It is known that classical solutions called nontopological solitons exist in a class of scalar field theories which have the global U(1) invariance. Especially, spherically symmetric nontopological solitons are called Q-balls because they have conserved charge Q. The Q-balls are considered as a dark matter candidate in our universe. In the scalar field theories which admit Q-ball solutions, artificial potential forms of the complex scalar field are assumed. I constructed the Q-ball solutions in more natural classical field theories[1][2]. Furthermore, I constructed soliton star solutions by taking the Einstein gravity into account.

Nontopological Solitons in a Spontaneously Broken U(1) Gauge Theory

We constructed the Q-ball solutions in a model which is generalization of the model by Friedberg, Lee, and Sirlin[1][2]. The new model consists of a complex scalar field, a complex Higgs scalar field, and a U(1) gauge field. Since both complex scalar fields have global U(1) gauge invariance, two complex scalar fields induce charge densities that become sources of the U(1) gauge field, respectively. By imposing boundary conditions such that the fields approach to the vacuum state at spatial infinity, local symmetry is spontaneously broken and therefore the gauge field acquires a mass. As a result, influence of the gauge field is confined in a region of scale of Compton length of the gauge field. In another point of view, this effect can be interpreted as follows; while the one complex scalar field induces positive charge, the other complex scalar field induces counter negative charge, and therefore the total charge inside the Q-balls is always totally screened. Then, the Q-balls are observed as electrically neutral objects for a distant observer. This indicate that the charge screened Q-balls have a desirable property for a dark matter candidate.

For unbroken U(1) gauged Q-balls which have been studied, since the charge of the Q-balls yields the Coulomb repulsive force mediated by the gauge field, it is difficult to construct large gauged Q-balls. However, owing to the charge screening effect, our Q-balls can acquire large mass. The large Q-balls can be classified into three types by equation of state inside the Q-balls. I called these solutions “dust balls”, “shell balls”, and “potential balls”, respectively.

Soliton Stars in a Spontaneously Broken U(1) Gauge Theory

I have taken an Einstein gravity into account and constructed soliton solutions. The soliton solutions in coupled systems of bosonic fields and gravitational fields are called boson stars. Especially, the boson stars by gravitating Q-balls are also called soliton stars.

By numerical calculations, I showed that the charge screening always occurrs inside the soliton stars as the Q-balls. I also showed that an upper bound of mass appears for stable soliton stars. The study is ongoing.