Electrodynamics of pairing phase transition in Nuclei

Afaque Karim[1],* Shakeb Ahmad[1], and Tasleem Ahmad Siddiqui[1]
[1] *Department of Physics,Aligarh Muslim University,Aligarh-202002, INDIA*

1. Introduction

It has been known that the pairing correlation play an important role in finite and infinite nuclear system.The most prominant evidence for pairing correlation was odd-even effect. Mass of an odd nucleus is larger than mean of adjacent two even -even nuclei masses. Moreover, the energy gap in odd-even and even-odd nuclei (especially deformed nuclei) have energy spectra different from even-even nuclei[1]. This additional energy arises primarily from the short range interaction of correlated pairs of nucleons.Thus, in calculation of various nuclear parameters, it is therefore crucial to consider pairing effects.A sopisticated pairing model and an appropriate choice of pairing model parameters are both important for obtaining realistic results.The Standard theory regarding this pairing correlation is Bardeen-Cooper-Schrieffer (BCS) theory, which is mean field approximation based on grand-canonical ensemble.The pairing correlation in nuclear many body problems was first proposed by Bohr and Mottelson, and Pines in 1958[2].Moreover, like superconductors, Nucleus also show superfluid as well as normal state behaviour.So, Thermodynamics properties of nuclei have been a topic of much interest in nuclear physics[3].From the theoretical point of view,thermodynamic properties of any system can be studied by using statistical ensemble approaches.These approaches are derived based on solutions of the BCS and self-consistent quasiparticle random-phase approximation[4].Apart from it, Like superconductors Nuclei should also show electrodynamical properties at pairing phase transition.Though In most of the nuclear properties study ,electrodynamics of nuclei at pairing phase transition has not been studied but our group has tried their effort to study the electrodynamical properties of nuclear system at pairing phase transition. In this paper, The electrodynamical properties of nuclear system is studied for nuclei throughout the periodic system.We have presented the formalism for critical current density (j_c) due to protons along with their values for all the light,medium and heavy nuclei.Results shows that the contribution of j_c seems to be significant in nuclear system.

*Electronic address: afaquekrm@gmail.com

2. Electrodynamics of nuclei

The electrodynamics study of superconductors have been discussed by several authors around the globe.It has been discussed using London equations and in the framework of the phenomenological Ginzburg-Landau theory.These properties has also been studied using BCS theory.Our present interest lies in electrodynamical property study at pairing pahse transition in nuclei.We have used the BCS theory of nuclear pairing correlation to study the critical current density,i.e. the transition point at which the cooper pairs will break down. The cooper pairs of the BCS state are formed by nucleons with the wave vectors k and $\bar{k}$.Their total momentum is zero.Pairs with finite momentum $\hbar q$ are obtained if nucleons with $k + q/2$ and $\bar{k} + q/2$ are bound together.If q is the same for all pairs,this is equivalent to considering type original BCS state in a moving frame that is boosted with velocity $-\hbar q/2m_p$.Since the centers of mass of the pairs drift with velocity $\hbar q/2m_p$,a current flows in the sample with current density

$$j = en_p \frac{\hbar q}{2m_p} \quad (1)$$

Where,e is electric charge of proton, m_p is mass of proton and n_p is density of nucleons(proton) and is defined by the expression

$$n_p = \frac{Z}{V} = \frac{3Z}{4\pi {r_o}^3 A} \quad (2)$$

Now,Considering a pair(k+q/2,$\bar{k}$+q/2).If this pair is broken and the nucleon with wave vector $k + q/2$ propagating in the direction of the currrent is scattered elastically into state with the wave vector $\bar{k} + q/2$,the conservation of energy can be met provided that

$$\frac{\hbar^2(k+q/2)^2}{2m_p} \geq \frac{\hbar^2(\bar{k}+q/2)^2}{2m_p} + 2\Delta_0, \quad (3)$$

since the minimum energy needed to break up a pair is $2\Delta_0$.This leads to the condition

$$q\frac{\hbar^2 k_F}{m_p} \geq 2\Delta_0 \quad (4)$$

It can be satisfied only if q exceed a certain critical value,which gives the estimate

$$j_c = \frac{en_p\Delta_0}{\hbar k_F} \quad (5)$$

for the critical current density.

3. Results and Discussion

In this section we discuss the new aspects of calculated critical current density for all set of nuclei.We have considered that as the nucleon pair is destroyed then the scattering between them results in decrease in current.In other words,At a particular value of current ,the cooper pairs are broken and after that the nuclei transits at normal phase.This value can be considered at ground state properties studied.Here, Table 1 describes the value of j_c for few set of nuclei.The j_c values decreases with the higher Z/N.This confirms that at higher Z/N the closeness of shells results in the easily transition of nuclei from superfluid to normal state and increament in the scattering between the free nucleons.

TABLE I: The Value of Critical current density at pairing phase transition for a set of nuclei

Nucleus	j_c(A/fm^2)	Nucleus	j_c(A/fm^2)
$^{4}He_2$	6.021×10^{16}	$^{11}B_5$	3.819×10^{16}
$^{16}O_8$	3.793×10^{16}	$^{28}Si_{14}$	3.147×10^{16}
$^{40}Ca_{20}$	2.794×10^{16}	$^{56}Fe_{26}$	2.303×10^{16}
$^{58}Ni_{28}$	2.399×10^{16}	$^{89}Y_{39}$	1.763×10^{16}
$^{207}Pb_{82}$	1.008×10^{16}	$^{238}U_{92}$	8.892×10^{15}

4. Summary

We have discussed that electroynamics of nuclei at pairing phase transition using BCS approach.One get that at a certain value of current density the nuclei transits from superconducting to normal state and at this value the cooper pairs are mainly destroyed.Moreover,one can infer that this value of current does flows only at the surface of nucleus when properties are studied at ground state level.Moreover,One gets that the value is significant at nucleonic level i.e at the order of fermi.Thus,the finite size nucleons i.e mainly protons play an importanmt role in several scattering events and should not bne treated as a static source of Electromagnetic field.Moreover,the significant value of current does seems to be important in several nuclear experiments.

References

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