Interpretation of anomalous normal state optical conductivity of K_3C_{60} fullerenes

K K CHOUDHARY

Department of Physics, Shri Vaishnav Institute of Technology and Science, Indore 453 331, India

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Abstract. The observed frequency dependent optical response of alkali-metal-doped fullerene superconductors ($T_c \approx 19$ K) has been theoretically analysed. The calculations of the optical conductivity, $\sigma(\omega)$, have been made within the two-component schemes: one is the coherent Drude carriers (electrons) responsible for superconductivity and the other is incoherent motion of carriers from one atom to other atom of C_{60} molecule to a pairing between Drude carriers. The approach accounts for the anomalies reported (frequency dependence of optical conductivity) in the optical measurements for the normal state. The model has only one free parameter, the relaxation rate. The frequency dependent relaxation rates are expressed in terms of memory functions. The coherent Drude carriers form a sharp peak at zero frequency and a long tail at higher frequencies, i.e. in the infrared region. However, the hopping of carriers from one atom to the other (incoherent motion of doped electrons) yields a peak value in the optical conductivity centred at mid-infrared region. It is found that both the Drude and hopping carriers will contribute to the optical process of conduction in the K_3C_{60} and shows similar results on optical conductivity in the mid-infrared as well as infrared frequency regions as those revealed from experiments.

Keywords. Optical conductivity; Drude carriers; hopping carriers.

1. Introduction

Since the discovery of superconductivity in the alkali-doped fullerenes, A_3C_{60} ($A = K, Rb$, etc) (Hebard *et al* 1991b), the family of related compounds has been studied extensively. The optical conductivity, $\sigma(\omega)$, is believed to be a powerful probe in determining electronic characteristics of a variety of materials. Despite a large number of experimental and theoretical efforts, full explanation of anomalous behaviours of optical conductivity in A_3C_{60} has not been established yet. The photo-emission and inverse photo-emission experiments have shown that there exists a strong coulomb interaction between two electrons on the same C_{60} molecule (Lof *et al* 1992; Weaver 1992) which is hypnotized as coherent motion electrons, i.e. Drude carriers in our proposed model to explain the anomalies observed in optical conductivity of K_3C_{60} . Further, the Raman and neutron scattering studies have shown that there exist a strong coupling between the conduction electrons and the intramolecular phonons (Duclos *et al* 1991; Pintschovius 1996) which is presented as hopping of carriers from one C_{60} molecule to another.

It is identified that in alkali-metal-doped fullerenes, the phonon spectrum has a wide frequency region. The vibrational spectrum is classified into two regions. One of them belongs to the rotation of C_{60} molecule and the intermolecular vibrations. The others are the intramolecular vibrations. Actually, the intramolecular phonons span a large frequency

range, 2×10^2 – 2×10^3 cm^{-1} , while intermolecular vibrations and soccer ball vibrations (restricted rotations) go down to a low energy interval, 10–100 cm^{-1} (Prassides *et al* 1991). High frequency intramolecular vibrational modes or electronic excitations would tend to favour the weak coupling theory, whereas intermolecular modes would require strong coupling theory (Varshney *et al* 1998).

In the optical conductivity spectra, there exists not only the Drude component but also the mid-infrared absorption (DeGiorgi *et al* 1992; Iwasa and Kaneyasu 1995) that is not expected in simple metal. Most importantly, the reason why A_3C_{60} remains metallic, although both the electron–electron and electron–phonon interactions are considerably strong, has not been revealed yet at all. The optical conductivity of A_3C_{60} has an unusually interesting behaviour (Iwasa *et al* 1992; DeGiorgi *et al* 1994a,b; DeGiorgi 1995) where weight of the Drude peak is reduced by one order of magnitude relative to the weight for free electrons with appropriate band mass. Much of the missing weight appears instead in a ‘mid-infrared’ structure at about 0.06 eV which suggests very strong interaction effect, e.g. electron–electron or coulomb interaction. The main experimental findings of DeGiorgi *et al* are (a) the total Drude weight is about 0.1–0.2 and (b) MIR absorption is very broad, which begins at around 0.02 eV, has a peak around 0.07 eV (DeGiorgi *et al* 1994a,b; DeGiorgi 1995) and shows strong coulomb interaction between conduction electrons in addition to the electron phonon interactions. The understanding of the optical absorption could, therefore, contribute much to the understanding also of other properties of A_3C_{60} . The strong

(kkchoudhary1@yahoo.com)

reduction of the Drude width suggests very strong renormalization effect, e.g. due to the electron–phonon or electron–electron interactions. The fullerenes have phonons with energy of about 0.06 eV that show a strong coupling to the electrons (Gunnarsson 1997).

The optical conductivity, $\sigma(\omega)$, represents the rate at which electrons absorb the incident photons at energy, ω and is a useful probe in determining electronic characteristics of the material under study. For an ideal free electron gas with the impurity scattering rate $1/\tau \rightarrow 0$, where the interactions between the electrons and between the electrons and phonons are neglected, $\sigma(\omega)$ collapses to a delta function, $\sigma(\omega) = D_{\text{tot}}\delta(\omega)$, where the coefficient, D_{tot} , represents the total spectral weight. In this case the optical conductivity sum rule, $\int_0^\infty d\omega \sigma(\omega) = D_{\text{tot}} = \pi e^2 n/m$, where n is the density and m the mass of electrons, is exhausted entirely by the delta-function Drude contribution alone. When the material becomes dirtier, the Drude peak of optical conductivity acquires the Lorentzian shape with the width of $1/\tau$. The conductivity sum rule is still exhausted by the Drude part alone when only the impurity scatterings are present in the system. The total weight, D_{tot} , however, can change as impurity scatterings or other interactions are introduced when we consider a finite bandwidth, because the projection to a restricted basis set disregards all excitations to higher energy than the bandwidth. When other interactions are present, the free carrier Drude weight is reduced by the quasiparticle renormalization factor, Z , such that $D = Z^{-1}D_{\text{tot}}$, and the missing spectral weight from the Drude part is transferred to a higher-energy region of $\sigma(\omega)$ reflecting the excitation of incoherent scatterings (Yoo and Choi 2000).

For a better understanding of the electronic properties of A_3C_{60} , not only the low frequency responses but also high frequency responses are very important. The high frequency response of the non-superconducting compounds is also important because the mechanism of the breakdown of band picture in A_xC_{60} (at $x = 4$) compounds might be related to the anomalous $N(\epsilon_F)$ enhancement in the superconducting $x = 3$ compounds.

The plan of the present investigation is as follows. In § 2, we develop a model with electron–electron (Coulomb) and electron–phonon interactions. The aim of this paper is to explain theoretically some of the features observed in the experimental data on frequency dependent optical conductivity of normal state, using a simple model. The electronic dielectric function is evaluated following random phase approximation of polarizabilities. A coupling between the two electrons of C_{60} molecule is taken into consideration for calculating polarization function. Further, ω and T dependence of damping function, $\gamma(\omega, T)$, is determined following the memory function approach for $T > T_c$.

The first channel to conductivity is the coherent Drude, i.e. due to coupling of electron with phonon with temperature dependent damping. Secondly, the MIR component of electrons from one atom of C_{60} to another. It is worth mentioning here that the experimental results for optical

conductivity in the alkali–metal-doped fullerenes suggest that there exist at least two species of carriers contributing to the optical conduction in the C_{60} molecules over the infrared and lower frequency regimes in the light of the conductivity rules. These experimental observations have led us to perform a phenomenological calculation of the optical conductivity based on two-component model that could satisfactorily reproduce the experimental results including the mid-infrared anomaly.

Section 3 deals with the estimation of parameter along with results and discussion. A realistic appraisal of the optical conduction requires the values of band structure parameters (n_c and m^*) which are extracted from experimental data on lattice parameter. We choose the values of relaxation rates to calculate the frequency dependence of optical conductivity. From the present analysis, we are able to reproduce the experimental results of optical response. The main findings include: (a) in the metallic normal phase, $\sigma(\omega)$ consists of a Drude term centred at zero frequency whose shape depends on temperature and (b) hopping of the carriers from one atom to the other of C_{60} contributes to a peak value in mid-infrared region. Our main conclusions are presented in § 4.

2. The model

The undoped C_{60} molecule is a pure carbon compound and possesses a spherical structure. The C_{60} molecule has been found to crystallize in the *fcc* phase with lattice parameter $a = 14.20 \text{ \AA}$. When the C_{60} molecule is doped with alkali metal (K) atoms, the semiconducting C_{60} becomes metallic; at the K_6C_{60} composition it shows superconducting nature with critical transition temperature, $T_c \approx 20 \text{ K}$ and then becomes insulating at K_3C_{60} . The distance between the centres of the nearest neighbour C_{60} cages is $d = 10 \text{ \AA}$. With the alkali metal doping, K atoms become fully ionized in the C_{60} crystal and give up their electrons to the highly polarizable C_{60} molecule. The C_{60} –K bonds are in tetrahedral and octahedral positions and at the tetrahedral position r_{K-C} is $6 \text{ \AA}$. The alkali metal doped fullerenes have their own internal degrees of freedom, electronic structure and vibrational modes. The characteristic intermolecular vibration is expressed as $\omega_{\text{er}} \approx v_s/d \approx v/d\sqrt{m/M}$. Here the symbols v_s , v , d , m and M represent velocity of sound, electron velocity, distance between nearest neighbour C_{60} molecules, electron mass and molecular mass of the soccer ball, respectively.

Let us start with the calculation of the optical conductivity as

$$\sigma(\omega) = \lim_{q \rightarrow 0} [\omega \text{Im}\epsilon(q, \omega)] / 4\pi, \quad (1)$$

where $\epsilon(q, \omega)$ represents the longitudinal dielectric response function, q the wave vector and ω the frequency. $\epsilon(q, \omega)$ is given by

$$\epsilon(q, \omega) = \epsilon_\infty + P(q, \omega), \quad (2)$$

where ε_∞ is the high-frequency dielectric constant accounting for core electron polarization and $P(q, \omega)$ represents the electronic polarizability. For an attractive interaction, $\varepsilon(q, \omega)$ must be negative. The charged quasi particles are being scattered by optical phonons, the charge fluctuations as well as impurities and possess a finite damping rate, Σ .

We shall now proceed to include polarizability of carriers in the long wavelength limit.

The electronic polarizability within random phase approximation for carriers follows (Varshney *et al* 2003)

$$P(q, \omega) = -2\pi Z^2 e^2 n_c q / m_\mu^* \omega (\omega + i \Sigma(\omega)), \quad (3)$$

Ze being the sum of the ionic charge and the free electron charge, n_c the density and m_μ^* the effective mass. The frequency dependent damping function or the inverse of relaxation time is denoted as $\Sigma(\omega)$.

Equations (2) and (3) yield model longitudinal dielectric response as

$$\varepsilon(q, \omega) = \varepsilon_\infty - \frac{2\pi Z^2 e^2 n_c q}{m_\mu^* \omega [\omega + i \Sigma(\omega)]}. \quad (4)$$

The frequency dependent damping function of the quasi particles are expressed in terms of memory functions, $\Gamma_\mu(\omega)$ (Yoshida and Takeno 1989), as

$$\Sigma_\mu(\omega) = \Sigma_\mu(0) + [\Sigma_\mu(\infty) - \Sigma_\mu(0)][-i\omega\Gamma_\mu(\omega)], \quad (5)$$

here μ is either '0' (D) or '1' (h). Furthermore, we denote $\Sigma_\mu(0) = \gamma_{\mu 0}$ and $\Sigma_\mu(\infty) = \gamma_{\mu \infty}$ as the low and high frequency limits of the damping function of the quasi particles, respectively. In order to satisfy the requirements of causality, the memory functions are

$$\Gamma_\mu(\omega) = \int_0^\infty \Gamma'_\mu(t) e^{i\omega t} dt, \quad (6)$$

where $\Gamma'_\mu(t = 0) = 1$ and $\Gamma'_\mu(t = \infty) = 0$. Using the Gaussian forms of Γ for memory function, viz. by setting

$$\Gamma'_\mu(t) = \exp(-t^2/\gamma_{\mu c}^2), \quad (7)$$

$\gamma_{\mu c}$ being the characteristic relaxation rates. Physically, $\gamma_{\mu 0}$ and $\gamma_{\mu \infty}$ are the inverse of life times of quasi particles, due to the scattering by external fields. While to that, $\gamma_{\mu c}$ is regarded as those associated with the motion of scatterers. However, there are no constraints on the ordering in magnitude among these three damping functions of quasi-particles.

Using the developed expression for optical conductivity, with two-channels of optical conduction, we need to simulate a combination of band structure parameters (n_c and m_μ^*) and relaxation rates (γ_0 , γ_∞ and γ_c) to analyse the optical conductivity for alkali metal doped fulleride superconductors. We shall show that the calculations of the optical conductivity, $\sigma(\omega)$ and the processing of the results within the two-component scheme with frequency dependent scattering rate, are similar to the experimental results and are presented along with discussion in the following section.

3. Results and discussion

For the actual appraisal of the optical response of K_3C_{60} ($T_c \approx 19$ K) superconductor, it is necessary to determine realistic values of some physical parameters that are derived from the experimental data as follows. The effective mass is $m^* \cong 3m_e$ (Noviko *et al* 1992), the Fermi velocity, $v_F \cong 1.8 \times 10^7$ cm s⁻¹ (Zhang and Guo 1994) and $n_c = (4 \times 3)/a^2 = 4.21 \times 10^{14}$ cm⁻², is obtained. The parameters related to ions, background dielectric constant, ε_∞ , for K_3C_{60} is used as 4.4 (Hebard *et al* 1991a) and ionic charge Ze being $7e$. For the Drude term, i.e. electron-phonon interaction, we follow $m_D^* = 3m_e$. The optical conductivity sensitively depends on the values of relaxation rates. Before proceeding for further analysis, we may first comment on the relaxation rates of the quasi particles. The quasi particle relaxation rates γ_{D0} , $\gamma_{D\infty}$ for the Drude component dominates the low frequency behaviour of optical conductivity. They represent the inverse of the lifetime of carriers having a well defined Fermi surface. The relaxation rates are temperature dependent and for $T = 300$ K, we take $\gamma_{D0} = 300$, $\gamma_{D\infty} = 500$ and $\gamma_{Dc} = 200$ cm⁻¹, respectively. Physically, choice of the relaxation rates corresponds to the scattering process well described by phenomenological Drude model. However, the time $1/\gamma_{Dc}$ in which the scatterers return to the initial state is much larger than the time $1/\gamma_{D0}$ and $1/\gamma_{D\infty}$ for which the carriers can move freely without being scattered, the scatterers can respond to the motion of the electrons quickly enough. An estimate of the coupling strength for the carriers may also be made from the frequency dependent scattering rate, $\gamma(1/\tau) \cong 2\pi\lambda_{tr}k_B T$. At $T = 300$ K, with γ_{D0} of 300 cm⁻¹ yields 0.23, which places this material in the weak coupling limit and are consistent with the previous reporting (Alexandrov 2001) of coupling strength, λ_{tr} , in K_3C_{60} , i.e. 1.0. It is worth to comment that the effects of reduced coupling strength, as well as the enhanced effective mass of carrier have important implications for the transport properties of the doped fullerides. The optical conductivity essentially depends on the value of relaxation rates representing the lifetime of free charge carriers and is roughly estimated as $\gamma \approx 2-5 k_B T$. Assuming the validity of this fact for fullerides, we could use these values of damping function of quasi particles. With these reservations, we show in figure 1, the results for the optical conductivity that corresponds to simple Drude model. We find from the present calculations that a peak value of $\sigma(\omega)$ at zero frequency is observed which develops for the coherent motion of charge carriers and a tail at higher frequencies. The above feature is consistent with the earlier theoretical proposals (Yoo and Choi 2000).

Switching to the second mode of conduction, i.e. the transfer of electrons from one atom to other atom of C_{60} molecule through hopping, the values of n_c and m^* are same as those for the earlier case. It is useful to mention that the effective mass, m_h^* , for the hopping component is difficult to determine through the de Haas-van Alfen experiments due to shortness of the mean free path. The relaxation rates, γ_{h0} and $\gamma_{h\infty}$, for the hopping component dominating the mid-infrared

Figure 1. Variation of optical conductivity with frequency in K_3C_{60} .

behaviours of the optical conductivity, their magnitudes are thus estimated to be ~ 0.1 – 1.0 eV. The characteristic rates, γ_{Dc} , are regarded as the motion of the excitations, which scatter the free carriers. The excitations may be substantiated by the phonon, the magnon or the hopping component. While to that the localized spin system or the lattice system are to be considered to interact with the hopping component with characteristic rate, γ_{hc} . The magnitudes of these parameters lie in the range 0.01 – 0.5 eV. Furthermore, the relaxation rates at $T = 300$ K are chosen as $\gamma_{h0} = 800$ cm^{-1} , $\gamma_{h\infty} = 500$ cm^{-1} and $\gamma_{hc} = 200$ cm^{-1} , respectively. The above parameters correspond to those situations that may well be described in terms of the t – J model (Moreo and Dagotto 1990; Anderson 1997). The relaxation times $1/\gamma_{h0}$ and $1/\gamma_{h\infty}$ points to the process in which the electrons transfer from atom to atom through hopping. Physically, the motion of electrons disturbs the antiferromagnetically ordered spin configurations localized on the C atoms. The time $1/\gamma_{hc}$ refers to a characteristic time in which the spin configurations return to the initial state. It is worth to point that the time $1/\gamma_{h0}$ and $1/\gamma_{h\infty}$ are smaller than the time $1/\gamma_{hc}$, this relaxation process cannot immediately follow the motion of electrons.

We plot the contribution of second channel for the optical conductivity in the same figure that corresponds to a non-Drude behaviour and a peak value at about 1000 cm^{-1} is obtained. Indeed this non-Drude behaviour is interpreted in terms of hopping of electrons from one atom to another atom of C_{60} molecule. It may be pointed out that the relaxation rates γ_{h0} and $\gamma_{h\infty}$ are involved in the hopping process and in fullerenes superconductors, $\gamma_{h0} > \varepsilon_F$, so the motion of electrons from one atom to another atom within the molecule is no doubt hopping like. Both contributions are then clubbed and the resultant optical conductivity is consistent with the reported data on K_3C_{60} superconductor (DeGiorgi *et al* 1994a,b; DeGiorgi 1995).

We made some comments on the magnitude of characteristic relaxation rates chosen in the calculations. As pointed

out, we enumerate electronic charge fluctuations as excitations interacting with the Drude component; the relaxation rate, γ_{Dc} , is regarded as a quantity, which characterizes the motion of excitations. One may also seek that the phonons, magnons and other excitations are also interacting with the Drude component. It is, however, difficult to accurately determine the magnitude of γ_{Dc} from comparison between experimental and calculated results, as the calculated values for the optical conductivity do not sensitively depend on the values of γ_{Dc} . It is, therefore, a formidable problem to specify which excitation is the most important for scattering the Drude component. A representative value, $\gamma_{Dc} = 200$ $\text{cm}^{-1} = \gamma_{hc}$, has thus been taken in the present study.

Furthermore, the mean free path L of the Drude carriers deduced from γ_{D0} (300 cm^{-1}) and the Fermi velocity ($v_{FD} \cong 1.8 \times 10^7$ cm s^{-1}) yields a value of about 3.15 nm at $T = 300$ K which points to the coherent motion [$L > a$] (a being the lattice parameter and is about 1.42 nm (Huffman 1991; Hebard 1992)) of Drude carriers within the C_{60} molecule. Also, the Mott–Ioffe–Regel criterion for metallic conductivity is valid, as the mean free path is several times larger than the distance between the centres of the nearest neighbour C_{60} cages (~ 1.0 nm). A significantly enhanced mean free path is an indication of metallic conduction as the product $k_F L$ (~ 17.2) seems to be much larger than unity.

The relaxation times associated with the hopping component satisfy a relation that $\gamma_{hc} < \gamma_{h\infty} < \gamma_{h0}$. This relation represents such a situation that the motion of the scatterers cannot afford to follow that of the carriers, corresponding to a state called an incoherent motion within the context of the t – J model (Moreo and Dagotto 1990; Anderson 1997). It is observed in this case that a peak structure in the optical conductivity appears in the mid-infrared region. It is thus anticipated that the frequency-dependent effective mass rapidly decreases. It is, however, difficult to specify the excitations, which strongly interact with the hopping carriers based on the comparison between the calculated and experimental results as in the case of the Drude component. We note that the mean free path of the hopping carriers in K_3C_{60} estimated from γ_{h0} ($= 800$ cm^{-1}) and the Fermi velocity, $v_{Fh} = 1.8 \times 10^7$ cm s^{-1} , is about 1.18 nm which may imply that the motion corresponds to the interatomic hopping in the C_{60} molecules. It is thus anticipated that Fermi surface of the hopping component almost loses its sense.

The optical spectra of doped fullerenes in the normal state were found to exhibit some unusual features. The optical conductivity, $\sigma(\omega)$, deviates considerably from the Drude-like feature expected for conventional metals. This indeed points to the fact that the strong interaction effects due to the Coulomb and electron–phonon interactions should be important in the optical spectra of fullerene. In principle, the optical conductivity represents the rate at which electrons absorb the incident photons at energy, ω , and is a meaningful concept in revealing the electronic characteristics of the test material. For an ideal free electron gas, where interactions between the electrons, between the electrons and phonons are neglected, and the impurity scattering rate $\tau^{-1} \rightarrow 0$, $\sigma(\omega)$

collapses to a delta function. In this case, the optical conductivity sum rule is exhausted by the delta function Drude contribution alone. When the material becomes dirtier, the Drude peak of optical conductivity acquires Lorentzian shape with a width of τ^{-1} .

The conductivity sum rule is still exhausted by the Drude part alone when only impurity scatterings are present in the material. As pointed out by the experimental observations (DeGiorgi *et al* 1994a,b; DeGiorgi 1995), the total spectral weight in view of optical conductivity sum rule differs from the conventional metals. It should be emphasized that the one-component model is the model that the optical response can be expressed by only one physical origin. However, in the present model calculations, with two-channels well separated in energy fits the reported experimental data have clearly different physical meanings associated with optical transport. Nonetheless, we believe that the two-component model seems to be suitable because of the failure of the Drude explanation in fullerenes. Similar argument has also been reported in the studies of t - J model (Moreo and Dagotto 1990; Dagotto 1992, 1994; Anderson 1997). We should mention that the electrons in C_{60} molecule respond to the incident light in two ways: while an electron moves together with charge fluctuations at low frequencies leads to a coherent motion and when it moves independently i.e. hopping from one atom to another at frequencies higher than a characteristic energy of charge fluctuations, it is incoherent motion.

To summarize, a two-component model of conductivity, in which two-channels of conductivity is included: the first is coherent Drude component with a temperature dependent damping function, and the second is the incoherent hopping component that is essentially temperature independent. The inclusion of the frequency dependent relaxation rates for the carriers is essential to account for the anomalous density fluctuations observed in the infrared region in optical conductivity. We have quantitatively investigated the contributions to optical conductivity in the normal state following the RPA form of polarizability in the relaxation time approximation. The Fermi liquid model can consistently account for the anomalous behaviour of optical conductivity in the far-infrared and mid-infrared regions of the spectra. In this connection, we point out that it is necessary to take into account the fluctuations that arise due to the phonons, the magnons and other excitations. If we add the contribution from the inter-band transition (Sawada *et al* 1995) corresponding to charge transfer gap, which is not considered in the present model, the calculation can consistently reproduce the experimental results at room temperature.

4. Conclusions

In order to simulate the actual situation occurring in the optical response of the normal state of the alkali-metal-doped fullerenes superconductors, we developed a more sophisticated two-carrier model to discuss the optical conduction

with effective electric charge, Ze , effective mass, m^* , carrier density, n_c , and temperature, T , embedded in a uniform background of neutralizing charges. A dielectric response function for the two-component charged particle system is constructed, and a physical property such as the optical responses is discussed in this framework. Special attention is paid in this approach to the inclusion of the relaxation effect of the motion of carriers. Henceforth, we consider a two-component charged Fermi system with the effective masses, m_μ^* , the electric charges, Ze and the carrier density, n_μ ($\mu = D, h$). We refer to the component for reasons, which are earlier described as Drude and hopping carriers. The Drude component dominates the magnitude of optical conductivity in the low-frequency limit, and the hopping component dominates the mid-infrared regime.

The present study focuses on the frequency dependent behaviour of optical conductivity in fullerenes. In this work, we have devoted our efforts to understand, in particular, (a) the observed anomalous behaviour in mid-infrared region of K_3C_{60} at $T = 300$ K and (b) the role of hopping component in the optical conduction process as to reproduce the experimental behaviour. We find that low energy charge density fluctuations effectively contribute in the normal state optical conduction. Physically, the Drude carrier couples weakly with low energy excitations, yielding a sharp value at zero frequency. Using the memory function approach for frequency dependent relaxation rates, we obtained the expressions for characteristic scattering rates and the assumed values are large of the order of T_c in fullerene superconductors.

In principle, within the proposed two-component scheme, the Drude ($\mu = D$) component is regarded as a collection of carriers responsible for superconductivity. In continuation, the second ($\mu = h$) i.e. hopping component, is regarded as that producing a pairing force between the Drude carriers instead of the phonons in the conventional superconductors. With these reservations, we find that the two-channel of optical conduction i.e. the coherent Drude component with temperature dependent relaxation rates essentially describes the peak value centred at $\omega \approx 0$ cm^{-1} as well as the long tail in the infrared region. Secondly the hopping of electrons from one atom to other (incoherent motion of doped electrons) describes a peak value centred at mid-infrared region ($\omega \approx 1000$ cm^{-1}). As far as the origin of optical conductivity in the mid-infrared region, we believe that it is attributed to incoherent motion of doped electrons against the background of charge fluctuations with a gap spectrum. Precisely, the two species of charge carriers, which are earlier observed experimentally, can describe better the reported anomalies in the frequency dependent infrared spectrum.

The scheme opted in the present study is so natural that it extracts only the essential contributions to describe the physical properties of the fullerenes superconductors. We should emphasize that our conclusions have been established only within the framework of two-component model. In order to carry out a more complete comparison on the optical properties between theory and experiment, it is, therefore,

necessary to include the effects brought about by the phonons, the magnons, the high-frequency excitons and other excitations. Nevertheless, it has been found that this simple model may account for a considerable part of the experimental results for the optical spectra. Conclusively, we have made an attempt to estimate the optical response based on the dielectric function in the relaxation time approximation, regarding the Drude component and the hopping component as the superconducting component and the pairing mediation component, respectively. The proposed model may, in spite of its simple structure, provide a consistent account for the experimental fact, such as: the anomalous structure of optical conductivity in the mid-infrared region. Therefore, this two-component model could be a promising candidate for describing the physical properties of alkali-metal-doped fullerenes superconductors.

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