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LATTICE QCD AND THE SOLITON BAG MODEL

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A B S T R A C T

The parameters of the soliton bag model of Friedberg and Lee can be related to the following results of lattice gauge theory: transition temperature T_c , string constant E/l , glueball mass m_{GB} .

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1. - INTRODUCTION

Several models have been developed in order to describe the confinement of quarks phenomenologically: the MIT bag model¹⁾, the hybrid bag model²⁾, the soliton bag model with a scalar field σ representing averaged gluon configurations³⁾, the chiral bag model with mesonic σ - and π - fields⁴⁾, and the non-relativistic constituent quark model with confining potential⁵⁾. The main approach in these models is to choose parameters which fit the baryon and meson spectra. Then one extrapolates these models to problems in many-quark systems like the baryon-baryon or meson-baryon interaction.

In this paper we use an alternative philosophy. We relate the parameters of the non-topological soliton model to the results of QCD simulations on the lattice. The soliton bag model was initiated by Friedberg and Lee³⁾ and has become quite popular by the work of Goldflam and Wilets⁶⁾ and many others⁷⁾. The lattice formulation of QCD was introduced by Wilson⁸⁾ and has made important progress⁹⁾ during the last years through the application of the Monte Carlo method. Since a direct evaluation of important features of low energy nuclear physics problems is still impossible using the lattice formulation, it looks advantageous to construct a phenomenological model. We propose to relate such a model to the results of lattice QCD. Clearly the soliton model would gain in credibility if it can be connected with the underlying microscopic dynamics and at the same time successfully describes hadron spectroscopy.

What are the principal quantities evaluated in lattice simulations? We consider in the following pure SU(3) gauge theory without light quarks. Numerical simulations on the lattice have proved to be more reliable for this problem than for the full quark-gluon Hamiltonian. Their most significant results are the determination of the string tension E/l , the transition temperature T_c and the glueball mass m_{GB} . Lattice gauge calculations compare expectation values of gauge invariant operators calculated for different QCD coupling constants with the behaviour expected from the renormalization group equation. This equation links the lattice distance a to the coupling constant g by demanding that the observable mass (e.g., the glueball mass) is invariant under combined scale and coupling constant transformations. To leading order in g^2

$$m(g, a) = \text{const} \cdot \frac{1}{a} \cdot \exp\left(-\frac{1}{2\beta_0 g^2}\right) = \text{const} \cdot \Lambda_L \quad (1.1)$$

with

$$\beta_0 = \frac{11}{16 \cdot \pi^2} \quad (1.2)$$

Therefore a small g is necessary to approach the desired continuum limit of $a \rightarrow 0$ in the functional integration of the gluon action $S = -(1/g^2) \int d^4x F_{\mu\nu} F_{\mu\nu}$. The quantity Λ_L in Eq. (1.1) is independent of a and g and defines the physical scale. All observables can be expressed in units of this scale Λ_L . Recent calculations give results¹⁰⁾⁻¹⁵⁾ in the following ranges

$$T_c = (55 - 100) \cdot \Lambda_L \quad (1.3)$$

$$m_{GB}(0^{++}) = (260 - 280) \Lambda_L \quad (1.4)$$

$$\sqrt{E/l} = (90 - 150) \Lambda_L \quad (1.5)$$

From charmonium spectroscopy¹⁶⁾ one can deduce a string tension such that

$$\sqrt{E/l} = 420 \text{ MeV} \quad (1.6)$$

This value (1.6) then fixes the scale Λ_L which gives according to Eq. (1.5) $\Lambda_L = 4.7 \text{ MeV}$ or $\Lambda_L = 2.8 \text{ MeV}$. Consequently we have taken two sets (α, β) of input parameters. Set (α) corresponds to the small $\Lambda_L \approx 2.8 \text{ MeV}$. Set (β) is related to the large Λ_L .

(α)

$$\Lambda_L = 2.8 \text{ MeV}$$

$$m_{GB} = 260 \Lambda_L = 720 \text{ MeV} \quad (1.7)$$

$$T_c = 55 \Lambda_L = 154 \text{ MeV}$$

$$\sqrt{E/l} = 150 \Lambda_L = 420 \text{ MeV}$$

(β)

$$\Lambda_L = 4.7 \text{ MeV}$$

$$m_{GB} = 260 \Lambda_L = 1220 \text{ MeV}$$

$$T_c = 55 \Lambda_L = 260 \text{ MeV} \quad (1.8)$$

$$\sqrt{E/\ell} = 90 \Lambda_L = 420 \text{ MeV}$$

We are going to compare the quantities of Eqs. (1.7) and (1.8) to solutions of the soliton model without quarks.

The outline of the paper is as follows. In Section 2 we present the effective Hamiltonian containing the soliton field σ and the gluon field which is modified by the colour dielectric function $\epsilon(\sigma)$. We identify the glueball mass in this Hamiltonian. In Section 3 we calculate the deconfinement phase transition in the soliton model. We find that at high temperature the requirement of asymptotic freedom and the value of the transition temperature determines all the parameters. Finally in Section 4 we calculate the string constant and check how the results of the effective Hamiltonian agree with the empirical value of $\sqrt{E/\ell} = 420 \text{ MeV}$ fitted by Λ_L in gauge theory.

2. - PARAMETRIZATION OF THE SOLITON FIELD HAMILTONIAN

We use the following σ -field Hamiltonian^{3),6)} to describe non-perturbative and non-linear QCD effects phenomenologically.

$$\begin{aligned} \mathcal{H} &= \int d^3x (\mathcal{H}_\sigma + \mathcal{H}_A) \\ \mathcal{H}_\sigma &= \frac{1}{2} \pi_\sigma^2 + \frac{1}{2} (\vec{\nabla} \sigma)^2 + \mathcal{U}(\sigma) \\ \mathcal{H}_A &= \frac{1}{2} \epsilon(\sigma) \sum_{a=1}^8 (\vec{E}_a^2 + \vec{B}_a^2) \end{aligned} \quad (2.1)$$

Here σ represents the scalar (0^+) field, which is assumed to arise from averaging over gluon configurations¹⁷⁾. Its self-interaction is given by the potential $\mathcal{U}(\sigma)$ which has an absolute minimum at $\sigma = \sigma_v = 0$. Through the colour dielectric function $\epsilon(\sigma)$ the dynamics of the soliton field σ is coupled to an

averaged gauge field¹⁷⁾ A_μ^a which has only low momentum components. Therefore it may suffice to consider only the Abelian part of the gauge field Hamiltonian which is given in Eq. (2.1) in terms of colour electric and magnetic fields

$$E_a^i = \partial^i A_a^0 - \partial^0 A_a^i \quad \text{and} \quad B_a^i = -\frac{1}{2} \epsilon_{ijk} (\partial^j A_a^k - \partial^k A_a^j)$$

In vacuum $\epsilon(\sigma)$ has to vanish $\epsilon(\sigma = \sigma_v) = 0$, thus suppressing free gluons. In the presence of colour charges the strong vacuum fluctuations are absent and ϵ has values between zero and one, i.e., $0 < \epsilon < 1$. Perturbative QCD is regained in the interior of the string where ϵ comes close to one. We shall assume that $\epsilon(\sigma=0) = 1$ represents the stable solution of the soliton-gluon dynamics also at large temperature when deconfinement takes place. In order to have free colour fields, ϵ has to become one in this case. Between $\epsilon(\sigma=0)$ and $\epsilon(\sigma=\sigma_v)$ we interpolate with a third order polynomial

$$\epsilon(\sigma) = \left(1 - \frac{\sigma}{\sigma_v}\right)^2 \left(2 \frac{\sigma}{\sigma_v} + 1\right) \quad (2.2)$$

This form is fixed by demanding a vanishing $(\partial\epsilon/\partial\sigma)$ at $\sigma = \sigma_v$ and at $\sigma = 0$, which is necessary for stability of the asymptotically free system and the vacuum as we will show. In principle renormalizability has already been destroyed via the σ -gluon coupling. The parametrization of $U(\sigma)$ is therefore mostly a matter of convenience. Goldflam and Wilets⁶⁾ give $U(\sigma)$ in the form

$$U(\sigma) = \frac{a}{2} \sigma^2 + \frac{b}{6} \sigma^3 + \frac{c}{24} \sigma^4 + B \quad (2.3)$$

We shall use the more convenient expression

$$U(\eta) = B(1-\eta)^2(1+2\eta+(A+3)\eta^2), \quad \eta = \frac{\sigma}{\sigma_v} \quad (2.4)$$

The particular form of Eq. (2.4) was chosen because it constrains

$$U(\sigma = \sigma_v) = 0, \quad \frac{\partial U}{\partial \sigma} \Big|_{\sigma = \sigma_v} = 0 \quad \text{and}$$

$$\frac{\partial U}{\partial \sigma} \Big|_{\sigma = 0} = 0.$$

The relation between both parametrizations is

$$\begin{aligned} a &= 2BA\sigma_v^{-2}, & b &= -12B(A+2)\sigma_v^{-3}, \\ c &= 24B(A+3)\sigma_v^{-4}. \end{aligned} \quad (2.5)$$

The parameter B may be considered as a generalized bag constant, since it represents the energy per volume of a region with $\sigma = 0$ compared to the vacuum value $U(\eta=1) = 0$. It may be used for estimates of T_c and of other hadronic properties in the framework of the MIT bag model. However, finally the soliton model itself must determine these observables explicitly.

The σ field can be excited around its vacuum value σ_v . Following Ref. 20), we conjecture that this excitation can be identified with a 0^+ glueball. Recently it has been shown that a similar scalar σ field can be constructed from the QCD Lagrangian by a suitable average of the phase factor

$$\chi(x_0) = \frac{1}{N_c} \text{av Tr } \mathbb{P} \exp i \oint_{x_0} A_\mu dx^\mu \quad \text{and} \quad \chi(x_0) = 1 - \frac{\sigma(x_0)}{\sigma_v}.$$

From Eq. (2.3), the glueball mass is obtained as

$$m_{GB}^2 = \left. \frac{\partial^2 U}{\partial \sigma^2} \right|_{\sigma=\sigma_v} = 2B(A+6)\sigma_v^{-2}. \quad (2.6)$$

This relation fixes σ_v if A and B are given. The parameter A defines the shape of the curve $U(\eta)$, see Fig. 1. We shall determine A through the requirement that at large temperature σ approaches zero.

3. - CALCULATION OF THE TRANSITION TEMPERATURE T_c

The effective potential $U(\sigma)$ and the dielectric function $\epsilon(\sigma)$ determine the dynamics at zero temperature. The consequences of a finite temperature will be investigated now. In principle the dielectric function may change with increasing temperature (and/or baryon density). Since we are not able to calculate $\epsilon(\sigma)$ we have to assume $\epsilon(\sigma)$ independent of T and we use the functional form of $\epsilon(\sigma)$ [Eq. (2.2)] for all temperatures. To study the variation of the vacuum expectation value of σ from $\langle \sigma \rangle = \sigma_v$ to $\langle \sigma \rangle = 0$ we must minimize the free energy density $G(\sigma_c, T)$ under the constraint that for the classical value of σ , $\langle \sigma \rangle = \sigma_{cl}$, G attains its minimum, i.e., $\partial G / \partial \sigma \Big|_{\sigma=\sigma_{cl}} = 0$.

The free energy is calculated by integrating out the thermal fluctuations given by the Hamiltonian Eq. (2.1). In the limit of large temperature the finite temperature contribution $\Delta U(\sigma, T)$ to the effective potential has a simple form^{18),19)}

$$\Delta U(\sigma_a, T) = -\frac{\pi^2}{90} T^4 + \frac{1}{24} \left(\frac{\partial^2 U}{\partial \sigma^2} \right) \Big|_{\sigma=\sigma_a} \cdot T^2 + O(T) \quad (3.1)$$

Adding the gluon fluctuations modified by $\varepsilon(\sigma_{cl}, T=0)$ we find the free energy $G(\sigma_{cl}, T)$

$$G(\sigma_a, T) = -\varepsilon(\sigma_a) \frac{16\pi^2}{90} T^4 + U(\sigma_a, T=0) + \Delta U(\sigma_a, T) \quad (3.2)$$

The value of σ_{cl} also determines the dielectric function which approaches one with $\sigma_{cl} \rightarrow 0$. The energy density W is obtained from Eq. (3.2) by

$$W = -\frac{\partial G}{\partial T} \cdot T + G \quad (3.2)$$

where $-G$ equals the pressure P of the system. Now the soliton model should simulate real QCD in the following way. At large temperatures W must approach the free-gluon energy density of $\langle W_{\text{gluon gas}} \rangle = (48\pi^2/90)T^4$. Obviously [cf. Eq. (3.1)] the soliton model will contain in addition the thermal glueball modes, which do not disappear at large temperature. Therefore the minimal requirement will be that these modes decouple from the gluon energy (i.e., $\varepsilon \rightarrow 1$) at large T . This condition immediately constrains the effective Hamiltonian with respect to σ -variations near $\sigma = 0$, namely

$$\frac{\partial G}{\partial \sigma_a} \Big|_{\sigma_a=0} = 0, \quad \text{for large } T \quad (3.4)$$

Equation (3.4) is equivalent to demanding $\partial \varepsilon / \partial \sigma \Big|_{\sigma=0} = 0$ and $\partial U / \partial \sigma \Big|_{\sigma=0} = 0$. The first condition is fulfilled by the form of $\varepsilon(\sigma)$ in Eq. (2.2) and insures asymptotic freedom at high temperature. The second condition imposes the parameters b and A from Eqs. (2.3) and (2.5) to assume the values $b = 0$ and $A = -2$.

Using $b = 0$ or $A = -2$ the glueball mass is obtained as

$$m_{GB}^2 = 8B/\sigma_V^2 \quad (3.5)$$

Equation (3.5) leaves only one free parameter (B or σ_V) to fit the transition temperature T_c . For the parameter set (α) we find a first-order phase transition at the critical temperature

(α) $T_c = 158$ MeV with the parameters

$$\begin{aligned} B^{1/4} &= 203 \text{ MeV} \\ \sigma_V &= 160 \text{ MeV} \\ m_{GB} &= 720 \text{ MeV} \end{aligned} \quad (3.6)$$

For the large $\Lambda_L = 4.7$ MeV we find that $B^{1/4} = 330$ MeV and $\sigma_V = 252$ MeV give the wanted transition temperature $T_c \approx 260$ MeV. In this case

(β) $T_c = 260$ MeV with the parameters

$$\begin{aligned} B^{1/4} &= 330 \text{ MeV} \\ \sigma_V &= 252 \text{ MeV} \\ m_{GB} &= 1220 \text{ MeV} \end{aligned} \quad (3.7)$$

Note that $B^{1/4}$ and consequently also σ_V scale like the temperature T_c . The determination of the transition temperature from the Friedberg-Lee soliton model, Eq. (3.2), can be compared to the simpler MIT-bag model where the free energy above T_c for a free gluon gas in SU(3) without quarks reads

$$G = - \frac{16\pi^2}{90} T^4 + B_{MIT}$$

Here B_{MIT} is the MIT-bag constant. Below T_c one may describe the hadronic phase by a pion gas, then $G = -(3\pi^2/90)T^4$. Deconfinement occurs when G for the gluon gas phase is lower than G for the pion gas. In the above model the critical temperature is $T_c \approx 0.92 B_{MIT}^{1/4}$ for the set (α) of 171 MeV and for the set (β) of 283 MeV. For the soliton bag model $B^{1/4} = U^{1/4}(\sigma)$ at $\sigma = 0$ plays the rôle of the energy density of the soliton field in the deconfined phase at $T = 0$. One

sees that the soliton-bag values for $B^{1/4}$ are about 20% higher than the MIT estimate $B_{MIT}^{1/4}$.

4. - CALCULATION OF THE STRING CONSTANT AND STRING PROFILE

The Friedberg-Lee soliton model can also be applied to calculate the potential energy between a heavy quark antiquark pair. We assume that the colour electric field is independent of the separation distance of the colour charges and given by the chromoelectric charge

$$q_0 = \sqrt{\frac{16\pi\alpha_s}{3}} \quad (4.1)$$

alone. Here we use $\alpha_s = 0.45$ which is close to the QCD-coupling constant $\bar{\alpha}_s = 0.412$ obtained from a phenomenological analysis of heavy $q\bar{q}$ -bags¹⁷⁾. The value $\alpha_s = 0.45$ is much smaller than the value of $\alpha_s(Q^2)$ for light quark systems. With the Hamiltonian H of Eqs. (2.1) and (2.2) we minimize the energy subject to the constraint that the chromoelectric flux

$$\int \vec{D} d\vec{s} = \int \epsilon(\sigma) \vec{E} d\vec{s} \quad (4.2)$$

yields the chromoelectric charge. The colour dielectric model yields field lines between the heavy quark and antiquark which are confined into a narrow tube connecting the two sources. This happens because the free ($\epsilon=1$) field of the two charges is compressed, since the energy $U(\sigma)$ corresponding to $\epsilon(\sigma=0) = 1$ is very high and can only be realized in a small transverse region. The colour electric field strength tends to widen the tube and the $(\vec{\nabla}\sigma)^2$ term prefers a diffuse surface. The Friedberg-Lee soliton bag model allows us to calculate the string tension and the string profile for the two different parameters sets we established in Section 3.

The energy E of the tube per length l can be written with $\eta = \sigma/\sigma_V$ as

$$\kappa = E/l = 2\pi \int g dg \left[\epsilon(\eta(g)) \frac{\vec{E}^2}{2} + U(\eta(g)) + \frac{\sigma_V^2}{2} \left(\frac{d\eta}{dg} \right)^2 \right] \quad (4.3)$$

This energy has to be minimized with the constraint that

$$q = 2\pi \int \rho d\rho \epsilon(\eta(\rho)) E_z = q_0 \quad (4.4)$$

where $\vec{E} = E_z \vec{e}_z$ is the colour electric field assumed to be independent of z ; ρ is the radial cylindrical co-ordinate. Including the constraint we minimize the functional

$$F = \int \mathcal{F} d\rho = \kappa - \lambda (q - q_0) \stackrel{!}{=} \min \quad (4.5)$$

From $\partial F / \partial E_z = 0$ we get

$$E_z \epsilon(\eta) - \lambda \epsilon(\eta) = 0 \quad (4.6)$$

hence

$$\lambda = E_z \quad (4.7)$$

The second variational equation

$$\frac{\partial \mathcal{F}}{\partial \eta} - \frac{d}{d\rho} \frac{\partial \mathcal{F}}{\partial \eta_{,\rho}} = 0 \quad (4.8)$$

has the general form using Eq. (3.7)

$$\frac{\partial u}{\partial \eta} - \frac{E_z^2}{2} \frac{\partial \epsilon}{\partial \eta} = \frac{\sigma_v^2}{2} \left(\frac{d^2 \eta}{d\rho^2} + \frac{1}{\rho} \frac{d\eta}{d\rho} \right) \quad (4.9)$$

From this equation one sees that $\partial \epsilon / \partial \eta$ must approach zero, when $\eta \rightarrow 1$ asymptotically. Therefore the form proposed in Ref. 3) $\epsilon = (1 - \sigma / \sigma_v) = (1 - \eta)$ does not work as a dielectric function. We have chosen $\epsilon(\eta) = (1 - \eta)^2 (2\eta + 1)$ given in Eq. (2.2) which fulfils

$$\frac{\partial \epsilon}{\partial \eta} = -6\eta(1-\eta) \xrightarrow{\eta \rightarrow 1} 0 \quad (4.10)$$

Equation (4.9) can be conveniently written with scaled variables

$$\rho = \frac{\sigma_v}{\sqrt{B}} x, \quad E_z = \sqrt{2B} \cdot e \quad (4.11)$$

so that all quantities are dimensionless. Now for

$$\varepsilon = (1 - \sigma/\sigma_v)^2 (2\sigma/\sigma_v + 1) \quad (4.12)$$

it reads

$$\frac{d^2\eta}{dx^2} = -\frac{1}{x} \frac{d\eta}{dx} + 6e^2(1-\eta)\eta + 2\eta(1-\eta)(A - 2(A+3)\eta) \quad (4.13)$$

The boundary conditions are

$$\eta'(0) = 0 \quad \text{and} \quad \eta(\infty) = 1 \quad (4.14)$$

The string constant and the chromoelectric charge can be expressed with the new variables (4.11) as

$$K = \sqrt{\frac{Bq^2}{2}} e + \frac{4\pi B(A+6)}{m_{GB}^2} \int x dx \left[(1-\eta)^2 (1 + 2\eta + (A+3)\eta^2) + \frac{1}{2} \left(\frac{d\eta}{dx} \right)^2 \right] \quad (4.15)$$

$$q = 4\pi \frac{A+6}{m_{GB}^2} \sqrt{2B} \cdot e \int x dx (1-\eta)^2 (2\eta+1) \quad (4.16)$$

Equation (3.13) is solved iteratively by improving a guess of $\eta(0)$ and e until agreement with $\eta(\infty) = 1$ and $q = q_0$ is reached. The resulting string constants for the different parameter sets are

$$\begin{aligned} (\alpha) \quad \sqrt{E/\ell} &= 450 \text{ MeV} \\ (\beta) \quad \sqrt{E/\ell} &= 730 \text{ MeV} \end{aligned} \quad (4.17)$$

The first value $\sqrt{E/\ell} = 450 \text{ MeV}$ is very close to the one found in spectroscopy¹⁶⁾ and suggests the set (α) as a consistent parametrization for the soliton bag model. The second result is scaled by $T_c(\beta)/T_c(\alpha)$. It is unacceptably high. With the dielectric constant $\varepsilon(\sigma)$ given in Eq. (2.2) we have always found softer and wider flux-tubes than with the parametrization $\varepsilon(\sigma) = (1 - \sigma/\sigma_v)^2$ which is possible if one would not demand $\partial\varepsilon(\sigma)/\partial\sigma = 0$ at $\sigma = 0$. A larger ε on the average necessitates a smaller $\vec{E}$ field to conserve the chromoelectric charge. The smaller $\vec{E}$ field does not dig such a strong hole into the

vacuum, i.e., σ still stays at 40% of its vacuum value in the centre of the flux tube (cf. Fig. 2). The average width of the flux tube, where σ has approached 90% of its vacuum value, is $R(\alpha) = 1.3$ fm and $R(\beta) = 0.8$ fm in the two cases. Naturally a stronger B compresses the flux tube more. With the above size $R(\alpha)$ the strings overlap strongly in the baryon and form an extended region of nearly free-gluon interactions ($\epsilon \approx 0.7$). Therefore one would expect a bag model to be a good approximation for the baryon.

5. - SUMMARY

In this paper we have calculated the three parameters A , B and σ_V of the non-linear σ interaction $U(\sigma)$ from the 0^{++} glueball mass and the transition temperature T_c . We have evaluated the string tension with the same parameters. We find that the set (α) of lattice gauge results ($\Lambda_L = 2.8$ MeV, $m_{GB} = 729$ MeV, $T_c = 158$ MeV and $\sqrt{E/\lambda} = 420$ MeV) can be reproduced rather accurately in the soliton model by choosing $A = -2$, $B = (203 \text{ MeV})^4$ and $\sigma_V = 160$ MeV. For larger T_c corresponding to $\Lambda_L = 4.2$ MeV we cannot obtain a consistent parametrization.

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REFERENCES

- 1) A. Chodos, R.L. Jaffe, K. Johnson and C.B. Thorn - Phys.Rev. D10 (1974) 2599.
- 2) G.E. Brown and M. Rho - Phys.Lett. 82B (1979) 177;
A.W. Thomas - Adv.Nucl.Phys. Vol. 13 (1982), 1, Eds. J. Negele and E. Vogt.
- 3) R.Friedberg and T.D. Lee - Phys.Rev. D15 (1977) 1964;
T.D. Lee - Particle Physics and Introduction to Field Theory (Harwood Academic, New York, 1981).
- 4) S. Kahana, G. Ripka and V. Soni - Nucl.Phys. A415 (1984) 351;
M.C. Birse and M.K. Banerjee - Phys.Lett. 136B (1984) 284.
- 5) D. Gromes - Ordinary Hadrons, Lectures given at the Yukon Advanced Study Institute (1984) HD-THEP-84-32.
- 6) R. Goldflam and L. Wilets - Phys.Rev. D25 (1982) 1951.
- 7) R. Saly and M.K. Sudaresan - Phys.Rev. D29 (1984) 525;
Th. Köppel and M. Harvey - Chalk-River preprint ACEL-8480 (1984).
- 8) K. Wilson - Phys.Rev. D10 (1974) 2445;
K. Wilson - Erice Lectures (1975).
- 9) B. Berg - To be published in Proceedings of the 10th International Conference on "Particles and Nuclei", Heidelberg (1984), CERN Preprint TH. 3798 (1984).
- 10) A.D. Kennedy, J. Kuti, S. Meyer and B.J. Pendleton - Preprint UCSDF-10P10-234 (1984).
- 11) T. Celik, J. Engels and H. Satz - Phys.Lett. 133B (1983) 427.
- 12) Ph. de Forcrand, G. Schierholz and M. Teper - Preprint DESY 84-X (1984).
- 13) B. Berg and A. Billoire - Nucl.Phys. B221 (1983) 109.
- 14) F. Gutbrod, P. Hasenfratz, Z. Kunszt and I. Montvay - Phys.Lett. 128B (1983) 415.
- 15) G. Parisi, R. Petronzio and F. Rapuano - Phys.Lett. 128B (1983) 418.
- 16) E. Eichten, K. Gottfried, T. Kinoshita, K.D. Lane and T.M. Yan - Phys.Rev. D17 (1978) 3090.
- 17) H.B. Nielsen and A. Patkos - Nucl.Phys. B195 (1982) 137.
- 18) G. Chanfray, O. Nachtmann and H.J. Pirner - Phys.Lett. 147B (1984) 249.
- 19) L. Dolan and R. Jackiw - Phys.Rev. D9 (1974) 3320;
S. Weinberg - Phys.Rev. D9 (1974) 3357.
- 20) K. Johnson and C.B. Thorn - Phys.Rev. D13 (1976) 1934.

FIGURE CAPTIONS

Fig. 1 The shape of the soliton self-energy potential $U(\sigma)$ defined in Eq. (2.3) for three values of the parameter A :

$A = 5$ (dot-dashed), $A = -1$ (solid line), $A = -2$ (dashed).

Fig. 2 The field $\eta(\sigma) = \sigma/\sigma_V$ for $B^{1/4} = 203$ MeV, $m_{GB} = 0.72$ GeV, $A = -2$, $\sigma_V = 160$ MeV, $\alpha_s = 0.45$.

4058-84 MPI H

Fig. 1

Fig . 2