～18:00
※休館日：12.31（月）、1.1（木）、1.14（月）、1.21（月）、2.1（月）、2.2（火）、2.8（月）、2.10（水）
入館無料（定休日のみ）

【入場料】一般1,400円（1,200円）
中学生・高校生1,000円（800円）
小学生800円（400円）、家族学年割引料

富山市ガラス美術館
〒930-8555
富山市西園1-1-1
富山市役所西園支所(富山市役所本庁舎)
TEL：076-221-6551
FAX：076-221-6553
E-mail：glass@fukaya-city.jp
ウェブサイト：http://www.fukaya-city.jp/glass/

【利用案内】駅から徒歩で約１０分
公共交通機関利用の場合、富山市役所前バス停下車
利用時の交通状況により、開館時間は変更となる場合があります。
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水戸、偕楽園の梅祭り
• With students & friend
• With students & friend
• With students & friend
With students & friend
$K^0\Lambda$ photoproduction off the neutron with nucleon resonances

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Effective Lagrangian approach
t-channel Regge trajectories
Nucleon resonances

Abstract

We investigate kaon photoproduction off the neutron target, i.e., $\gamma n \rightarrow K^0\Lambda$, focusing on the role of nucleon resonances given in the Review of Particle Data Group in the range of $\sqrt{s} \approx 1600$–2200 MeV. We employ an effective Lagrangian method and a Regge approach. The strong couplings of nucleon resonances with $K\Lambda$ vertices are constrained by quark model predictions. The numerical results of the total and differential cross sections are found to be in qualitative agreement with the recent CLAS and FOREST experimental data. We discuss the effects of the narrow nucleon resonance $N(1685, 1/2^+)$ on both the total and differential cross sections near the threshold energy. In addition, we present the results of the beam asymmetry as a prediction.

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Mass spectra of heavy mesons with instanton effects

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We investigate the mass spectra of ordinary heavy mesons, based on a nonrelativistic potential approach. The heavy–light quark potential contains the Coulomb-type potential arising from one-gluon exchange, the confining potential, and the instanton-induced nonperturbative local heavy–light quark potential. All parameters are theoretically constrained and fixed. We carefully examine the effects from the instanton vacuum. Within the present form of the local potential from the instanton vacuum, we conclude that the instanton effects are rather marginal on the charmed mesons.
Instanton effects on charmonium states

Ulugbek Yakhshiev,¹,* Hyun-Chul Kim,¹,²,³,† and Emiko Hiyama²,⁴,⁵,‡

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The instanton effects on the charmonium spectrum are discussed in the framework of the nonrelativistic potential model. The results from the constituent quark model without inclusion of instanton effects are compared with the results for the potential from the constituent quark model plus the contribution from the instanton liquid model. We consider two models with the corresponding instanton potentials and discuss their relevance to explanations of the origin of phenomenological parameters used in the nonrelativistic potential models. We also present the universal instanton potential in a parametrized form, which can be useful in practical calculations.
New narrow nucleon resonances $N^*(1685)$ and $N^*(1726)$ within the chiral quark-soliton model

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(Dated: September 21, 2018)

We investigate the strong and radiative decay widths of the narrow nucleon resonances $N^*(1685)$ and $N^*(1726)$ within the framework of the SU(3) chiral quark-soliton model. All the relevant parameters are taken from those used to describe the properties of the baryon octet and decuplet in previous works. The masses of the antidecuplet nucleon and the eikosiheptaplet (27-plet) nucleon with spin 3/2 are determined respectively to be $(1690.2 \pm 10.5)$ MeV and $(1719.6 \pm 7.4)$ MeV. The decay width for $N^*(1685) \rightarrow \eta + N$ is found to be approximately three times larger than that for $N^*(1685) \rightarrow \pi + N$. The width of the decay $N^*(1726)\, 3/2^+ \rightarrow \eta + N$ is even about 31 times larger than that of $N^*(1726)\, 3/2^+ \rightarrow \pi + N$. The ratio of the radiative decays for $N^*(1685)$ is obtained to be $\Gamma_{nn^*(1685)}/\Gamma_{pp^*(1685)} = 8.62 \pm 3.45$ which explains very well the neutron anomaly. In contrast, we find $\Gamma_{pp^*(1726)}/\Gamma_{nn^*(1726)} = 3.72 \pm 0.64$, which indicates that the production of $N^*(1726)$ is more likely to be observed in the proton channel. We also examined the decay modes of these narrow nucleon resonances with the strangeness hadrons involved.

PACS numbers: 13.30.Eg, 13.60.Rj, 14.20.-c, 14.20.Gk, 14.20.Pt
Keywords: narrow nucleon resonances, hadronic decays, exotic baryons, pentaquarks, the chiral quark-soliton model
Modification of hyperon masses in nuclear matter

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3School of Physics, Korea Institute for Advanced Study (KIAS), Seoul 02455, Republic of Korea
(Dated: February 18, 2019)

We investigate the properties of baryons within the framework of the in-medium modified SU(3) Skyrme model. The modification is performed by a minimal way, the medium functionals in the SU(2) sector being introduced. These functionals are then related to nuclear matter properties near the saturation point. The modifications in the SU(3) sector are performed by changing additionally kaon properties in nuclear matter. The results show that the properties of baryons in the strange sector are sensitive to the in-medium modifications of the kaon properties. We discuss the consistency of the in-medium modifications of hadron properties in this approach, comparing the present results with those from other models.

Keywords: Skyrmions, nucleons, hyperons, nuclear matter
Effects of nucleon resonances on $\eta$ photoproduction off the neutron reexamined

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(Dated: October 12, 2018)

We investigate $\eta$ photoproduction off the neutron target, i.e., $\gamma n \to \eta n$, employing an effective Lagrangian method combining with a Regge approach. As a background, we consider nucleon exchange in the s-channel diagram and $\rho$- and $\omega$-meson Regge trajectories in the t channel. The role of nucleon resonances given in the Review of Particle Data Group in the range of $W \approx 1500 - 2100$ MeV and the narrow nucleon resonance $N(1685, 1/2^+)$ is extensively studied. The numerical results of the total and differential cross sections, double polarization observable $E$, and helicity-dependent cross sections $\sigma_{1/2}$, $\sigma_{3/2}$ are found to be in qualitative agreement with the recent A2 experimental data. The predictions of the beam asymmetry are also given.

Keywords: $\eta$ photoproduction off the neutron, narrow nucleon resonances, effective Lagrangian approach, $t$-channel Regge trajectories
Vector and Axial-vector form factors in radiative kaon decay and flavor SU(3) symmetry breaking

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(Dated: October 17, 2018)

We study the vector and axial-vector form factors of radiative kaon decay within the framework of the gauged nonlocal effective chiral action from the instanton vacuum, focusing on the effects of flavor SU(3) symmetry breaking. The general tendency of the results are rather similar to those of radiative pion decays: The nonlocal contributions make the results of the vector form factor increased by about 20%, whereas they reduce those of the axial-vector form factor by almost 30%. Suppressing the prefactors consisting of the kaon mass and the pion decay constant, we scrutinize how the kaon form factors undergo changes as the mass of the strange current quark is varied. Those related to the vector and second axial-vector form factors tend to decrease monotonically as the strange quark mass increases, whereas that for the axial-vector form factor decreases. When $K \to e\nu\gamma$ decay is considered, both the results of the vector and axial-vector form factors at the zero momentum transfer are in good agreement with the experimental data. The results are also compared with those from chiral perturbation theory to $p^6$ order.

Almost accepted by PLB.
Submitted manuscripts

Nucleon and Δ isobar in a strong magnetic field

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(Dated: February 4, 2019)

We investigate the static properties of the nucleon in the presence of strong magnetic fields and discuss the consequent changes of the nucleon structure, based on the Skyrme model. The results show that at large values of the magnetic field (∼ 10¹⁷ to 10¹⁸G), which is supposed to appear in heavy-ion collision experiments at RHIC energies, the soliton starts to deviate from the spherically symmetric form and its size starts to change. At extremely large values of the magnetic field (∼ 10¹⁹ G), which may be found at the LHC experiments, the soliton becomes more compact than in free space. The results also show that in the presence of the external magnetic field, the mass of the nucleon tends to increase in general and the mass degeneracy of the Δ isobars from isospin symmetry will be lifted. We also discuss the changes in the mass difference between the Δ and the nucleon, ΔmΔN, due to the influence of the external magnetic field. We find that ΔmΔN increases as the strength of the magnetic field grows.
• Manuscripts in preparation

• Electromagnetic form factors of the baryon decuplet (June-Young Kim & HChK)

• Electromagnetic transition form factors of the baryon decuplet to the octet (June-Young Kim, HChK, and Makoto Oka)

• **Killing or Saving the Pentaquark:** Feasibility of the K+D -> K0 pp reaction for Theta+ (Takayasu Sekihara, HChK, and Atsushi Hosaka)
Electromagnetic form factors of the baryon decuplet with flavor SU(3) symmetry breaking

June-Young Kim\textsuperscript{1,*} and Hyun-Chul Kim\textsuperscript{1,2,3,†}

\textsuperscript{1}Department of Physics, Inha University, Incheon 22212, Republic of Korea
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(Dated: February 13, 2019)

Electromagnetic transitions of the light baryons in the self-consistent SU(3) chiral quark-soliton model

Junc-Young Kim\textsuperscript{1,*} and Hyun-Chul Kim\textsuperscript{1,2,†}

\textsuperscript{1}Department of Physics, Inha University, Incheon 22212, Republic of Korea
\textsuperscript{2}School of Physics, Korea Institute for Advanced Study (KIAS), Seoul 02455, Republic of Korea
(Dated: November 7, 2018)
Killing or saving the $\Theta^+$ pentaquark? Feasibility in the $K^+d \rightarrow K^0pp$ reaction

Takayasu Sekihara$^{1,*}$, Hyun-Chul Kim$^{1,2,3}$ and Atsushi Hosaka$^{1,4}$

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Killing or Saving pentaquarks

Hyun-Chul Kim
Inha University
ASRC, JAEA

In the Last October, 2018
Selected work
Instanton effects on quarkonia

QCD Lagrangian

\[ \mathcal{L} = \bar{\psi} (i \not{D} - m) \psi - \frac{1}{4} G^a_{\mu \nu} G^{\mu \nu \ a} \]

This classical Lagrangian looks simple but has profound nonperturbative nature.

1. **Confinement** (Understood only qualitatively)

2. **Chiral symmetry and its spontaneous breakdown**

Chiral symmetry comes into play for light-quark systems.
Static quark confinement

Wilson’s criteria of the quark confinement

\[ W_J = \text{Tr} \left[ P \exp i \int dx^\mu A_\mu^a t_J^a \right] \]

\[ \langle W_J \rangle = \exp \left[ -V(R)T \right] \text{ at } T \to \infty \]

Heavy-quark propagator

Wilson’s Area Law

\[ W \sim \exp(-\sigma \text{Area}) \]

a linearly rising potential

\[ V(R) \sim \sigma R \]

\[ \sqrt{\sigma} = 420 \text{ MeV} \]
Heavy-quark potential

In the limit of infinitely heavy quark mass

\[ V_{\text{Cornell}} = \sigma r - \frac{e}{r} \]

\[ \sqrt{\sigma} = 420 \text{ MeV} \]

Linear confining potential

Coulomb-type potential from one-gluon exchange

G. S. Bali, K. Schilling, A. Wachter, hep-lat/9506017 (RCNP, Confinement 1995)
Heavy-quark potential

Motivations

\[ V_C^{(P)} = \kappa r - \frac{4\alpha_s}{3r} \]
\[ \kappa \approx 0.18 \text{ GeV}^2 \]

- Almost all potential models are based on perturbative QCD.
- Values of parameters are arbitrary.

\[ \alpha_s(\mu) = \frac{4\pi}{\beta_0 \ln(\mu^2/\Lambda_{QCD}^2)} \]
\[ \beta_0 = (11N_c - 2N_f)/3 \]
\[ \mu \approx m_c \]
\[ \Lambda_{QCD} = 0.217 \text{ GeV} \]
Heavy-quark potential

Motivations

\[ V_C^{(P)} = \kappa r - \frac{4\alpha_s}{3r} \quad \kappa \approx 0.18 \text{ GeV}^2 \]

- Almost all potential models are based on perturbative QCD.
- Values of parameters are arbitrary.

\[ \alpha_s(\mu) = \frac{4\pi}{\beta_0 \ln(\mu^2/\Lambda_{\text{QCD}}^2)} \quad \beta_0 = \frac{(11N_c - 2N_f)}{3} \]

\[ \mu \approx m_c \]

\[ \Lambda_{\text{QCD}} = 0.217 \text{ GeV} \]

- Instanton effects may lead us to improve the physical understanding of the heavy-quark potential.
Heavy-quark potential

Motivations

• In order to proceed to heavy-light quark systems, it is essential to understand first the heavy-quark propagator from the instanton vacuum.

Conventional mesons and Tetraquarks (X, Y, Z, Tcc)
Heavy-quark propagator

• Decompose the QCD Lagrangian

\[ \mathcal{L}_{\text{QCD}} = q^\dagger (i\not{D} + im) q + Q^\dagger (i\not{D} + iM) Q - \frac{1}{4g^2} G^2 \]

Foldy-Wouthuysen transformation (Heavy-quark expansion)

\[ Q^\dagger \left( iv \cdot D + \frac{1}{4M_Q} \sigma \cdot B + \frac{1}{2M_Q} (iD)^2 \right) Q \]

• Wilson-loop as a heavy-quark propagator

\[ W = \text{Tr} \left[ P \exp i \oint dx_\mu \sum_{I\bar{I}} A^I_{\mu} \right] \]
Heavy-quark potential

- Gauge-invariant definition of the static potential

\[ V(r) = - \lim_{T \to \infty} \frac{1}{T} \ln \langle 0 | \text{Tr} \{ W_C[A] \} | 0 \rangle \]

- Wilson loop

\[ W_C[A] = P \exp \left( i \oint_C dz \mu A_\mu(z) \right) \]

- Expectation value of the Wilson loop

\[ \langle W_C[A] \rangle = \int DA_\mu \text{Tr} P \exp \left( i \oint_C dx \mu A_\mu(x) \right) e^{-S_{YM}} \]
Heavy-quark potential

Wilson loop in the instanton vacuum

\[ W_C[I, \bar{I}] = P \exp \left( i \oint_C \mathrm{d}t \sum_{I, \bar{I}} a_{I, \bar{I}} \right) \]

\[ W(L_1 L_2) \sim \exp(-V(R)T) \]

Heavy-quark propagator:

\[ S_0^{(i)}(x, y; a_{I, \bar{I}}) = \langle y | \left( \frac{d}{dt} - \sum_{I, \bar{I}} a_{I, \bar{I}}^{(i)} + i\epsilon \right)^{-1} | x \rangle \]
Heavy-quark potential

\[ W(L_1 L_2) \sim \exp(-V(R)T) \]

\[ \text{Tr} W_C = \left\langle \text{Tr} \left[ S_0^{(1)}(x_1, -T/2, y_1, T/2 ; a_I, \bar{I}) S_0^{(2)}(x_2, -T/2, y_2, T/2 ; a_I, \bar{I}) \right] \right\rangle \]

\[ V(R) = \frac{N}{2VN_c} \int d^3 z_I \text{Tr}_c \left[ 1 - P \exp \left( i \int_{L_1} dx_4 A_{I4} \right) P \exp \left( -i \int_{L_2} dx_4 A_{I4} \right) \right] + (I \rightarrow \bar{I}) \]

\[ V(0) = 0, \quad V(\infty) = 2\Delta M \quad \Delta M \text{ Instanton contribution to the heavy-quark potential} \]

Heavy-quark potential

Instanton contribution to the heavy-quark mass: $\Delta M$

- **How to fix parameters: Two fundamental parameters**
    \[
    \rho = \frac{1}{3} \text{fm}, \quad \bar{R} = 1 \text{ fm} \quad \Delta M \simeq 66.6 \text{ MeV}
    \]
    \[
    \rho = 0.35 \text{ fm}, \quad \bar{R} = 0.856 \text{ fm} \quad \Delta M \simeq 143.06 \text{ MeV}
    \]
    \[
    \rho = 0.36 \text{ fm}, \quad \bar{R} = 0.89 \text{ fm} \quad \Delta M \simeq 135.72 \text{ MeV}
    \]
Heavy-quark potential

Central part + spin-dependent part

\[ V_{QQ}(r) = V_C(r) + V_{SS}(r)(S_Q \cdot S_{\bar{Q}}) + V_{LS}(r)(L \cdot S) \]
\[ + V_T(r) \left[ 3(S_Q \cdot n)(S_{\bar{Q}} \cdot n) - S_Q \cdot S_{\bar{Q}} \right] \]
Parameters

Note that we do not aim at fitting the experimental data but try to understand the physical implications of these parameters.

- Actual values of the strong coupling constants

\[
\alpha_s(\mu = 1.275 \text{ GeV}) = 0.4258, \quad \text{MWOI}
\]
\[
\alpha_s(\mu = 1.343 \text{ GeV}) = 0.4137, \quad \text{M-I}
\]
\[
\alpha_s(\mu = 1.411 \text{ GeV}) = 0.4029, \quad \text{M-IIb}
\]

## Results

<table>
<thead>
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<th>State</th>
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<th>MWOI</th>
<th>M-I</th>
<th>M-IIb</th>
<th>Exp. [52]</th>
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<td>$J/\psi (1^3S_1)$</td>
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<td>$\eta_c (1^1S_0)$</td>
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<td>2998</td>
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<td>3635</td>
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<td>3615</td>
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<td>$\psi (4^3S_1)$</td>
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<td>$4421 \pm 4$</td>
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<td>$\eta_c (4^1S_0)$</td>
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<tr>
<td>$\chi_{c2} (1^3P_2)$</td>
<td>3428</td>
<td>3607</td>
<td>3740</td>
<td></td>
<td>$3556.17 \pm 0.07$</td>
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<tr>
<td>$\chi_{c1} (1^3P_1)$</td>
<td>3437</td>
<td>3589</td>
<td>3715</td>
<td></td>
<td>$3510.67 \pm 0.05$</td>
</tr>
<tr>
<td>$\chi_{c0} (1^3P_0)$</td>
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<td>$3862^{+26+40}_{-32-13}$</td>
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</table>
Conclusions

★ Instanton effects are marginal and do not seem to show any significant improvement in comparison with the experimental data.
★ However, the constraint on the parameters can be achieved by introducing the nonperturbative instanton effects.

Outlook

★ Instanton contribution to the one-gluon exchange potential: the effective gluon mass: The Yukawa-type screened potential
★ Virtual light-quark contributions to the heavy-quark potential
★ Color-octet potential
★ We aim finally at deriving the heavy-light quark interactions from the instanton vacuum.
ACKNOWLEDGMENTS

Oka Makoto & Hosaka Atsushi for invitation to the ASRC.

Maruyama Toshiki, Philip Gubler as my office mates.

丸山さんに色々お世話になっておりました。

In particular, I am very grateful to 飯岡さん for all administrative help and supports.

I would like to continue to collaborate with members at ASRC in the future. My 6-month stay at ASRC is just the starting point.
Though this be madness, yet there is method in it.

Hamlet Act 2, Scene 2
by Shakespeare

以上で、今日のセミナーを終わります。

どうもありがとうございました。