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Research Article

TEMPERATURE DEPENDENCE OF BARYON MAGNETIC MOMENT AND CHARGE RADIUS OF NEUTRON USING THERMODYNAMICAL BAG MODEL

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ABSTRACT

We estimate the magnetic moment of proton and neutron using Thermodynamical Bag Model (TBM). In our evaluation, temperature is a function of square four momentum transfer. As temperature increases, quark mass increases and the magnetic moment of proton decreases and neutron magnetic moment increases. Our estimated values are in agree with other theoretical predictions and also squared charge radius of neutron obtained which is in close agreement with experimental results.

INTRODUCTION

Since each nucleon has different constituent of quark flavors, and hence nucleon has different physical and chemical properties. Still now the nucleon structure is an important puzzle in physics. Nucleons having the magnetic moments which are imposed by the charge and mass of quark contents. Due to the complainty of low energy QCD, more understanding of the magnetic moments of hadron become very difficult. But lattice QCD calculations give the successful in reproducing the measurement of magnetic moments by the fundamental Lagrangian approach[1] which provides the number separation between the hadron's quark and gluon content. After years advent of QCD, our knowledge of hadron's magnetic moment calculations done by a few models like Chiral quark soliton model, skyrme model and NJL model[2-4]. The naive SU(6) constituent quark model has only limited quantitative success in accounting for the magnetic moment and semileptonic decays of the baryon. In the earlier, Seghal[5] shown the large portion of nucleon spin is composed by the orbital motion of constituents by relating quark spin, nuclear magnetic moments and axial coupling constant of baryon. This idea has been generalized to all octet baryon to explain both deep inelastic scattering fraction of quarks spin and baryon magnetic moments[6-8]. The magnetic moment of nucleon is calculated by the quark models with up, down and strange quarks[9-10].

G.C.Strobel[11] made the difference between the magnetic moment of proton and neutron by using the strange quark wave function, which is spin dependent in which the wave function of quark spin is parallel and anti parallel. Xiaotong Song[12] presented the successful explanation of many puzzles of nucleon structure. The baryon magnetic moments are calculated by the inclusion of orbital angular momentum contributions. Tiwari Gupta[13] shown the baryon magnetic moments are estimated in terms of quark moments depend only upon various mass parameters associated with corresponding quark moment with linear or Columbian interaction potential by the quantum mechanical method. Mahavash zandy[14] presented the calculation of electric and magnetic form factors of the proton using MIT bag model. The radius of the bag can be calculated in the limit $Q^2 \rightarrow 0$ from which the magnetic moment of nucleon is obtained.

Contribution to the magnetic moment of baryon from quark intrinsic moment depends also on the orientation of the spin of each quark. Since the orbital motion does not enter here, the magnetic moment reduces to the simple situation given only by the number of quark flavor in each one of the two possible spin orientation. In a proton we can account the number $u\uparrow, u\downarrow$, $d\uparrow$ and $d\downarrow$ explicitly using the chemical potential. In the present work, the thermodynamical bag model evaluation of temperature dependence of baryon magnetic moment is compared with other model calculations [15-17] and obtain squared charge radius of neutron is compared with experimental result[18].

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Thermodynamical Bag Model(TBM)

In TBM, the excited nucleon is described as a statistical thermodynamical bag and quarks and gluons are treated as fermions and bosons[19-23]. The number density, energy density and parton distributions are obtained based on the statistical nature of partons as a function of temperature and chemical potential. The temperature of the hadron and chemical potential of up and down quarks are treated by the number density equation

$$6\left(n_u - n_{\bar{u}}\right) = \frac{2}{V} = «_u T^2 + \frac{«_u^3}{®^2} \quad (1)$$

$$6\left(n_d - n_{\bar{d}}\right) = \frac{1}{V} = «_d T^2 + \frac{«_d^3}{®^2} \quad (2)$$

The above equations are solved to yield the chemical potentials at any temperatures. The energy densities of up quark, down quark and gluons are estimated by

$$£_u + £_{\bar{u}} = \left(\frac{1}{8®^2}\right)«_u^4 + \left(\frac{1}{4}\right)«_u^2 T^2 + \left(\frac{7®^2}{120}\right)T^4 \quad (3)$$

$$£_d + £_{\bar{d}} = \left(\frac{1}{8®^2}\right)«_d^4 + \left(\frac{1}{4}\right)«_d^2 T^2 + \left(\frac{7®^2}{120}\right)T^4 \quad (4)$$

$$£_g = \frac{®^2 T^4}{30} \quad (5)$$

The total energy density of the system is equal to the sum of quarks, antiquarks and gluons are given by

$$£(T) = 6(£_u + £_{\bar{u}}) + 6(£_d + £_{\bar{d}}) + 16£_g \quad (6)$$

Where 6 and 16 denotes the degeneracy of quarks and gluon orderly.

The invariant mass of the final hadron is given by

$$W^2 = M^2 + 2M¬ - Q^2 \quad (7)$$

Where M is the nucleon mass, ¬ is the energy transfer and Q^2 is the four momentum transfer.

Magnetic moment calculation

From equations (3) and (4), we obtain the energy of quarks

$E_q = \varepsilon_q$ x V (8)

In the present relativistic evaluation, we equate the energy of the quark as mass of the quark. The magnetic moment of quarks are evaluated using the relation,

$$«_q = \frac{e_q \hbar}{2m_q} \quad (9)$$

Where q is the flavor dependence either up or down and e_q is their respective charge.

Since proton is made up of two up valence quarks and one down valence quark in the naive parton model, then the magnetic moment of proton is the vector sum of the magnetic moments of two up quarks and one down quark and with corresponding charge and the final combination yields,

$$«_p = \frac{4}{3}«_u - \frac{1}{3}«_d \quad (10)$$

Similarly the neutron magnetic moment becomes the interchange of up and down quark as,

$$«_n = \frac{4}{3}«_d - \frac{1}{3}«_u \quad (11)$$

Since an atomic nucleus composites of a bound state of proton and neutron, the magnetic moments of the nucleons contribute to the nuclear magnetic moment. The nuclear magnetic moment also includes contributions from the orbital motion of the nucleons. The dueteron has the simplest example of a nuclear magnetic moment with measured value 0.857μ_N. This values within 3% of the sum of the moments of proton and neutron which gives 0.879μ_N. In the deuteron, the spins of the nucleon is aligned but their magnetic moments offset due to the negative value of neutron magnetic moment. In nonrelativistic model calculation, quantum mechanical wave function for baryons composed of three quarks and it gives accurate estimate for the magnetic moment of proton, neutron and other baryons with assumption of the quarks behave like pointlike Dirac particle, each having their own magnetic moment.

Neutron charge radius

At small Q^2, the expansion of Fourier transform of a spherical charge distribution to extract the electric charge radius. The charge radius squared of the neutron can be expressed through the neutron form factor is given by[12]

$$< r^2 >^n{}_{ch} = -6\frac{d}{dQ^2}\left[G_E^n(Q^2)\right]_{Q^2=0} \quad (12)$$

Electric and magnetic form factors can be written in the form $F_1(Q^2)$ and $F_2(Q^2)$ as, of covariant vertex

$$G_E(Q^2) = F_1(Q^2) - \frac{Q^2}{4M_N^2}F_2(Q^2) \quad (13)$$

$$G_M(Q^2) = F_1(Q^2) + F_2(Q^2) \quad (14)$$

For neutral charged particle $F_1(Q^2 \to 0)$ and we obtained simply the magnetic moment of it. Now charge radius squared of the neutron can be written as,

$$< r^2 >^n{}_{ch} = -6\frac{d}{dQ^2}\left[F_1(Q^2)\right]_{Q^2=0} + \frac{3«_n}{2M_N^2} \quad (15)$$

Where μ_n is the neutron magnetic moment and M_N is nucleon mass. In non-relativistic approximation with use of SU(6) symmetry wave function, neutron charge form factor is zero. To incorporate the relativistic effects, one proceeds the wave function and relativistic spins rotation by the means of Melosh matrices. It breaks SU(6) symmetry and give a non-zero value of charge radius[24]. The contribution of Foldy term[25] which appears due to the generation of the electric field by the neutron magnetic moment. With neutron magnetic moment, one can find the Foldy term r^2_{Foldy} = -0.126fm^2. The similarity between Foldy term and squared charge radius of the neutron argued that Dirac form factor should be interpreted as the intrinsic charge distribution of the neutron.

RESULTS AND DISCUSSIONS

The magnetic moment of proton and neutron have been evaluated using theoretical predictions. In our thermodynamical approach, as x $\rightarrow$1 the nucleon is at ground state where as x $\rightarrow$ 0 the nucleon gets excited state. The proton has the positive value magnetic moment and neutron has the negative value magnetic moment because of positive charge of up quark and negative charge of down quark.

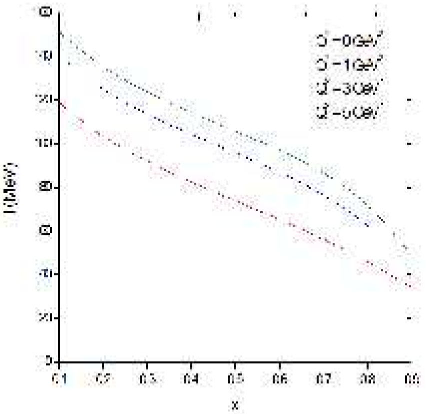

Fig. 1 Variation of temperature with x for various Q^2 (GeV^2)

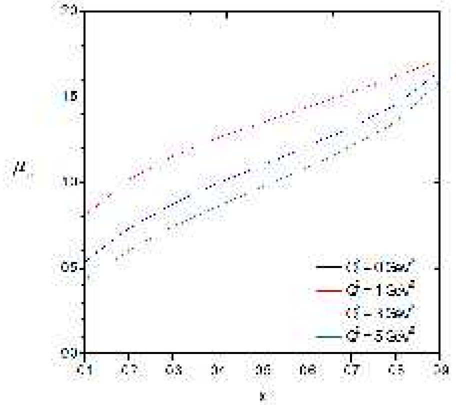

Fig. 2 Up quark magnetic moment as a function of Q^2 and x

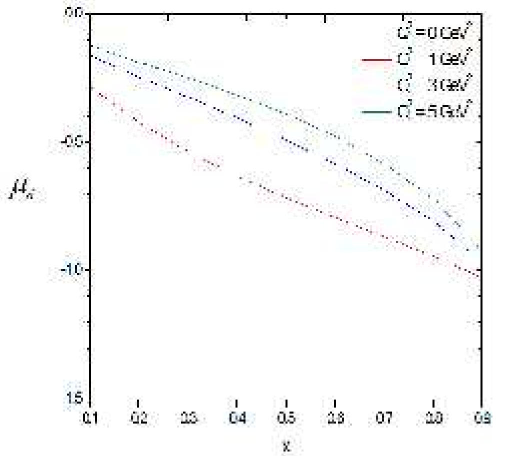

Fig. 3 Down quark magnetic moment as a function of Q^2 and x

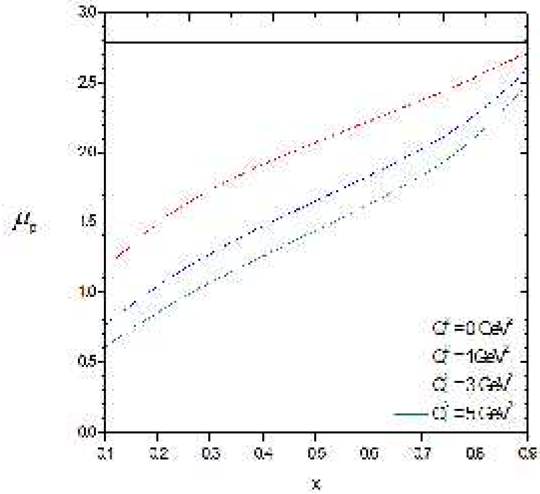

Fig. 4 Proton magnetic moment as a function of Q^2 and x.

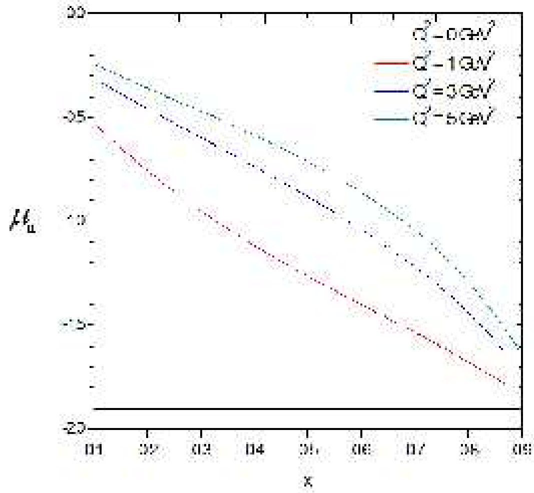

Fig. 5 Neutron magnetic moment as a function of Q^2 and x.

The variation of temperature with Bjorken variable x is shown in figure 1. At Q^2 = 0, temperature do not change with x. As Q^2 increases, the temperature become increases. In figure 2, up quark magnetic moment is plotted for different Q^2. The magnetic moment of up quark and down quark are calculated at Q^2 = 0,1,3 and 5 GeV^2 with variation of Bjorken variable between 0 and 1. At Q^2 = 0, up quark magnetic moment does not dependent on temperature and then increasing Q^2, it becomes decreases. Similarly down quark magnetic moment decreasing in negative value is shown in figure 3. Figure 4 and 5 represent the variation of proton and neutron magnetic moment for various Bjorken values. Increasing the temperature i.e. as Q^2 increases, the mass of quark also increases and then the magnetic moment of proton decreases and neutron magnetic moment increases depending on Q^2 which is in accordance with Xing[15] and disfavored with Abu-Shady[16] in which temperature increases mass also increases but the change of magnetic moments are against. When increasing the temperature, energy density also increases in our model disagree with Quark- meson coupling model[17] in which temperature increases, decreasing the mass and the magnetic moment increases. The ratio of neutron to proton is evaluated at x = 0.9 with different Q^2 values which are given in Table1. This ratio at Q^2 = 0 Gev^2, consistent with CODATA experimental result.

Table-1 Comparison of ratio of neutron magnetic moment to proton magnetic moment.

$Q^2(GeV^2)$	$\frac{«_n}{«_p}$	CODATA
0	-0.681232	-0.68497934
1	-0.674806	
3	-0.664566	
5	-0.656386	

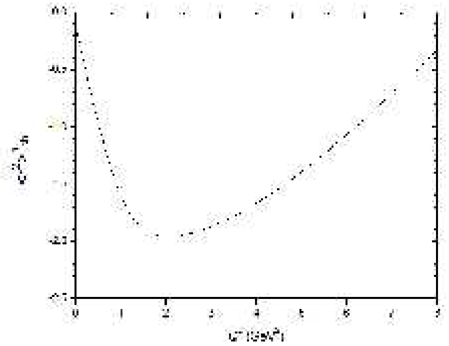

Fig. 6 The squared charge radius of neutron as a function of different four momentum transfer $Q^2(GeV^2)$.

The squared charge radius of neutron with different Q^2 as shown in figure 6. At $Q^2 = 0$, we obtained the squared charge radius of neutron. As Q^2 increases, squared charge radius of neutron decreases up to $Q^2 = 2\ GeV^2$. Further increasing Q^2 value, it increases. Obtain the squared charge radius of neutron and experimental results are given in the table.

Table-2 Comparison of neutron charge radius

	Experimental value[18]	TBM
$< r^2 >^n{}_{ch}$	-0.113 $\pm$ 0.005	-0.117

CONCLUSION

We conclude that on the basis of our thermodynamical bag model, the magnetic moment of proton decrease with increasing temperature and magnetic moment of neutron increases with increasing temperature and squared charge radius of neutron is consistent with the experimental results. The present evaluation of contribution of different quark flavor for the magnetic moment gives more information about the internal structure of the baryon which confirms the experimental determination of the structure of the proton and neutron.

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