

Bogoliubov quasiparticle in high-Tc superconductors observed by angle-resolved photoemission spectroscopy

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Kamerlingh Onnes (1911)



Superconducting wire



Ultra-fast computer



Linear motor car

Progress of superconductivity





High-Tc superconductor





Fulleren & MgB2





Fulleren & MgB2





BCS theory

Phys. Rev. 108 (1958) 1175.









J.R. Shrieffer

Cooper pair



Nobel Prize (1972)

Normal state

 $T > T_{\rm c}$

e-

Superconducting state

 $T < T_{\rm c}$

Bogoliubov quasiparticles (BQPs)



Bogoliubov transformation

 $\gamma_{k0} = \mathcal{U}_k C_{k\uparrow} - \mathcal{V}_k C_{-k\downarrow}^{\dagger}$ $\gamma_{k1}^{\dagger} = \mathcal{V}_k^* C_{k\uparrow} + \mathcal{U}_k^* C_{-k\downarrow}^{\dagger}$



N.N.Bogoliubov

J. Phys. USSR 11 (1947) 23 Nuovo Cimento 7 (1958) 794



How to observe BQPs ?

How to observe BQPs ?

Each QP has a characteristic energy In sold : Energy dispersion (Energy as a function of momentum)

Band dispersion of BQPs

Formation of Bogoliubov quasiparticle band



How to measure the band dispersion of BQPs ?



ARPES

Angle-resolved photoemission spectroscopy

Angle-Resolved Photoemission Spectroscopy (ARPES)



ARPES apparatus at Tohoku University





What to measure to observe BQPs?





$Bi_2Sr_2Ca_2Cu_3O_{10}$ (Bi2223)





High-resolution ARPES spectra of Bi2223





ARPES spectra of Bi2223 divided by FD function

В

-80

T = 60 K

Intensity / FD function (arb. units)

80

40

 $E_{\rm F}$

Binding Energy (meV)

-40



Evidence for BQP band in Bi2223



FD-divided ARPES intensity plot near EF



BQP picture is qualitatively established. How abut the coherence factors ?

Coherence factors $|u_k|^2$ and $|v_k|^2$





Comparison of BQP dispersion and coherence factors between "experiment" and "theory"



Excellent quantitative agreement !



BCS theory is quantitatively verified.

Bogoliubov quasiparticles do exist !



ARPES confirms it 50 yrs after the proposal !



BCS theory is a universal concept in describing superconductivity for low and high-T_c superconductors

BCS theory + Bogoliubov quasiparticle



Phys. Rev. 108 (1958) 1175.



BCS theory + Bogoliubov quasiparticle











Kamerlingh Onnes (1911)















Variety of new hgh-Tc superconductor









Application of high-Tc superconductors







BCS theory + Bogoliubov quasiparticle



Phys. Rev. 108 (1958) 1175.





Comparison of coherent peak between Bi2212 and V₃Si

