Specific heat and compressibility of quasi-particles in metals.

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Abstract

In this paper the specific heat and compressibility of quasi-particles were computed based on the modified Landau theory of Fermi Liquids using the electron density parameter. The Landau Fermi liquid theory's basic idea is to compare the excited states of the quantum liquid with those of the free Fermi gas. The excited states of the system consist of states where one or more fermions are excited to higher energy states. The method was used to compute the specific heat and compressibility of quasi-particles for some metals. The result obtained revealed that as temperature increases the specific heat of quasiparticles in metals increases. For compressibility, at high density region, there is good agreement between experimental compressibility of metals, computed and Landau values for compressibility of quasi-particles while at low density limit, the level of disagreement between them increases with increase in electron density parameter.The Landau Fermi liquid theory overestimated some properties of quasi-particles, which are supposed to be a contribution to bulk properties of metals. But the modified Landau Fermi liquid theory give a better estimation of the contribution of quasi-particles to the bulk properties of metals when compared with experimental values. The agreement between the computed results and experimental valuesrevealed that the introduction of the electron density parameter in the Landau theory of Fermi Liquidsis promising in predicting the contribution of quasi-particles to the bulk properties of metals.

Keywords: Quasi-particles, Specific heat, Compressibility, Fermi liquid, and Electron density parameter

1.0 Introduction

The free electron model formulated by Drude described the valence electrons of the atoms in a metal as a gas of non-interacting conduction electrons. They are non-interacting in the sense that no forces are assumed to act between the particles, or between the particles (electrons) and the positively charged ions of the lattice. A quasi-particle is a type of low-lying excited state of the system (a state possessing energy very close to the ground state energy) that is known as an elementary excitation. As a result of this closeness, most of the other low-lying excited states can be viewed as states in which multiple quasi-particles are present, because interactions between quasi-particles become negligible at sufficiently low temperatures. By investigating the properties of individual quasi-particles, it is possible to obtain a great deal of information about low-energy systems, including the flow properties and heat capacity. Landau's theory is to a large extent based on the idea of a continuous and one-to-one correspondence between the eigen states (ground state andexcited states) of the non-interacting and the interacting system[1]. Landau's Fermi liquid theory is concerned with the properties of a many-fermions system at low temperatures (much lower than the Fermi energy) in thenormal state, that is in the absence or at least at temperatures above any symmetry breaking phase transition (superconducting, magnetic, or otherwise). The ideal example for Landau's theory is liquid ^{3}He, above its superfluid phase transition, however, the conceptual basis of Landau's theory is equally applicable to a variety of other systems, in particular electrons in metals [2].In quantum mechanics, a group of particles known as fermions (for example, electrons, protons and neutrons) obey the Pauli Exclusion Principle. This states that no two fermions can occupy the same (one-particle) quantum state. The states are labelled by a set of quantum numbers. In a system containing many fermions (like electrons in a metal), each fermions will have a different set of quantum numbers. To determine the lowest energy a system of fermions can have, we first group the states into sets with equal energy, and order these sets by increasing energy. Starting with an empty system, we then add particles one at a time, consecutively filling up the unoccupied quantum states with the lowest energy. When all the particles have been put in, the Fermi energy is the energy of the highest occupied state.The Landau Fermi liquid theory overestimated the properties of quasi-particles, which are supposed to be a contribution to bulk properties of metals[3-6]. The modified Landau Fermi liquid theory is therefore used to study the contribution of quasi-particles to the bulk properties of some metals. Andrey *et al.*, [7] considered the non-analytic temperature dependences of the specific heat coefficient, $C(T)/T$, and spin susceptibility, $\chi_s(T)$ of 2-dimensional interacting fermions beyond the weak-coupling limit. The study was demonstrated within the Luttinger-Ward formalism that the leading temperature dependences of $C(T)/T$ and $\chi_s(T)$ are linear in *T*, and are described by the Fermi liquid theory. The temperature dependences were shown to be universally determined by the states near the Fermi level and, for a generic interaction, are expressed via the spin and charge components of the exact backscattering amplitude of quasi-particles. Katnelson and Trevilov, [8] obtained the general expressions for the contributions of the Van Hove singularity (VHS) in the electron density of states to the thermodynamic potential V in the framework of a microscopic Fermi-liquid theory. The renormalization of the singularities in V connected with the Lifshitz electronic topological transition (ETT) is found. Screening anomalies due to virtual transitions between VHS and the Fermi level are considered. It is shown that, in contrast with the one-particle picture of ETT, the singularity in V turns out to be two sided for interacting electrons.Li *et al.*, [9] studied the thermodynamic response, effective masses, and collective excitations for thin (submonolayer) ^{3}He films as a function of density and polarization using Fermiliquid theory. The Landau parameters $f^{\uparrow\uparrow}$, $f^{\uparrow\downarrow}$, $f^{\downarrow\downarrow}$ were obtained to quadratic order in the low-density s-wave and p-wave T-matrix interaction parameters. Values for the effective interaction components are determined by fitting zero-polarization experimental data for the cases of thin ^{3}He films on graphite and also thin ^{3}He films in surface states of thin superfluid ^{4}He films. By fitting the interaction parameters, the Landau parameters were calculated to all orders, and showed results for the behaviour of $F\tilde{}_\ell^{\uparrow\uparrow}for\ell \leqslant 30$. With knowledge of the Landau parameters the polarization dependence of the state-dependent effective masses, compressibility, spin susceptibility, and zero-sound spectra for the mobile submonolayer range of a real densities were calculated. The results predicted a dramatic decrease in the effective masses for ^{3}He on graphite as a function of polarization at higher coverages. At fixed density, the compressibility is shown to decrease monotonically with increasing polarization. At small polarization the inverse spin susceptibility is largest for small density whereas at large polarization it is largest for large density. The result also showed that zero sound will propagate at all densities and polarizations whereas spin zero sound does not propagate in these systems. The condition for thermodynamic stability in an arbitrarily polarized Fermiliquid film is derived and discussed. The Fermi surface distortion due to the presence of a zero-sound mode was explicitly stated. Sykes and Brooker [10] derived exact expressions for the transport properties of a degenerate Fermi liquid. The coefficients of shear viscosity, thermal conductivity, diffusion and second viscosity were evaluated giving solution for shear viscosity, and diffusion that agree within 25% with those originally quoted. However, the thermal conductivity is reduced by a factor of about 2. The coefficient of second viscosity was shown to vary with temperature like T^2. Caspar and Götz [11] introduced a continuous unitary transformation which realizes Landau's mapping of the elementary excitations (quasi-particles) of an interacting Fermi liquid system to those of the system without interaction. The conservation of the number of quasi-particles is important. The transformation is performed numerically for a one-dimensional system, that is, the worst case for a Fermi liquid approach. Yet evidence for Luttinger liquid behaviour is found. Such an approach may open a route to a unified description of Fermi and Luttinger liquids on all energy scales.

In this work, we modified the Fermi liquid theory using the electron density parameter and the modified Fermi liquid theory is used to compute the specific heat and compressibility of Fermi liquid in other to see the predictability of our modified Fermi liquid theory.

2.0 Theory and Calculations.

2.1 Specific heat of quasi-particles

The specific heat is the energy increase for a temperature increase of one Kelvin keeping the volume and the particle number constant. The general definition of specific heat is given as,

$$C = \frac{1}{N}\frac{\Delta Q}{\Delta T} \tag{2.1}$$

The Fermi liquid theory enables us to investigate the effect of particle interactions on macroscopic properties of the many-body system in terms of the phenomenological parameters of the quasi-particle model [12-15].

Considering the free energy for the thermodynamic properties, that is,

$$F \equiv E - \mu N = F_0 + \sum_{p\sigma}\left(\varepsilon_p - \mu\right)\delta n_{p\sigma} + \frac{1}{2}\sum_{pp'} f_{\sigma\sigma^1}\left(p, p'\right)\delta n_{p\sigma}\delta n_{p'\sigma'} \tag{2.2}$$

Where F is a function of the temperature, T, the number of particles, N, and the system volume, V.The dependence on temperature determines thermodynamic properties such as the specific heat at constant volume, given by,

$$C_v = \left(\frac{\partial F}{\partial T}\right)_{N,V} \tag{2.3}$$

The linear term in equation (2.2) is of order T^2, while the quadratic term is of order T^4. Hence, at low temperatures,

$$F(T) - F_0 = \left(\frac{\pi^2}{6}\right) g\left(\varepsilon_F\right)\left(K_B T\right)^2 + 0\left(T^4\right) \tag{2.4}$$

so that,

$$C_v = \gamma^* T + 0\left(T^3\right) \qquad (2.5)$$

where,

$$\gamma^* = \left(\frac{\pi^2}{3}\right) K_B^2 g\left(\varepsilon_F\right) \equiv \frac{m^* P_F K_B^2}{3\hbar^3} \qquad (2.6)$$

equation (2.6) is the coefficient of specific heat.

therefore, $C_v = \dfrac{m^* P_F K_B^2 T}{3\hbar^3}$ (2.7)

equation (2.7) is the Landau Fermi liquid theory's expression for specific heat of quasi-particles at constant volume.

Recall that the Fermi momentum at the Fermi surface is given by,

$$P_F = \hbar k_F = \hbar\left(\frac{9\pi}{4}\right)^{\frac{1}{3}} \frac{1}{r_s} \qquad (2.8)$$

inserting equation (2.8) into (2.7) the modified Landau Fermi liquid theory's expression for the specific heat of quasi-particles in terms of the electron density parameter r_s is obtained as,

$$C_v = \frac{m^* K_B^2 T}{3\hbar^2}\left(\frac{9\pi}{4}\right)^{1/3} \frac{1}{r_s} \qquad (2.9)$$

2.2 Compressibility of quasi-particles

Compressibility of solids is defined generally as the ratio between the volume changes in response to the change in pressure [12,14,15]. The compressibility for zero temperature is given by,

$$\sigma = -\frac{1}{V}\frac{\Delta V}{\Delta P} = \frac{1}{n^2}\frac{\partial n}{\partial \mu} \qquad (2.10)$$

Recall that the equilibrium distribution is given as,

$$n_{p\sigma}^0 = \frac{1}{e^{\left(\varepsilon_{p\sigma} - \mu\right)/K_B T} + 1} \qquad (2.11)$$

Then from equation (2.11) we find,

$$\delta n_{p\sigma} = \frac{\partial n_{p\sigma}^0}{\partial \varepsilon_{p\sigma}}\left(\delta\varepsilon_{p\sigma} - \delta\mu\right) \qquad (2.12)$$

Since, $\frac{\partial n_{p\sigma}}{\partial \varepsilon_{p\sigma}}$ vanishes except at the Fermi surface and μ produces a variation of $n_{p\sigma}$ that is isotropic (that is, exhibiting identical properties in all directions) and independent of spin, such that,

$$\delta \mathrm{E} = \sum_{\rho\sigma} \varepsilon_{\rho\sigma} \delta n_{\rho\sigma} \qquad and$$

$$f_l^{S(a)} = \frac{2l+1}{2}\int_{-1}^{1} d(\cos\xi) P_1(\cos\xi) \frac{f_{pp'}^{\uparrow\uparrow} \pm f_{pp'}^{\uparrow\downarrow}}{2} \qquad (2.13)$$

Then,

$$\delta\varepsilon_{p\sigma} = f_0^s \sum_{p'\sigma'} \delta n_{p'\sigma'} = f_0^s \delta n \qquad (2.14)$$

Summing equation (2.12) over pσ,

$$\delta n = N(0)\left(\delta\mu - f_0^s \delta n\right) \qquad (2.15)$$

Or equivalently,

$$\frac{\partial n}{\partial \mu} = \frac{N(0)}{1+F_0^s} \qquad (2.16)$$

Hence,

$$\sigma = \frac{1}{n^2}\frac{N(0)}{1+F_0^s} \qquad (2.17)$$

where equation (2.17) is the Landau Fermi liquid theory's expression for compressibility of quasi-particles.

Recall thatthe quasi-particle concentration at the Fermi surface is given by,

$$n = \frac{N}{V} = \left(\frac{3}{4\pi}\right)\frac{1}{r_s^3} \qquad (2.18)$$

and the quasi-particle density is given by [15],

$$N(0) = \frac{m^* P_F}{\pi^2 \hbar^3} \qquad (2.19)$$

then by inserting equation (2.8) into equation (2.19) we obtain,

$$N(0)=\frac{m^{*}}{\pi^{2}\hbar^{2}}\left(\frac{9\pi}{4}\right)^{1/3}\frac{1}{r_{s}} \tag{2.20}$$

Then, inserting equation (2.18) and equation (2.20) into (2.17) the modified Landau Fermi liquid theory's expression for the compressibility of quasi-particles in terms of the electron density parameter (r_s) is obtained as,

$$\sigma=3.4117\frac{m^{*}r_{s}^{5}}{1+F_{0}^{s}} \tag{2.21}$$

where F_o^s is the Landau parameter obtained from the dispersion relation,

$$\frac{\lambda}{2}\ln\frac{\lambda+1}{\lambda-1}-1=\frac{1}{F_{o}^{s}} \tag{2.22}$$

where $\lambda=\frac{\alpha r_{s}}{\pi}$ and α = 0.5211. (2.23)

3.0 Results and Discussion

3.1 Specific heat of quasi-particles

Figure 1 shows the variation of computed specific heat of quasi-particles with temperature for some metals. The result showed that as temperature increases the specific heat of quasi-particles increases for all the metals calculated. It is observed in Table 1 that the specific heat of quasi-particles for monovalent metals is larger in transitions metals (copper (Cu), silver (Ag) and gold (Au)) than most of the alkali metals. This is due to the d-block electrons that have filled electron shell which lies high up in the conduction band in noble metals. It is also revealed that the specific heat of quasi-particles for divalent metals is larger in transition metals than the alkali earth metals and this is because the transition metals have d-block and f-block electron shells that can enhance the value of the specific heat of quasi-particles. The result also revealed thatspecific heat of quasi-particles depends on the effective mass of the particles as the higher the effective mass the higher the specific heat capacity of quasi-particles in the metals. For example Niobium (Nb), Platinum (Pt), Manganese (Mn) and Nickel (Ni) have effective masses, of 12, 13, 27, and 28 respectively and they have higher values of specific heat. Generally, it is observed that for incomplete filled electron shell the specific heat of quasi-particles is large due to the motion of the free quasi-particles, which becomes more energetic at high temperatures [12]. This is more pronounced in transition metals because the quasi-particles in the incompletely filled d-blocks are close to the conduction band hence they could be excited at any temperature. The result further revealed that the computed value for the specific heat of quasi-particles of metals with large values of Fermi momentum is high. This may be due to the fact that as Fermi momentum of metals increases interaction among quasi-particles also increases and hence more quasi-particles are excited to the conduction band with increase in temperature.

It is observed from Table 1 that the experimental specific heat of metals is higher than the computed values of specific heat of quasi-particles at different temperatures. This may be due to the fact that the specific heat of metals has contributions from quasi-particles, electrons and other interactions in the metals. But for heavy metals, for example, Antimony (Sb) the computedspecific heat of quasi-particles is close to the values of experimental specific heat of metals. This may be because of the high number of quasi-particles that it contains. Furthermore, the computed value of specific heat of quasi-particles at 1200 K is closer to experimental value of specific heat of quasi-particles of some of the metals used in the work and for others it is higher compared to experimental values of specific heat of metals at lower temperatures. This may be due to the fact that as temperature increases the number of quasi-particles in the metals increases and their contribution to bulk specific heat of the metals increases.

Figure 2shows the variation of Landau specific heat of quasi-particles with temperature for some metals. Also as observed in the computedspecific heat of quasi-particles, heavy metals and transition metals have higher values of specific heat of quasi-particles compared to the simple and alkaline metals that their specific heat of quasi-particles is lower. It is observed also, that the values of Landau specific heat of quasi-particles are higher than bulk specific heat of metals. This may be due to the fact that the Landau parameter must have been over estimated in its application.

3.2 Compressibility of quasi-particles

Figure 3 shows the variation between experimental bulk compressibility of metals, computed and Landau compressibility of quasi-particles with electron density parameters. The figure 3 revealed that at high density limit there is agreement between experimentalbulk compressibility of metals, computed and Landau values for compressibility of quasi-particles. In this region$1 \leq r_s \leq 3\, a.u$, we have the transition, inner transition and noble metals. These metals have high number of quasi-particles and they are good representation of a system of quasi-particles. For$r_s > 3\, a.u$, the disagreement between the experimentalcompressibility of metals, computed and Landau values for compressibility of quasi-particles increases with increase in electron density parameter. These may be due to the fact that, the metals in these low density limit are simple and alkaline metals that have low concentration of quasi-particles. Hence, more quasi-particles could be excited from just below the Fermi energy to just above the Fermi energy. That is, as compressibility of the system is high the system requires only an infinitesimal energy for more quasi-particles to be added to the system [12, 14, 15]. From the figure it is observed that the computed and Landau values for compressibility of quasi-particles in metals are close and the level of disagreement between them increases with increase in electron density parameters. It is also, observed that the computed values of compressibility of quasi-particles is closer to experimental values of compressibility of metals than the Landau compressibility of quasi-particles in metals. This may be due to the fact that the introduction of the electron density parameter which modified the expression of Landau Fermi liquid theory might have given a better estimation of the computed values of compressibility of quasi-particles than Landau Fermi liquid theory.

It is observed from table 3 that the compressibility of quasi-particles of transition and heavy metals have smaller values than the compressibility of quasi-particles of simple and alkaline metals. This is because the electron density parameter of simple and alkaline metals is larger than the electron density parameter of the transition metals. This could also be attributed to the fact that transition metals have high concentration of quasi-particles which makes the system denser and will make the system not to accommodate more quasi-particles. Therefore, for the transition metals the system is more compressed, that is, more quasi-particles are found above the Fermi surface and adding more quasi-particles make the Fermi Sea denser or compressed.

4.0 Conclusion.

The expressions for the modified Landau Fermi Liquid Theory obtained in terms of the electron density parameter were used to compute the properties of quasi-particles and the computed values are compared with the Landau values and experimental values available and revealed that it can account and predict very well the contribution of quasi-particles to the bulk properties of metals. The specific heat of quasi-particles increases as temperature increases for all the metals investigated. The landau specific heat of quasi-particles is higher than experimental specific heat of metals but the computed values is smaller than the experimental specific heat of metals. For compressibility, at high density limit there is agreement between experimentalcompressibility of metals, computed and Landau values for compressibility of quasi-particles while at low density limitthe level of disagreement between them increases with increase in electron density parameters. These may be due to the fact that, the metals in these low density limit are simple and alkaline metals that have low concentration of quasi-particles. Hence, more quasi-particles could be excited from just below the Fermi energy to just above the Fermi energy.

Table 1: Computed Specific Heat of Quasi-particles in metals and its variationwith electron density parameter (r_s). The electron density parameter and Experimental Specific heat were taken from[12,15].

Metals	**Z**	**r_s**(a.u)	**Calculated values of the Specific Heat of quasi-particles at different Temperatures (J/kg K)**						**Exp. Specific heat (kJ/kg K)**
			200	400	600	800	1000	1200	300
Li	1	3.28	89.71	179.43	269.14	358.86	448.57	538.28	3.57
Na	1	3.99	41.69	83.37	125.05	166.74	208.42	250.11	1.21
K	1	4.96	30.95	61.91	92.86	123.81	154.77	185.72	0.75
Rb	1	5.23	31.802	63.60	95.41	127.21	159.01	190.81	0.36
Cs	1	5.63	34.09	68.17	102.26	136.35	170.44	204.52	0.24
Cu	1	2.67	62.29	124.59	186.88	249.17	311.46	373.76	0.39
Ag	1	3.02	46.60	93.20	139.80	186.40	233.00	279.60	0.23
Au	1	3.01	46.76	93.51	140.27	187.02	233.78	280.53	0.13
Be	2	1.87	28.74	57.47	86.21	114.94	143.68	172.41	1.83
Mg	2	2.66	62.53	125.05	187.58	250.11	312.64	375.16	1.05
Ca	2	3.27	70.43	140.85	211.28	281.70	352.13	422.55	0.63
Sr	2	3.57	71.68	143.35	215.03	286.70	358.38	430.05	0.30
Ba	2	3.71	48.28	96.56	144.84	193.12	241.40	289.68	0.20
Nb	2	3.07	500.09	1000.20	1500.30	2000.40	2500.50	3000.60	0.27
Fe	2	2.12	482.79	965.59	1448.40	1931.20	2414.00	2896.80	0.45
Mn	2	2.14	1614.20	3228.40	4842.60	6456.80	8071.00	9685.20	0.48
Zn	2	2.30	47.28	94.56	141.85	189.13	236.41	283.69	0.39
Cd	2	2.59	36.55	73.11	109.66	146.22	182.77	219.33	0.23
Hg	2	2.65	101.39	202.77	304.16	405.55	506.93	608.32	0.14
V	2	1.64	110.78	221.56	332.33	443.11	553.89	664.66	0.39
Ni	2	2.07	1730.60	3461.20	5191.80	6922.40	8653.00	10384.00	0.44
Zr	2	2.11	124.30	248.60	372.91	497.21	621.51	745.81	0.27
Bi	3	2.25	2.67	5.35	8.02	10.69	13.36	16.04	0.13
Ti	3	1.92	73.30	146.60	219.90	293.20	366.50	439.79	0.54
Al	3	2.07	86.53	173.06	259.59	346.12	432.65	519.18	0.90
Ga	3	2.19	36.22	72.44	108.66	144.88	181.10	217.32	0.37
In	3	2.41	79.63	159.26	238.89	318.52	398.15	477.78	0.24
Tl	3	2.48	56.75	113.50	170.24	226.99	283.74	340.49	0.13
Sn	4	2.22	74.92	149.84	224.76	299.68	374.60	449.52	0.21
Pb	4	2.30	105.69	211.38	317.07	422.76	528.45	634.14	0.13
Sb	5	2.14	22.72	45.44	68.16	90.87	113.59	136.31	0.21

Table2: Landau Specific Heat of Quasi-particles at different temperatures. The effective mass were taken from[12,15].

Metals	**Z**	**m^*/m**	**Landau Specific Heat of Quasi-particles at different Temperatures (kJ/kg K).**						
			200	400	600	800	1000	1200	1400
Li	1	2.30	26.81	53.63	80.44	107.25	134.06	160.88	187.69
Na	1	1.30	12.45	24.90	37.35	49.80	62.25	74.69	87.14
K	1	1.20	9.37	18.74	28.10	37.47	46.84	56.21	65.58
Rb	1	1.30	9.47	18.94	28.42	37.89	47.36	56.83	66.31
Cs	1	1.50	10.15	20.30	30.45	40.60	50.74	60.89	71.04
Cu	1	1.30	18.40	36.81	55.21	73.61	92.01	110.42	128.82
Ag	1	1.10	13.74	27.479.6	42.19	54.96	68.70	82.44	96.18
Au	1	1.10	13.85	27.71	41.56	55.42	69.27	83.13	96.98
Be	2	0.42	8.48	16.96	25.44	33.93	42.41	50.89	59.37
Mgq	2	1.30	18.54	37.08	55.62	74.15	92.69	111.23	129.7
Ca	2	1.80	20.80	41.59	62.39	83.19	103.99	124.78	145.58
Sr	2	2.00	21.23	42.47	63.70	84.94	106.17	127.41	148.64
Ba	2	1.40	14.28	28.56	42.84	57.12	71.41	85.69	99.97
Nb	2	12.0	147.39	294.78	442.17	589.56	736.95	884.34	1031.73
Fe	2	8.00	142.39	284.78	427.17	569.57	711.96	854.35	996.74
Mn	2	27.00	477.77	955.55	1433.32	1911.09	2388.87	2866.64	3344.41
Zn	2	0.85	13.98	27.96	41.94	55.92	69.90	83.88	97.86
Cd	2	0.74	10.78	21.57	32.35	43.13	53.92	64.70	75.48
Hg	2	2.10	29.95	59.89	89.84	119.79	149.74	179.68	209.63
V	2	1.42	23.50	47.00	70.50	94.01	117.51	141.01	164.51
Ni	2	28.00	501.30	1002.60	1503.90	2005.20	2506.50	3007.80	3509.10
Zr	2	2.05	28.38	56.76	85.14	113.52	141.90	170.28	198.66
Pt	2	13.00	208.39	416.79	625.18	833.57	1041.96	1250.36	1458.75
Bi	3	0.047	0.65	1.30	1.95	2.60	3.25	3.90	4.55
Ti	3	1.10	19.12	38.24	57.37	76.49	95.61	114.73	133.85
Al	3	1.40	25.50	51.00	76.50	102.01	127.51	153.01	178.51
Ga	3	0.62	10.71	21.43	32.14	42.85	53.56	64.28	74.99
In	3	1.50	23.58	47.15	70.73	94.30	117.88	141.46	165.03
Tl	3	1.10	16.72	33.43	50.15	66.87	83.58	100.30	117.02
Sn	4	1.30	22.19	44.38	66.58	88.77	110.96	133.15	155.34
Pb	4	1.90	31.25	62.50	93.75	125.00	156.24	187.49	218.74
Sb	5	0.38	6.72	13.45	20.17	26.90	33.62	40.35	47.07

Table 3: Computed Compressibility of Quasi-particles in terms of the electron density parameter (r_s). The Electron density parameter, Effective mass and Experimental Compressibility of metals were taken from[12,15] while the Landau parameter is computed using equation (2.22) and equation (2.23).

Metals	**Z**	**Electron density parameter (r_s) (a.u)**	**Effective mass (m^*/m)**	**Calculated Compressibility ($10^{-27}m^2/N$)**	**Experimental Compressibility ($10^{-11}m^2/N$)**	**Landau parameter $\left(F_0^1\right)$**
Li	1	3.28	2.30	6.28	8.62	-0.5679
Na	1	3.99	1.30	6.41	14.70	-0.3629
K	1	4.96	1.20	11.48	31.00	-0.0250
Rb	1	5.23	1.30	14.66	32.00	0.0783
Cs	1	5.63	1.50	21.41	50.00	0.2316
Cu	1	2.67	1.30	1.91	0.73	-0.7131
Ag	1	3.02	1.10	2.34	0.99	-0.6333
Au	1	3.01	1.10	2.32	0.58	-0.6358
Be	2	1.87	0.42	0.21	1.00	-0.8590
Mg	2	2.66	1.30	1.89	2.82	-0.7153
Ca	2	3.27	1.80	4.87	6.58	-0.5705
Sr	2	3.57	2.00	7.05	8.62	-0.4887
Ba	2	3.71	1.40	5.54	9.97	-0.4482
Nb	2	3.07	12.00	26.85	0.59	-0.6212
Fe	2	2.12	8.00	5.88	0.59	-0.8189
Mn	2	2.14	27.00	20.41	1.68	-0.8155
Zn	2	2.30	0.85	0.80	1.67	-0.7869
Cd	2	2.59	0.74	0.99	2.14	-0.7300
Hg	2	2.65	2.10	3.02	2.60	-0.7174
V	2	1.64	1.42	0.48	0.62	-0.8916
Ni	2	2.07	28.00	19.15	0.54	-0.8273
Zr	2	2.11	2.05	1.49	1.20	-0.8206
Bi	3	2.25	0.047	0.04	3.17	-0.7961
Ti	3	1.92	1.10	0.60	0.95	-0.8514
Al	3	2.07	1.40	0.96	1.39	-0.8273
Ga	3	2.19	0.62	0.50	1.76	-0.8068
In	3	2.41	1.50	1.62	2.43	-0.7661
Tl	3	2.48	1.10	1.30	2.79	-0.7524
Sn	4	2.22	1.30	1.10	0.90	-0.8015
Pb	4	2.30	1.90	1.78	2.33	-0.7869
Sb	5	2.14	0.38	0.29	2.61	-0.8155

Table 4: Landau Compressibility of Quasi-particles. Electron density parameter $r_s$andElectron concentration were taken from[12,15].

Metals	Z	Electron density parameter r_s (a.u)	Electron concentration ($10^{28}m^{-3}$)	Landau Compressibility ($10^{-47}m^2/N$)
Li	1	3.28	4.70	223.92
Na	1	3.99	2.65	221.81
K	1	4.96	1.402	389.66
Rb	1	5.23	1.15	529.48
Cs	1	5.63	0.91	793.22
Cu	1	2.67	8.45	71.61
Ag	1	3.02	5.85	87.28
Au	1	3.01	5.90	87.12
Be	2	1.87	24.20	8.19
Mg	2	2.66	8.60	70.18
Ca	2	3.27	4.60	182.42
Sr	2	3.57	3.56	261.22
Ba	2	3.71	3.20	201.47
Nb	2	3.07	27.80	40.13
Fe	2	2.12	17.00	216.87
Mn	2	2.14	16.50	758.21
Zn	2	2.30	13.10	30.47
Cd	2	2.59	9.28	36.97
Hg	2	2.65	8.65	112.90
V	2	1.64	14.44	82.88
Ni	2	2.07	18.28	692.45
Zr	2	2.11	8.58	171.30
Bi	3	2.25	8.46	3.55
Ti	3	1.92	16.98	3.56
Al	3	2.07	18.06	36.09
Ga	3	2.19	15.30	18.88
In	3	2.41	11.49	60.86
Tl	3	2.48	10.45	49.28
Sn	4	2.22	14.48	42.50
Pb	4	2.30	13.20	67.09
Sb	5	2.14	16.55	10.61

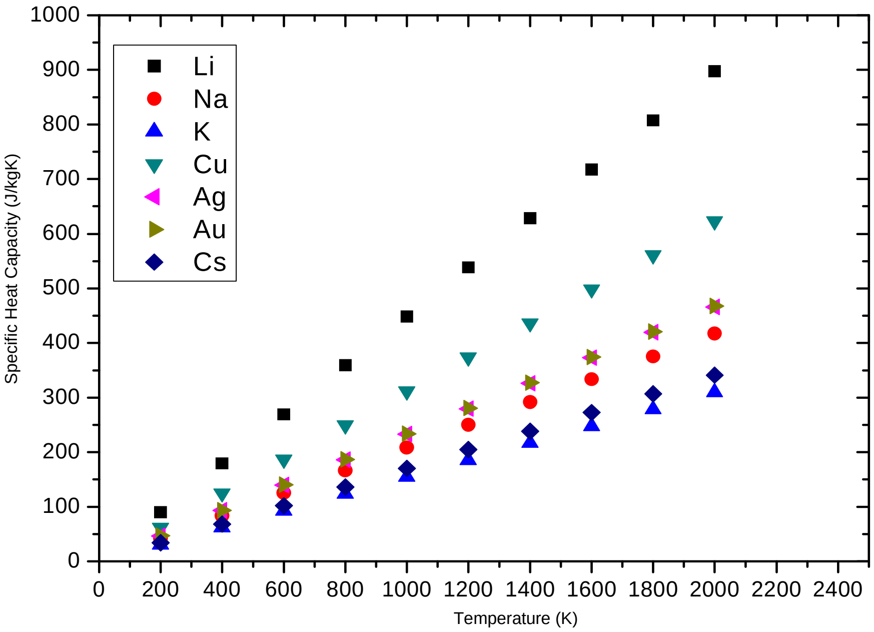

Fig. 1: Variation of Computed Specific heat of quasi-particles in metals in terms of electron density parameter (r_s) with temperature.

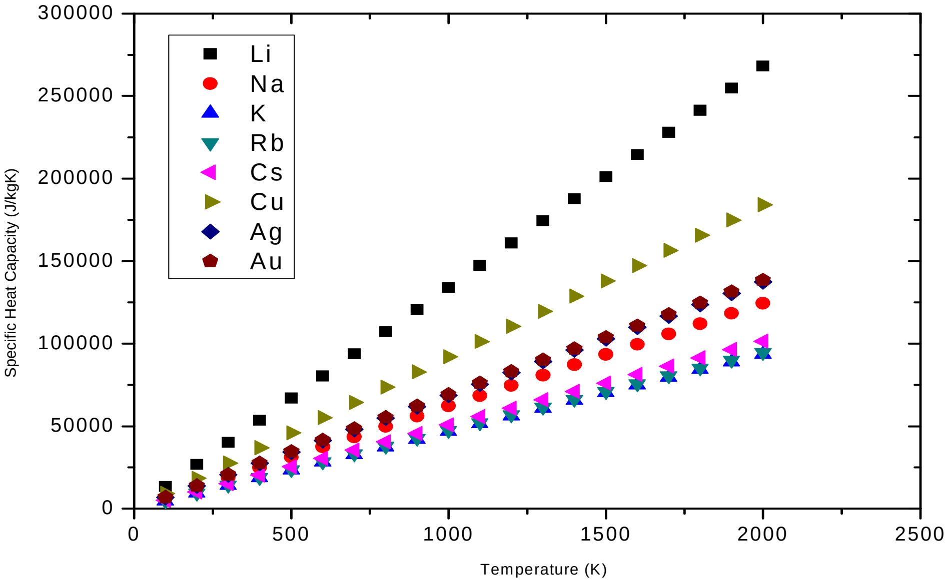

Fig. 2: Variation of Landau Specific heat of quasi-particles in metals with temperature.

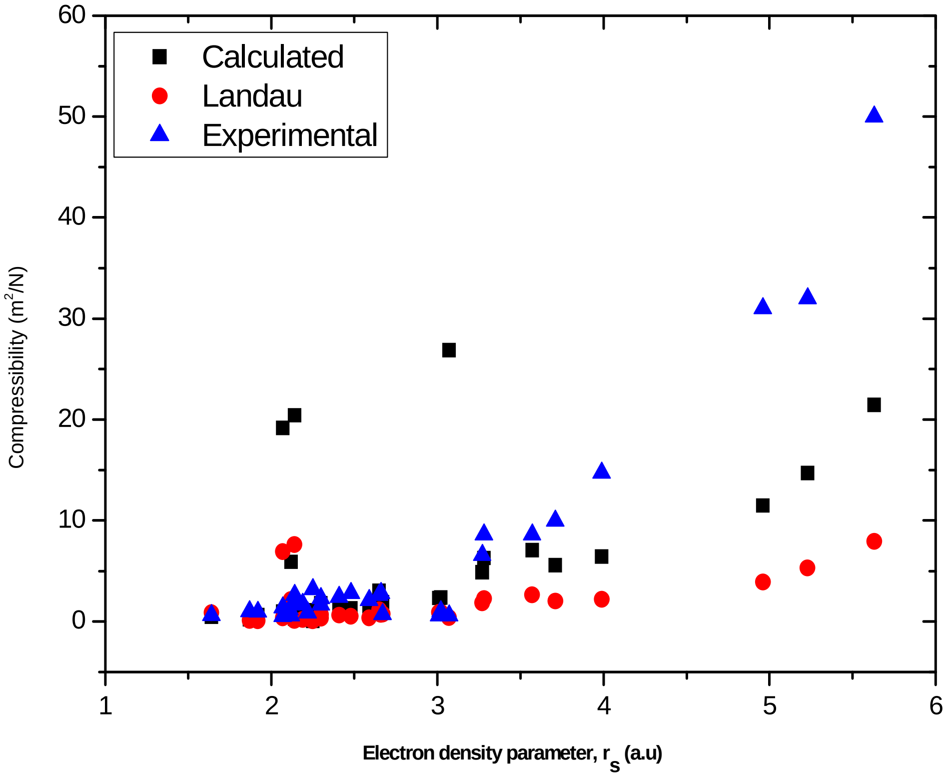

Fig. 3: Variation of Experimental Compressibility of metals, Computed, and Landau quasi-particles in metals with electron density parameter.

References

[1] Nodar, L. T. and Levan, N. T. (2010). Elementary Excitations in Quantum Fermi Liquid. Department of Plasma Physics, E. Andronikashvili Institute of Physics, Tbilisi, Georgia. arXiv:1006.0369v1 [quant-ph]

[2] Anderson, P. W. (1997). Concepts in Solids: Lectures on the Theory of Solids.World Scientific Publishing Co. Pte. Ltd., Singapore.

[3] Subir, S. (2012). Quantum Phase Transitions, (2nded.). Cambridge University Press, Cambridge.

[4] Fröhlich, B., Feld, M., Vogt, E., Koschorreck, M., Köhl, M., Berthod, C., and Giamarchi, T. (2012). A two-dimensional Fermi liquid with attractive interactions. arXiv:1206.5380v1 [cond-mat.quant-gas]

[5] Shaginyan, V. R., Amusiab, M. Ya. and Popvc, K. G. (2009). Strongly correlated Fermi-systems: Non-Fermi liquid behavior, quasi-particle effective mass and their interplay. Physics Letters A, 373,pp 2281–2286

[6] Thomas, P. (2011). Landau's Fermi Liquid Concept to the Extreme: The Physics of Heavy Fermions. XVI Training Course in the Physics of Strongly Correlated Systems, Salerno.

[7] Andrey, V.C., Dmitrii, L. M., Suhas, G. & Leonid, I. G. (2005).Thermodynamics of a Fermi Liquid beyond the low-energy limit.Physical Review Letters, 95,026402.

[8] Katsnelson, M. I. and Trefilov, A. V. (2000). Fermi Liquid Theory of Electronic Topological Transitions and Screening Anomalies in Metals, Physical Review B, 61, (3), pp 1643-1645.

[9] Li, D. Z., Anderson, R. H. and Miller, M. D. (1999). Fermi- liquid theory for thin arbitrarily polarized ^{3}He films. Physical Review B, 85, (22).

[10] Sykes, J. and Brooker, G. A., (1970). The Transport Coefficients of a Fermi Liquid. Annals of Physics. 56, (3), 1-39.

[11] Caspar, P. H. and Götz, S. U. (2002). Landau’s quasi-particle mapping:Fermi liquid approach and Luttinger liquid behavior. arXiv:cond-mat/0111078v2 [cond-mat.str-el].

[12] Kittel, C., (1996), Introduction to Solid State Physics (7th Edition). John and Sons, Inc., Singapore, New York.

[13] Pépin, C. and Coleman, P. (2002). Breakdown of the Fermi liquid theory in heavy fermion compounds. arXiv:cond-mat/0211284v1 [cond-mat.str-el].

[14] Kachhava, C.M. (1992). Solid State Physics. Tata McGraw Hill Publishing Company Ltd., India.

[15] Animalu, A.O.E. (1977). Intermediate Quantum Theory of Crystalline Solids. Prentice-Hall, Inc., Englewood Cliffs, New Jersey