us understand the decay process of unstable bound states from a time-dependent perspective.

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1 - 10 Skyrme Model and New Topologies*

Zou Liping and Zhang Pengming

Skyrmions has been shown that carries two independent topologies, the baryon topologies and the monopole topology[1]. The baryon number B of skyrmions could be expressed as $B=mn$, where m is the monopole number and n is the shell nubmer. These two topological numbers describe the topologies $\pi_1(S^1)$ and $\pi_2 S^2$, respectively.

In this report, we briefly review that topological structures in Skyrme model. Skyrme model is an effective model of quantum choromodynamics (QCD) at low energy, which could be understood from QCD lagrangian with Duan-Ge-Cho decomposition theory. With this and the the monopole topology in QCD, we discuss the decomposition of baryon topology in standard Skyrme model and Bogomol'nyi-Prasad-Sommerfield(BPS) Skyrme model. New BPS skyrmion solution is shown with different monopole topology and shell topology.

Duan-Ge-Cho decomposition tells that the QCD gauge field can be decomposed as

$$\hat{A}_\mu = A_\mu \hat{n} + \vec{C}_\mu, \quad \vec{C}_\mu = -\frac{1}{g}\hat{n}\times\partial_\mu \hat{n}. \tag{1}$$

$\hat{A}_\mu$ is the restricted potential which has the full non-Abelian gauge transformation

$$\delta\hat{A}_\mu = \frac{1}{g}\hat{D}_\mu\vec{\alpha},\ \delta\hat{n} = -\vec{\alpha}\times\hat{n}. \tag{2}$$

More importantly, the restricted potential retains all of the topological properties of QCD filed that represented by vector filed $\hat{n}$. To recover full dynamics of QCD we need to introduce the valence filed $\vec{X}_\mu$

$$\vec{A}_\mu = \hat{A}_\mu + \vec{X}_\mu = A_\mu\hat{n} - \frac{1}{g}\hat{n}\times\partial_\mu\hat{n} + \vec{X}_\mu. \tag{3}$$

so that we have

$$\vec{F}_{\mu\nu} = \partial_\mu\vec{A}_\nu - \partial_\nu\vec{A}_\mu + g\vec{A}_\mu\times\vec{A}_\nu = \hat{F}_{\mu\nu} + \hat{D}_\mu\vec{X}_\nu - \hat{D}_\nu\vec{X}_\mu + g\vec{X}_\mu\times\vec{X}_\nu, \tag{4}$$

and the QCD Lagragian is

$$\mathcal{L} = -\frac{1}{4}\hat{F}_{\mu\nu} - \frac{1}{4}(\hat{D}_\mu\vec{X}_\nu - \hat{D}_\nu\vec{X}_\mu)^2 - \frac{g}{2}\hat{F}_{\mu\nu}\cdot(\vec{X}_\mu\times\vec{X}_\nu) - \frac{g^2}{4}(\vec{X}_\mu\times\vec{X}_\nu)^2. \tag{5}$$

Moreover, since the restricted gluon filed $\hat{A}_\mu$ obtains mass due to confinement, QCD Lagrangian could be effectively expressed as

$$\mathcal{L} = -\frac{\mu^2}{2}\hat{A}_\mu - \frac{1}{4}\hat{F}_{\mu\nu} - \frac{1}{4}(\hat{D}_\mu\vec{X}_\nu - \hat{D}_\nu\vec{X}_\mu)^2 - \frac{g}{2}\hat{F}_{\mu\nu}\cdot(\vec{X}_\mu\times\vec{X}_\nu) - \frac{g^2}{4}(\vec{X}_\mu\times\vec{X}_\nu)^2. \tag{6}$$

Let us introduce

$$\vec{X}_\mu = f_1\partial_\mu\hat{n} + f_2\hat{n}\times\partial_\mu\hat{n},\ \phi = f_1 + if_2. \tag{7}$$

and condition $\partial_\mu\phi=0,\ A_\mu=\partial_\mu\omega$, we have

$$\mathcal{L}=-\frac{1}{4g^2}(1-g^2\phi^*\phi)^2(\partial_\mu\hat{n}\times\partial_\nu\hat{n})^2-\frac{1}{4}\phi^*\phi(\partial_\mu\omega\partial_\nu\hat{n}-\partial_\mu\omega\partial_\nu\hat{n})^2-\frac{\mu^2}{2}\left[(\partial_\mu\omega)^2+\frac{1}{g^2}(\partial_\mu\hat{n})^2\right]. \tag{8}$$

One can see that the above QCD Lagrangian looks very like Skyrme model[2]

$$\begin{aligned}\mathcal{L}&=\frac{\mu^2}{4}\mathrm{tr}\ L_\mu^2+\frac{\alpha}{32}\mathrm{tr}\left([L_\mu,L_\nu]\right)^2\\ &=-\frac{\mu^2}{4}\left[\frac{1}{2}(\partial_\mu\omega)^2+2\sin^2\frac{\omega}{2}(\partial_\mu\hat{n})^2\right]-\frac{\alpha}{16}\left[\sin^2\frac{\omega}{2}(\partial_\mu\omega\partial_\nu\hat{n}-\partial_\nu\omega\partial_\mu\hat{n})^2+4\sin^4\frac{\omega}{2}(\partial_\mu\hat{n}\times\partial_\nu\hat{n})^2\right],\end{aligned} \tag{9}$$

This tells that Skyrme model is indeed an effective model of QCD, and the topology in QCD must be seen as well as in Skyrme model. It could be mathematically proved that the baryon topology of skyrmion has an embedded monopole topology

$$\begin{aligned}B&=\tfrac{1}{8\pi^2}\int\epsilon_{ijk}\partial_i\omega\hat{n}\cdot(\partial_i\hat{n}\times\partial_j\hat{n})\sin^2\tfrac{\omega}{2}\mathrm{d}r^3=\tfrac{1}{8\pi^2}\int\sin^2\tfrac{\omega}{2}\tfrac{\mathrm{d}\omega}{\mathrm{d}x^i}\epsilon_{ijk}\hat{n}\cdot(\partial_i\hat{n}\times\partial_j\hat{n})\mathrm{d}x^j\mathrm{d}x^k\\ &=\tfrac{1}{4\pi^2}\int\sin^2\tfrac{\omega}{2}\mathrm{d}\omega\int\hat{n}\cdot(\mathrm{d}\hat{n}\wedge\mathrm{d}hatn)=mn.\end{aligned} \tag{10}$$

As it has been discussed in Ref. [1], skyrmion with shell number $n>1$ has energy like $E_n\sim E_1n(n+1)/2$ which violates the binding energy rules of stable nuclei. So in this report we discuss solutions in a generalized skyrme model without binding energy, this is called BPS Skyrme model. The BPS Skyrme model has wide applications in studies of heavy nuclei, nuclear matter and neutron star[3]. The Lagrangian is

$$\mathcal{L}_{\mathrm{BPS}}=\mathcal{L}_6+\mathcal{L}_0=\frac{\lambda^2}{24}\left[\mathrm{tr}(\epsilon^{\mu\nu\rho\sigma}U^\dagger\partial_\mu UU^\dagger\partial_\nu UU^\dagger\partial_\rho U)\right]^2-\mu^2V(U^\dagger U),\quad U=\mathrm{e}^{i\xi\hat{n}\cdot\vec{\tau}},\quad \hat{n}=\frac{1}{1+|u|^2}\begin{pmatrix}u+\bar{u}\\ -i(u-\bar{u})\\ |u|^2-1\end{pmatrix}. \tag{11}$$

where, $\xi=\xi(r),\ u(\theta,\phi)=g(\theta)e^{(im\phi)}$. With an appropriate potential, *i.e.* $V=\frac{1}{2}Tr(1-U)=1-\cos\xi$, which describes the correct boundary condition satisfying baryon topology, one could obtain the exact BPS skyrmion solution with different shell number. For example, for $n=1$， we have

$$\xi(r)=\begin{cases}2\arccos\sqrt[3]{\frac{\sqrt{2}}{4n}r^3} & r\in[0,\sqrt{2}\sqrt[3]{m}]\\ 0, & r\geq\sqrt{2}\sqrt[3]{m}\end{cases} \tag{12}$$

The corresponding total energy is $E=\frac{64\sqrt{2}}{15}\pi m\mu\lambda$. With shell number $n=2$ we have

$$\xi(r)=\begin{cases}2\arccos\sqrt[3]{\frac{\sqrt{2}}{4n}r^3-1} & r\in[0,\sqrt{2}\sqrt[3]{2m}]\\ 0, & r\geq\sqrt{2}\sqrt[3]{2m}\end{cases} \tag{13}$$

and the total energy $E=\frac{128\sqrt{2}}{15}\pi n\mu\lambda$. Details of the solutions could be seen in Fig. 1.

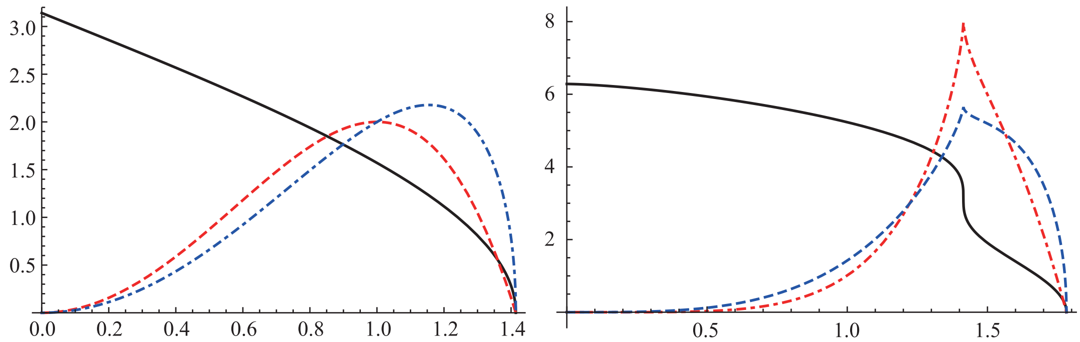

Fig. 1 (color online) BPS skyrmion with monopole number$m=1$ and shell number $n=1$(left panel) and $n=2$(right panel), the solid line is the solution of scalar field ξ, dashed line and dotted dashed line are energy density $\mathcal{E}$, baryon charge density $\mathcal{B}$ respectively. The dimensionless abscissa r is in the unite of $\sqrt[3]{u/\lambda}$.

As we can see from the above solutions, the BPS skyrmion solution has no binding energy which tells that the solution is stable and so the shell topology in BPS Skyrme model is also stable. Moreover, one can see a clear structure at the boundary of solution $n=1$. Checking the integral energy and baryon charge, we find that the boundary indeed separates $n=2$ solution into two skyrmioins with same energy and bayron charge and this could be viewed as shell structure in a baryon.

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1 - 11 Getting the Most Neutrinos out of IsoDAR*

E. Ciuffoli, H. Mohammed, J. Evslin, F.Y. Zhao and M. Deliyergiyev

Several experiments intend to use neutrinos produced via Isotope Decay At Rest (IsoDAR) to search for signs of the presence of sterile neutrinos. In most IsoDAR experiments spallation neutrons are absorbed in a ^{7}Li sleeve (converter), creating ^{8}Li, that will decay emitting $\bar{\nu}_e$. Often IsoDAR proposals plan to use existing detectors or accelerators, to reduce the cost of the experiment. In particular, it has been proposed to use as a neutron source the high-intensity proton accelerators that will be built as a part of the China Accelerator Driven System (C-ADS) program[1].

Using Geant4 and FLUKA simulations, we studied the optimization of the target station, focusing in particular on the neutron yield and on the ^{8}Li production. If the target is surrounded by a converter or a moderator, the neutrons can bounce back. This is a problem especially in the case of heavy metal targets, which have a large neutron absorption cross section: in the case of W, up to 40% of the neutrons can be lost due to the bounce back. We found out that this effect can be reduce by placing a gap (vacuum sleeve) between the target and the converter. For example, with a 20 cm gap the neutron loss can be decreased down to less than 20%.

In order to be absorbed in the converter, the neutrons must be first slowed down to thermal energies. In the first IsoDAR proposal, for this purpose a heavy water sleeve (moderator) was placed between the target and the converter; however in this way either most of neutrons are not thermalized or a significant fraction of them is absorbed inside the moderator. A possible solution is to mix the moderator with the converter. For example, using lithium deuteroxide (either in its anhydrous form, LiOD, or monohydrate, LiOD-D_2O), the deuterium in the compound acts as a moderator, slowing down the neutrons to thermal energies after just few centimeters: in this way we can avoid the problems related to an external moderator. We also considered a liquid converter, using a solution of LiOD in heavy water; it is more efficient for a very small amount of lithium, however the larger amount of H in the compound (due to the isotopic impurities of D) reduces the overall efficiency. Finally, we tested a FLiBe converter, which was suggested for IsoDAR@KamLAND[2]. When the incoming neutron energy is high (≥ 50 MeV) FLiBe is more efficient than LiOD, due to the neutron multiplication effect (*i.e.* additional neutrons can be knocked out from D or Be atoms). However usually if the neutrons are produced using a proton beam the fraction of high-energy neutrons is very small (more than 90% are below 10 MeV). This means that the overall efficiency of FLiBe in the cases considered is lower than LiOD's (this could change, however, if the neutron energy spectrum is different, for example if a deuteron beam is used) (Fig. 1).

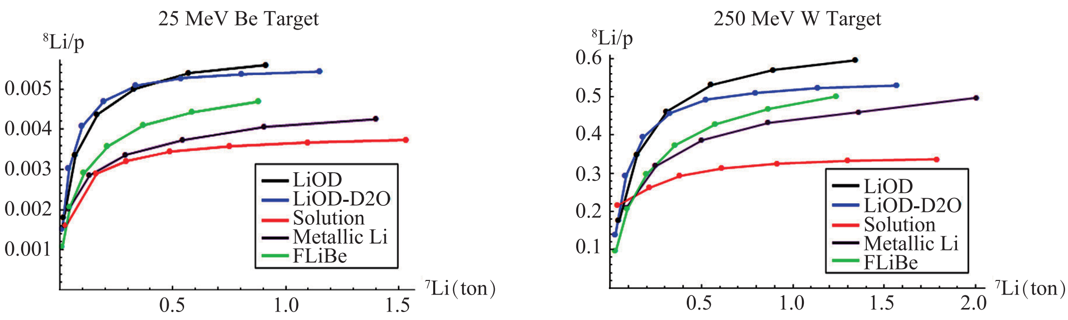

Fig. 1 (color online) ^{8}Li yield using a 25 MeV (left panel) or 250 MeV (right panel) proton beam.