Properties of Hadrons in medium in the context of Fermi liquid model and Diquarks

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Abstract

Fermi liquid model for hadrons has been suggested. Hadrons are described as Fermi excitation behaving like quasi particles. Effective masses are estimated. Specific heats, density of states, Landau parameters are investigated for light baryons and singly and triply heavy baryons. The potential well depths are extracted. Some interesting observations are made.

Fermi Liquid Model

- **Fermi liquid theory** (also known as **Landau–Fermi liquid theory**) largely applied to study many body problem. He^3 at low temp behaves like ideal Fermi gas with specific heat 2.7 time s more than ideal Fermi gas.[1].

- Generally it is a theoretical model of interacting fermions that describes the normal state of most metals at sufficiently low temperatures.

- Suggests as interaction between fermions is turned on, the spin, charge and momentum of the fermions corresponding to the occupied states remain unchanged, while their dynamical properties, such as their mass, magnetic moment etc. are renormalized to new values.

- [1]. L.D. Landau; Expt. Theoret. Phys. (U.S.S.R)3(6) (1956) 1058

Fermi Liquid Model

- In the context of Fermi liquids, these excitations are called "quasi-particles“ which behave differently incorporating the many body interaction inside the system with an effective mass m*.
- Widely used to study many body problem. Properties of electrons in metal and nuclear matter.
- These quasi particles are not point particles. With weak potential , the shape of the energy spectrum remains same only with a shift of energy.
- Modified density of states are:

$$g(\varepsilon) = m^{*} p_F / \pi^2 h^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

- Energy modified as:

$$\varepsilon (p \approx p_F) = p^2/ 2m + V(p) = p^2 /2m^{*} + \text{const}\ldots\ldots(2)$$

- V(p) , momentum dependent interaction potential,
$p^2 /2m^{*}$, modified K.E.

Fermi Liquid Model

At low temperature Effective mass m* of a quasi particle expressed as [2]:

$$m^* = \frac{p_F}{\left(\frac{\delta \varepsilon}{\delta p}\right) p = p_F} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Specific heats differs from ideal value at low temperature:

$$\frac{C_{V_{real}}}{C_{V_{ideal}}} = \frac{m^*}{m} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

- Fermi Liquid understood as ideal Fermi gas with dressed mass m*.

[2] R.K Pathria Statistical Mechanics ; Butterworth-Hienemann,(2001)

Fermi Liquid model of hadrons

- Similar type of model for hadrons as it propagates through medium .

- Hadrons behave like Fermi excitation while in medium.

  The potential V(p) expressed as [3]:

$$V(p) = V_0 e^{-\gamma(p^2/m)} \quad \ldots\ldots\ldots\ldots\ldots(5)$$

-

- Where $\gamma \cong 1/V_0$

[3] R. Chasman; Phys. Rev. C3 (1971) 1803.

With (2),(3) and (5) we come across:

$$1/m^* = 1/m - (2/m)\, e^{-\gamma(p^2/m)}|_{p=p_F} \quad \ldots\ldots\ldots..(6)$$

Effective mass can obtained with knowledge of pF.

The Fermi momentum s for particles extracted from Fermi distribution formula [4].

P_F for hadrons estimated with different values of radius parameters from literature and with a = 0.02 GeV^2 [5].

[4]. A. Bhattacharya et al; IL. Nouvo .Cim.125(2010) 1493

[5]. W. Lucha; Physics Reports 200(4) (1991), 127.

- The Group Velocity can be expressed as:
- $V_F = P_F / m^*$……………………….(7)
- The Landau parameter F_1^s related to effective mass as:

$m^*/m = 1 + F_1^s/3$ …………………….(8)

- The temperature dependence of m^* are studied.
- Equation (6) approximated as:

$m(1 + m/m^*) = 2\gamma p_F^2$ …………………..(9).

- Graphs are plotted for light and heavy baryons and values of γ are extracted from the slope.

We have studied the properties of baryons in medium in an analogy with the Fermi liquid model where the effect of the medium is incorporated via effective mass approximation.

Table 1: $\frac{m^*}{m}$ **for Light sector baryons.**

Hadron	Radius In GeV^{-1}	Fermi Momentum (p_f) in GeV	m^* in GeV	$\frac{m^*}{m}$
$\Lambda^0(uds)$	1.9895	0.2889	2.037	1.616
$\Sigma^-(dds)$	3.65	0.3915	1.393	1.1055
$\Xi^-(dss)$	3.3	0.3979	1.6512	1.1466
$\Omega^-(sss)$	2.9	0.3957	1.972	1.217

Table 2: $\frac{m^*}{m}$ for Single Heavy Baryons.

Hadron	Radius In GeV^{-1}	Fermi Momentum (p_f) in GeV	m^* in GeV	$\frac{m^*}{m}$
$\Lambda_C{}^+$(udc)	5.727	0.6582	2.3094	1.017
$\Lambda_b{}^0$(udb)	1.481	0.4928	11.775	2.3933
$\Sigma_C{}^+$(udc)	3.386	0.5061	2.5766	1.135
$\Sigma_b{}^0$(udb)	1.253	0.4533	16.6389	3.382
$\Xi_C{}^0$(dsc)	2.404	0.4430	3.3557	1.3696
$\Xi_b{}^0$(usb)	1.12	0.4363	23.88	4.682
$\Omega_C{}^0$(ssc)	2.5	0.4681	3.5026	1.332
$\Omega_b{}^-$(ssb)	2.0124	0.5951	8.431	1.5967

Table 3: $\frac{m^*}{m}$ for Triple Heavy Baryons.

Hadron	Radius In GeV^{-1}	Fermi Momentum (p_f) in GeV	m^* in GeV	$\frac{m^*}{m}$
$\Omega_{ccc}(ccc)$	1.5	0.4822	10.89	2.3419
$\Omega_{bbb}(bbb)$	1.25	0.7245	42.818	3.398
$\Omega_{ccb}(ccb)$	5	1.1029	7.5336	1.032
$\Omega_{bbc}(bbc)$	5	1.2877	10.2684	1.032

Table 4: $\frac{m^*}{m}$, ${F_s}^1$, $g(\epsilon_F)$ and v_F for Light and Single Heavy Baryons.

Hadron	$\frac{m^*}{m}$	${F_s}^1$	$g(\epsilon_F)$ in GeV^2	v_F
$\Lambda^0(uds)$	1.616	1.848	0.059	0.142
$\Sigma^-(dds)$	1.105	0.316	0.055	0.281
$\Xi^-(dss)$	1.147	0.439	0.067	0.241
$\Omega^-(sss)$	1.217	0.651	0.079	0.201
${\Lambda_C}^+(udc)$	1.017	0.051	0.154	0.285
${\Lambda_b}^0(udb)$	2.393	4.180	5.803	0.042
${\Sigma_C}^+(udc)$	1.135	0.435	0.132	0.196
${\Sigma_b}^0(udb)$	3.382	7.146	0.764	0.027
${\Xi_C}^0(dsc)$	1.369	1.109	0.151	0.132
${\Xi_b}^0(usb)$	4.682	11.046	1.056	0.018
${\Omega_C}^0(ssc)$	1.332	0.992	0.166	0.134
${\Omega_b}^-(ssb)$	1.597	1.790	0.508	0.071

Figure 1 and 2: Shows the variation of effective mass/particle mass ($\frac{m^*}{m}$) with temperature. The temperature dependent fermi momentum p_f induces change in m^*. The critical temperature is considered as T_C= 170 MeV. Fig. 1 shows the variation of $\frac{m^*}{m}$ vs. $\frac{T}{T_c}$ for light baryons and Fig. 2 shows variation of $\frac{m^*}{m}$ vs. $\frac{T}{T_c}$ for single heavy baryons.

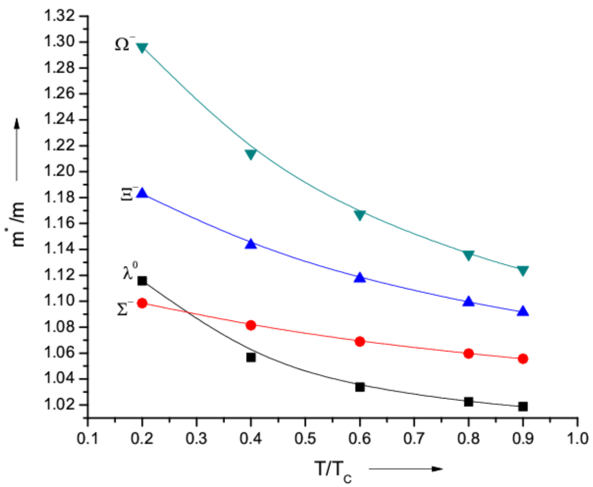

Figure: 1

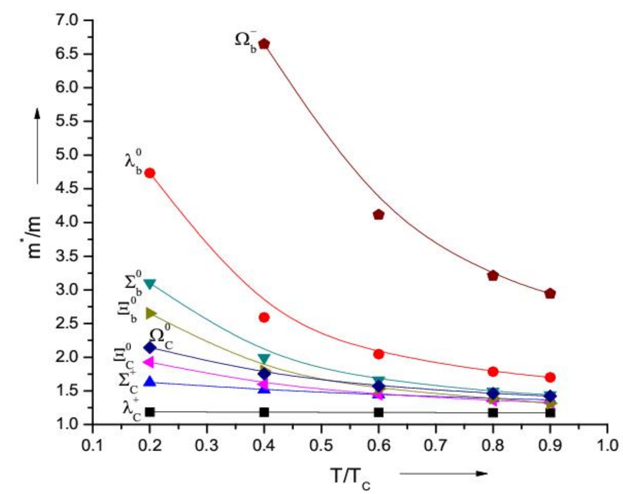

Figure: 2

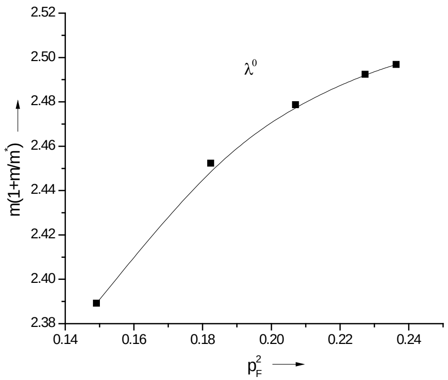

Figure 3: For $\Lambda^0(uds)$

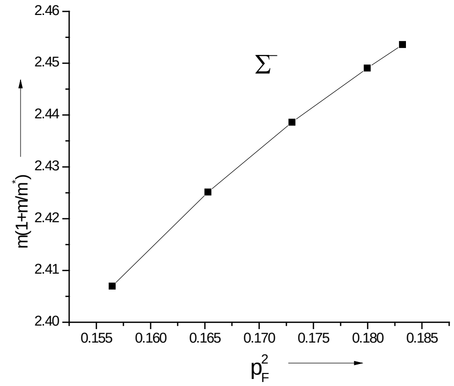

Figure 4: For $\Sigma^-(dds)$

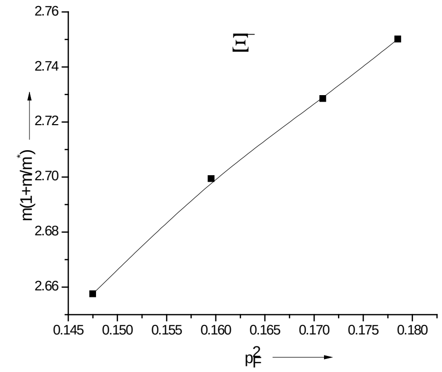

Figure 5: For $\Xi^-(dss)$

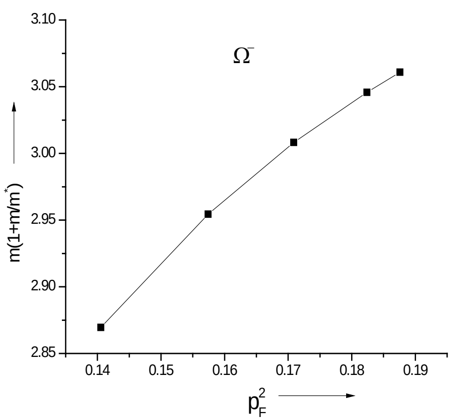

Figure 6: For $\Omega^-(sss)$

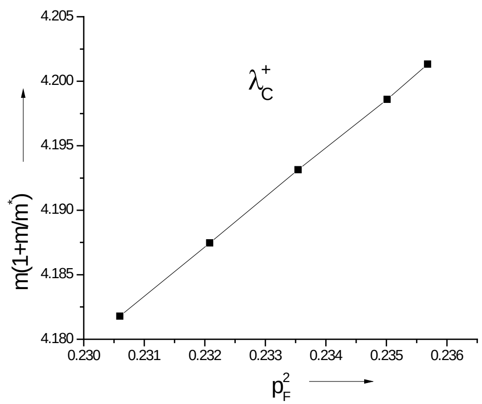

Figure 7: For$\Lambda_C{}^+$(udc)

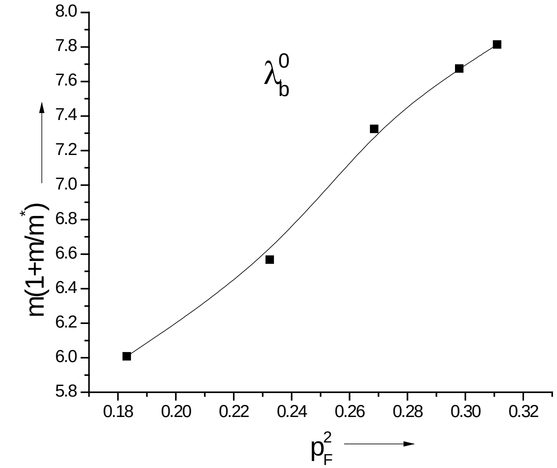

Figure 8: For $\Lambda_b{}^0$(udb)

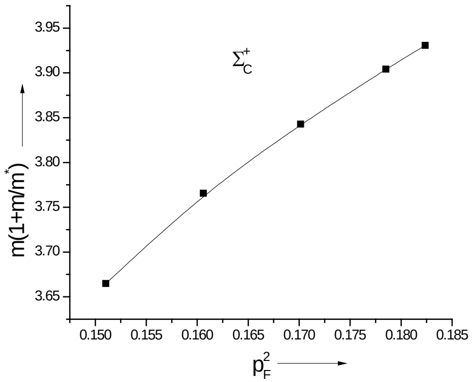

Figure 9: For $\Sigma_C{}^{+}$(udc)

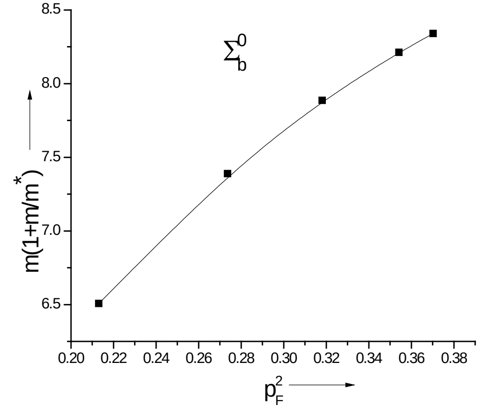

Figure 10: For $\Sigma_b{}^{0}$(udb)

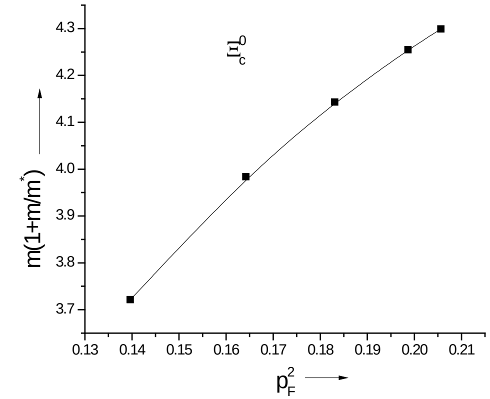

Figure 11: For$\Xi_C{}^{0}$(dsc)

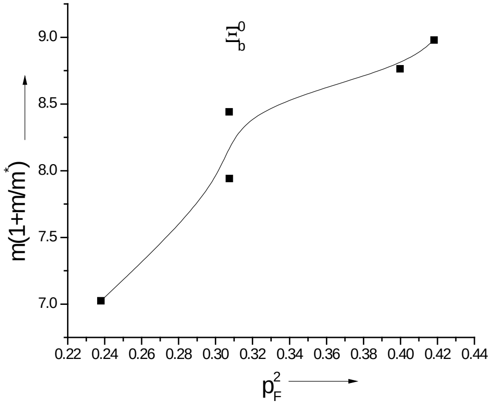

Figure 12: For $\Xi_b{}^{0}$(usb)

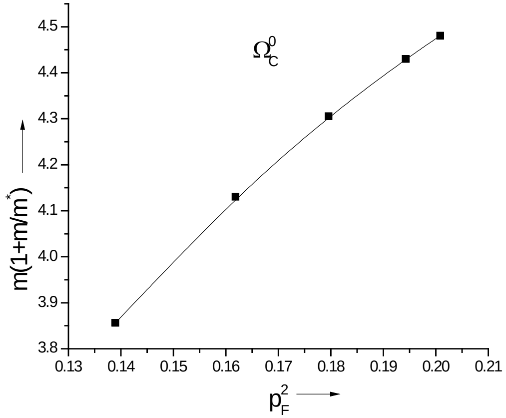

Figure 13: For$\Omega_C{}^{0}$(ssc)

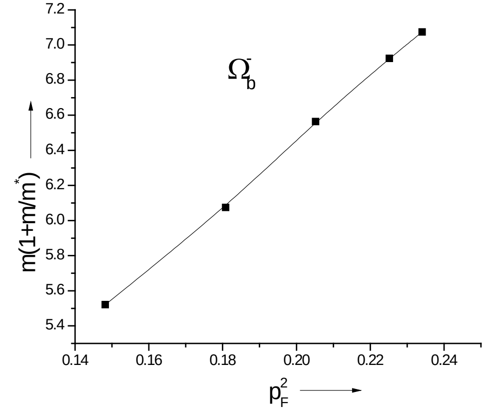

Figure 14: For$\Omega_b{}^{-}$(ssb)

Conclusions

- Fermi Liquid theory is paradigm of many body theory. System of Hadrons are described as Fermi excitation.
- Exact nature of effective mass till remained undetermined theoretically .
- Values are usually obtained by experimental fit with observable thermodynamic co-ordinates like Specific heats etc.

Conclusions

- A theoretical approach made to estimate effective mass of Fermi excitation m*.
- Effective masses estimated with momentum dependent potential. All values exceed 1 and varies between 1.1 to 1.3. Some larger values also observed.
- Potential well depths in medium extracted for Σ and Λ ~ 40 MeV , for Ξ and Ω ~ 28.5 MeV . For singly heavy baryons ~ 23.8 MeV. Good agreement with other estimates obtained [7,8,9,10].

[7] M. Kohono et al; Nucl. Phys. A 674 ,299, (2000).

[8] J. Schaffner- Bielich and A. Gal, Phys. Rev. C, *62*, 034311 (2000).

[9] C. B. Dover and A. Gal, Annals of Phys., *146*, 309 (1983).

[10] Xian-F. Zhao, J. Astrophys. and Ast., *32(3)*, 391-399 (2011).

Conclusions

- Landau parameter F_1 varies in wide range 0.051 to11
- Larger values of F shows a strongly interacting system.
- A temperature dependent effective mass equation has been extracted for both light and heavy baryons which are of universal application for the all baryons in the prescribed region.
- Study is important for understanding fermi excitation theoretically. More detailed investigation with momentum and density dependent potential would be studied in future works.
- Study the possibility of describing diquark as quasiparticle and baryons in diquark-quark configuration.

Thank you.