Обзор докладов конференции Confinement 2014

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23 Сентября, 2014

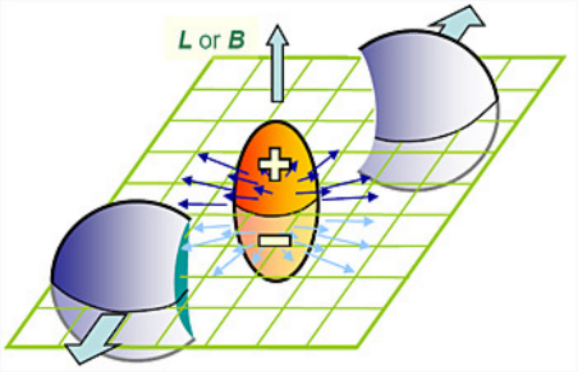
Magnetic properties of QCD matter: lattice results

Gunnar Bali

Universität Regensburg

Confinement XI, IX.IX.XIV

Collider experiment: non-central heavy ion collisions



Two very big currents at very short distances produce extremely strong magnetic fields.

LHC: $eB \lesssim 0.3\,\mathrm{GeV}^2 \approx 5 \cdot 10^{19}$ eG, RHIC: $eB \lesssim 0.04\,\mathrm{GeV}^2 \approx 6 \cdot 10^{18}$ eG.
This is bigger than $m_\pi^2 \approx 0.02\,\mathrm{GeV}^2$!
Fields have life time of only $\sim 0.1\,\mathrm{fm} = 10^{-16}\,\mathrm{m} \approx 5 \cdot 10^{-24}$ s.

Magnetic background field on the lattice

4-potential $(A_\nu) = (0, Bx, 0, 0) \Longrightarrow \mathbf{B} = (0, 0, B)$

Lattice: multiply links U_ν with $u_\nu = e^{iaqA_\nu} \in \mathrm{U}(1)$

$$\begin{aligned} u_y(n) &= e^{ia^2 qBn_x} & \\ u_x(n) &= 1 & n \neq N_x - 1 \\ u_x(N_x - 1, n_y, n_z, n_t) &= e^{-ia^2 qBN_x n_y} & \\ u_\nu(n) &= 1 & \nu \neq x, y \end{aligned}$$

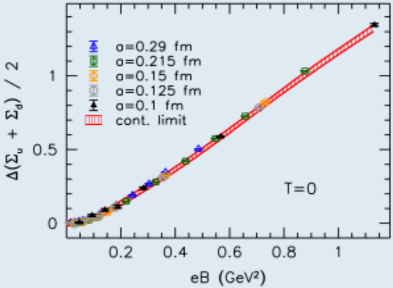
The magnetic flux through the x-y plane is constant:

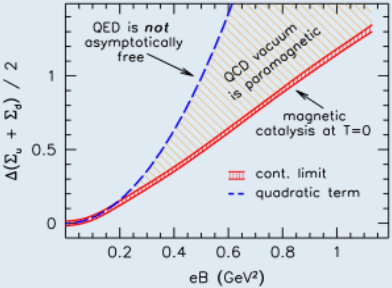
$$\exp\left(iq\int_F \mathrm{d}\sigma\, \mathbf{B}\right) = \exp\left(iq\int_{\partial F} \mathrm{d}x_\nu\, A_\nu\right) = e^{ia^2 N_x N_y qB}$$

Flux quantization due to the finite volume + boundary conditions:

$$a^2 N_x N_y \cdot qB = 2\pi N_b \qquad N_b \in \mathbb{Z}$$

Magnetic catalysis: $T = 0$



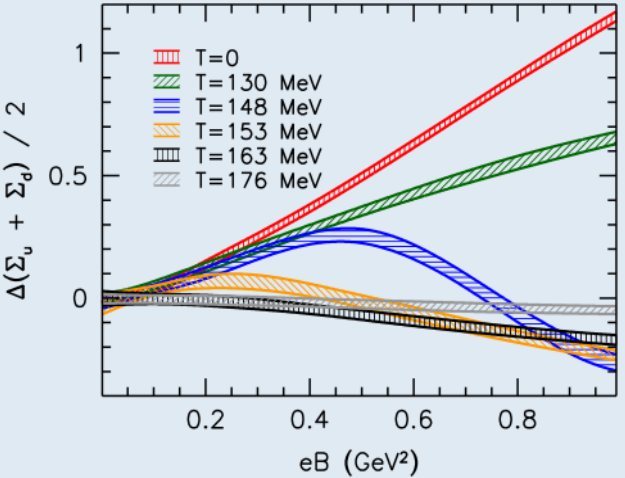


$$\Delta f = \int_{m_{\rm phys}}^{\infty} dm\, \Delta\bar{\psi}\psi\,, \qquad \mathcal{P}[X] = (eB)^2 \lim_{eB\to 0} \frac{X}{(eB)^2}$$

$$\underbrace{\mathcal{P}[\Delta f]}_{\sim b_1} + \underbrace{(\mathbb{1} - \mathcal{P})[\Delta f]}_{\sim -\mathcal{M}} = \int_{m_{\rm phys}}^{\infty} dm\, \left[\mathcal{P}[\Delta\bar{\psi}\psi] + (\mathbb{1} - \mathcal{P})[\Delta\bar{\psi}\psi]\right]$$

$\Longrightarrow$ magnetization $\mathcal{M} > 0$ at $T = 0$.

Inverse magnetic catalysis (continuum limit)



Two-color QCD with chiral chemical potential

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XIth Quark Confinement and the Hadron Spectrum

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[b] ITEP, Moscow
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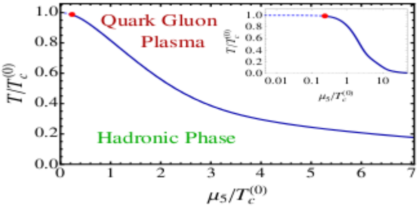
[d] JINR, Dubna
[e] Humboldt-Universität zu Berlin, Institut für Physik, Berlin

September 9, 2014

Phenomenological studies

M. N. Chernodub and A. S. Nedelin, Phase diagram of chirally imbalanced QCD matter, Phys. Rev. D**83**, 105008 (2011), arXiv: 1102.0188(hep-ph).



At large μ_5 crossover transforms to the first order phase transition (details differ in different papers).

Lattice setup

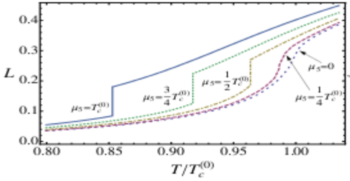
- $SU(2)$ gauge group for simplicity
- For gauge fields we adopted Wilson action

$$S_g = \frac{\beta}{4} \sum_{x,\mu\neq\nu} \mathrm{tr}\left(1 - U_\mu(x)U_\nu(x+\mu)U_\mu^\dagger(x+\nu)U_\nu^\dagger(x)\right)$$

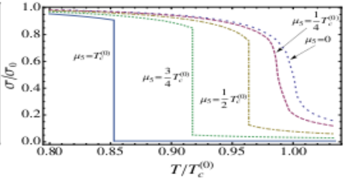
- 4 tastes of dynamical staggered fermions (without rooting)
- 2 values of μ_5: $460 MeV$, $920 MeV$
- Small $ma = 0.01$
- For each point N configurations $\sim O(1000)$

Results. Polyakov loop and chiral condensate

M. N. Chernodub and A. S. Nedelin, arXiv: 1102.0188(hep-ph)

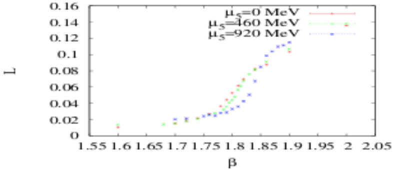


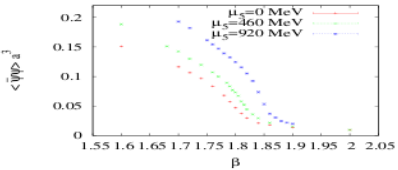
Polyakov loop



Chiral condensate

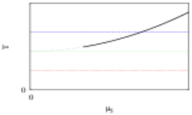
Results (Lattice 6×16^3)



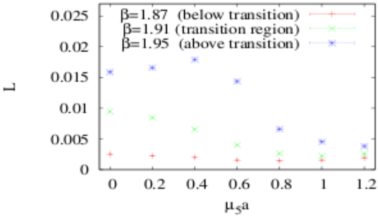


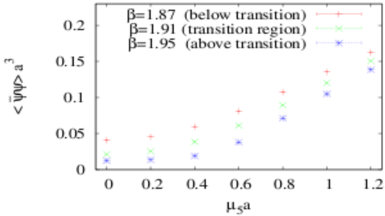
Results. Varying μ_5

Observables with respect to μ_5(β, lattice size are fixed) in different phases.
Lattice 10×28^3



Phase diagram





QCHSXI, Saint Petersburg, Russia, September 8 - 12, 2014

QCD with axial chemical potential: possible manifestations

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Effective scalar/pseudosalar meson theory with μ_5

Generalized Σ model

Effective Lagrangian:

$$\mathcal{L} = \frac{1}{4}\mathrm{Tr}\left(D_\mu H D^\mu H^\dagger\right) + \frac{b}{2}\mathrm{Tr}\left[M(H+H^\dagger)\right] + \frac{M^2}{2}\mathrm{Tr}\left(HH^\dagger\right)$$
$$-\frac{\lambda_1}{2}\mathrm{Tr}\left[(HH^\dagger)^2\right] - \frac{\lambda_2}{4}\left[\mathrm{Tr}\left(HH^\dagger\right)\right]^2 + \frac{c}{2}(\det H + \det H^\dagger)$$
$$+\frac{d_1}{2}\mathrm{Tr}\left[M(HH^\dagger H + H^\dagger HH^\dagger)\right] + \frac{d_2}{2}\mathrm{Tr}\left[M(H+H^\dagger)\right]\mathrm{Tr}\left(HH^\dagger\right)$$

where

$$H = \xi\Sigma\xi, \quad \xi = \exp\left(i\frac{\Phi}{2f}\right), \quad \Phi = \lambda^a\phi^a, \quad \Sigma = \lambda^b\sigma^b.$$

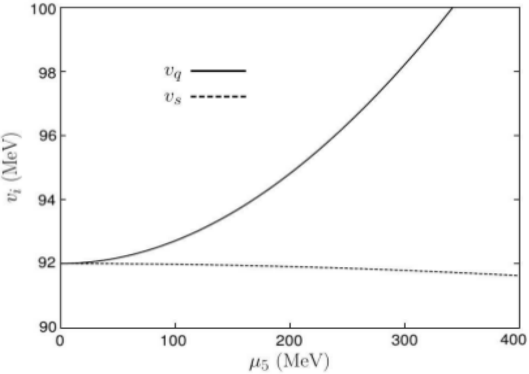
The v.e.v. of the neutral scalars are defined as $v_i = \langle\Sigma_{ii}\rangle$ where $i = u, d, s$, and satisfy the following gap equations:

$$M^2 v_i - 2\lambda_1 v_i^3 - \lambda_2 \vec{v}^2 v_i + c\frac{v_u v_d v_s}{v_i} = 0.$$

Effective scalar/pseudosalar meson theory with μ_5

Generalized Σ model

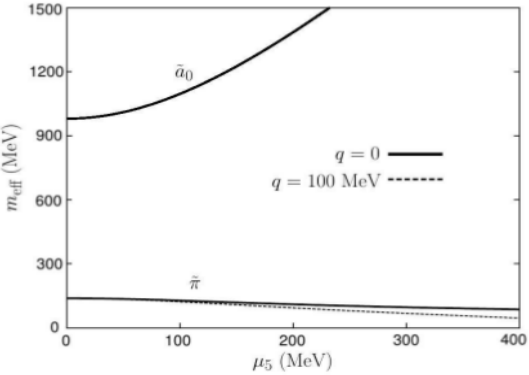
Vacuum: for non-vanishing isosinglet μ_5 we impose our solutions to be $v_u = v_d = v_q \neq v_s$.



Effective scalar/pseudosalar meson theory with μ_5

New eigenstates of strong interactions with LPB (isotriplet)

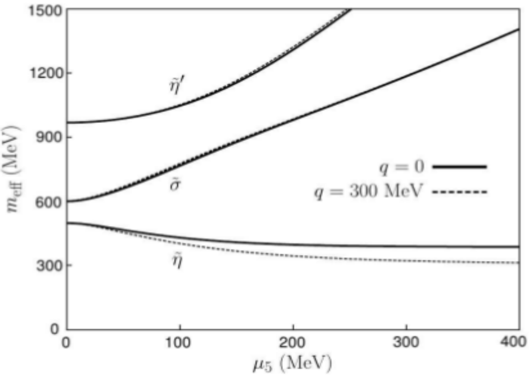
After diagonalization in the momentum representation, the new (momentum-dependent) eigenstates are defined $\tilde{\pi}$ and $\tilde{a}_0$.



Effective scalar/pseudosalar meson theory with μ_5

New eigenstates of strong interactions with LPB (isosinglet)

After diagonalization, the new eigenstates are $\tilde{\sigma}$, $\tilde{\eta}$ and $\tilde{\eta}'$.



Phase structure of the NJL quark model with μ_5

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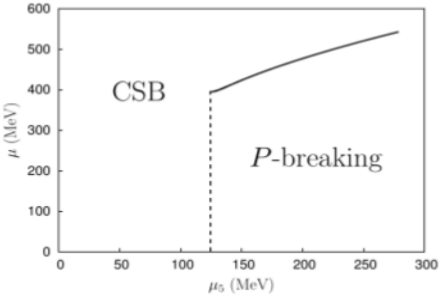

Transition line from the CSB to the P-breaking phase with $G_1 = -40/\Lambda^2$, $G_2 = -39.5/\Lambda^2$, $m = -5$ MeV and $\Lambda = 1$ GeV. The vertical dashed line is related to a 2nd order phase transition while the solid one corresponds to a 1st order one.

Quark–gluon plasma phenomenology from anisotropic lattice QCD

Jon-Ivar Skullerud

Collaborators:
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Simon Hands Tim Harris Aoife Kelly Dhagash Mehta
Maria-Paola Lombardo Seyong Kim Buğra Oktay Sinéad Ryan
Don Sinclair
+ Yannis Burnier Alexander Rothkopf

Maynooth University, FASTSUM

Confinement XI, St Petersburg, 8 Oct 2014

Lattice simulations

- QGP near crossover is strongly interacting: nonperturbative methods required
- Equilibrium thermal field theory formulated in euclidean space — suitable for Monte Carlo simulations

$$\langle \mathcal{O} \rangle = \int \mathcal{D}[\Phi]\mathcal{O}[\Phi]e^{-S[\Phi]}$$

- Temperature $T = \frac{1}{L_\tau} = (N_\tau a_\tau)^{-1}$
- Real-time quantities may be determined from spectral function

$$G_E(\tau; T) = \int_0^\infty d\omega K(\omega, \tau; T)\rho(\omega; T)$$

- 2+1 active light flavours required for quantitative predictions!

Dynamical anisotropic lattices

- A large number of points in time direction required to extract spectral information
- For $T = 2T_c$, $\mathcal{O}(10)$ points $\Longrightarrow a_t \sim 0.025$ fm
- Far too expensive with isotropic lattices $a_s = a_t$!
- Fixed-scale approach
  - $\rightarrow$ vary T by varying N_τ (not a)
  - $\rightarrow$ need only 1 $T = 0$ calculation for renormalisation
  - $\rightarrow$ independent handle on temperature

- Introduces 2 additional parameters
- Non-trivial tuning problem
  [PRD **74** 014505 (2006); HadSpec Collab, PRD **79** 034502 (2009)]

Transport coefficients

Transport coefficients can be related to spectral functions through Kubo relations

$$\kappa = c_\kappa \lim_{\omega \to 0} \frac{\rho(\omega)}{\omega}$$

$\rho(\omega)$ is the spectral function of the relevant conserved current. Conductivity and diffusion coefficients are both determined from the vector current correlator

$$G_{ij}(\tau, \vec{p}) = \int d^3x e^{i\vec{p}\cdot\vec{x}} \langle V_i(\tau, \vec{x}) V_j(0, \vec{0}) \rangle$$

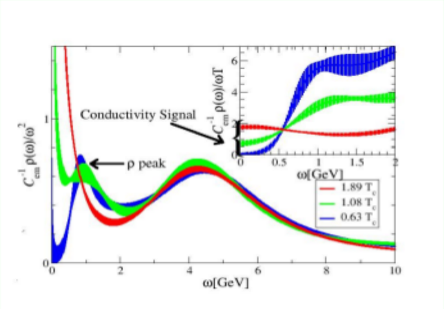
- Sensitive to long-distance, nearly constant modes
- Very high precision data required
- Model function must allow $\rho(\omega)/\omega$ finite as $\omega \to 0$

Conductivity

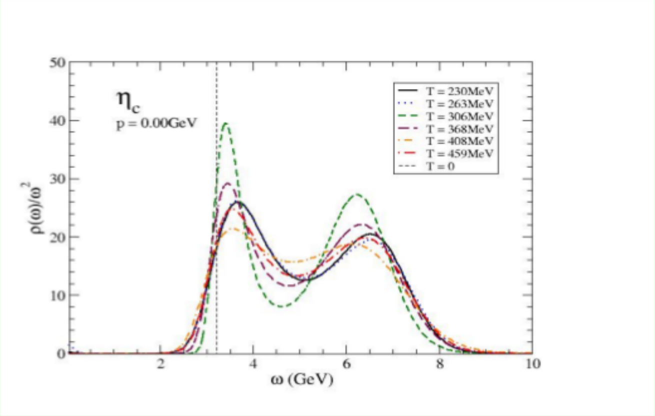
[PRL **111** 172001 (2013)] — 2nd generation

$$\sigma = \lim_{\omega \to 0} \frac{\rho_{ii}^{em}(\omega)}{6\omega}$$

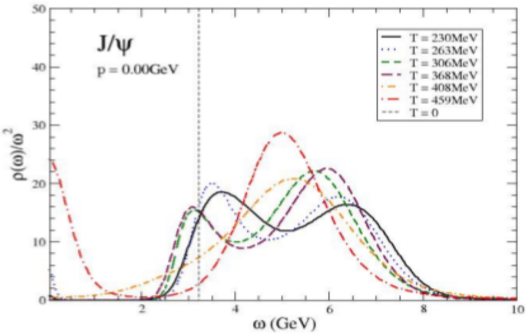
Used conserved vector current: no renormalisation required



S-wave T dependence (η_c)

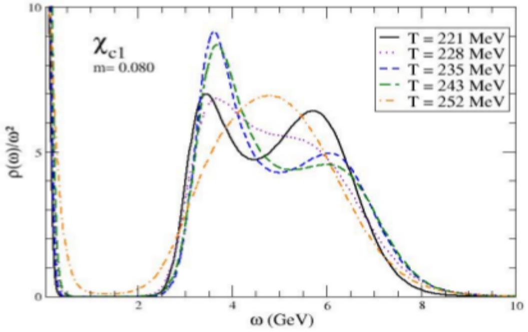


S-wave T dependence (J/ψ)



J/ψ (S-wave) melts at $T \sim 370 - 400$ MeV or $1.7 - 1.9\,T_c$?

P-waves

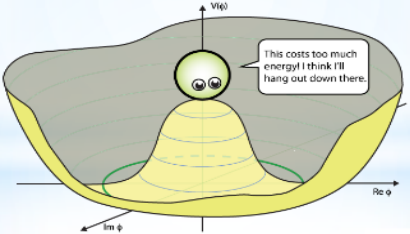


P-waves melt at $T < 250$ MeV or $1.2T_c$?

Summary

- Anisotropic lattices provide a wealth of information on QGP phenomenology
- Conductivity increasing with T across the transition
- Charge diffusion has dip near T_c
- Charmonium S-waves survive to $T \sim 1.6 - 2T_c$
- P-waves melt at $T < 1.3T_c$
- Significant momentum dependence in reconstructed corrs
- Charmonium potential is screened at high T

Spontaneous chiral symmetry breaking and chiral magnetic effect in Weyl semimetals [1408.4573]

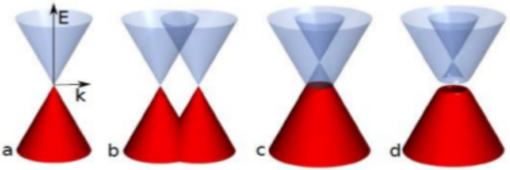


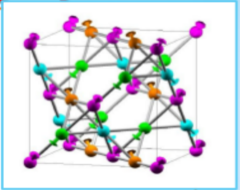
Pavel Buividovich
(Uni Regensburg)

Unterstützt von / Supported by
Alexander von Humboldt
Stiftung/Foundation

Confinement XI, 8-12 September 2014, St Petersburg

Weyl semimetals: 3D graphene





[Pyrochlore iridate]

- Take Dirac semi-metal/topological insulator
- Break $\mathcal{T}$ime reversal (e.g. magnetic doping) $\delta_H \sim \vec{b}\cdot\vec{\Sigma}$, $\vec{\Sigma}$ is the spin operator
- Break $\mathcal{P}$arity (e.g. chiral pumping) $\delta H \sim \gamma_5 \mu_A$
- $\Rightarrow$ Weyl fermions split, Dirac point $\Rightarrow$ Weyl points
- Broken $\mathcal{T}$: spatial shift, broken $\mathcal{P}$: energy shift

No mass term for Weyl fermions →

Weyl points survive ChSB!!!

Anomalous (*P/T*-odd) transport

Momentum shift of Weyl points:
Anomalous Hall Effect

$$\vec{j} = \frac{e^2}{2\pi^2}\vec{b} \times \vec{E}$$

Energy shift of Weyl points:
Chiral Magnetic Effect

$$\vec{j} = \frac{e^2}{2\pi^2}\mu_A \vec{B}$$

Also: Chiral Vortical Effect, Axial Magnetic Effect...

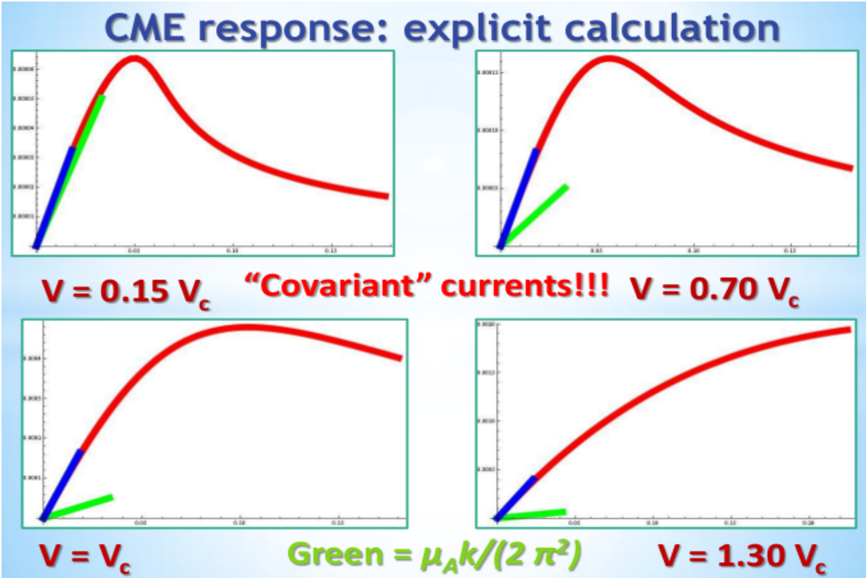
Chiral Magnetic Conductivity and Kubo relations

$$\Pi_{ij}\left(\vec{k}\right) = \langle\, j_i\left(\vec{k}\right) j_j\left(-\vec{k}\right)\rangle = \frac{\delta^2 \mathcal{Z}}{\delta A_i(\vec{k})\,\delta A_j(-\vec{k})}$$

$$\sigma_{CME} = \lim_{k_3 \to 0}\lim_{k_0 \to 0} \frac{i}{k_z}\Pi_{xy}\left(k_z\right)$$

~~MEM~~

Static correlators ➡ **Ground-state transport!!!**


CME response: explicit calculation
V = 0.15 V_c
"Covariant" currents!!!
V = 0.70 V_c
V = V_c
Green = μ_A k/(2 π^2)
V = 1.30 V_c

Thank you for your attention!!!