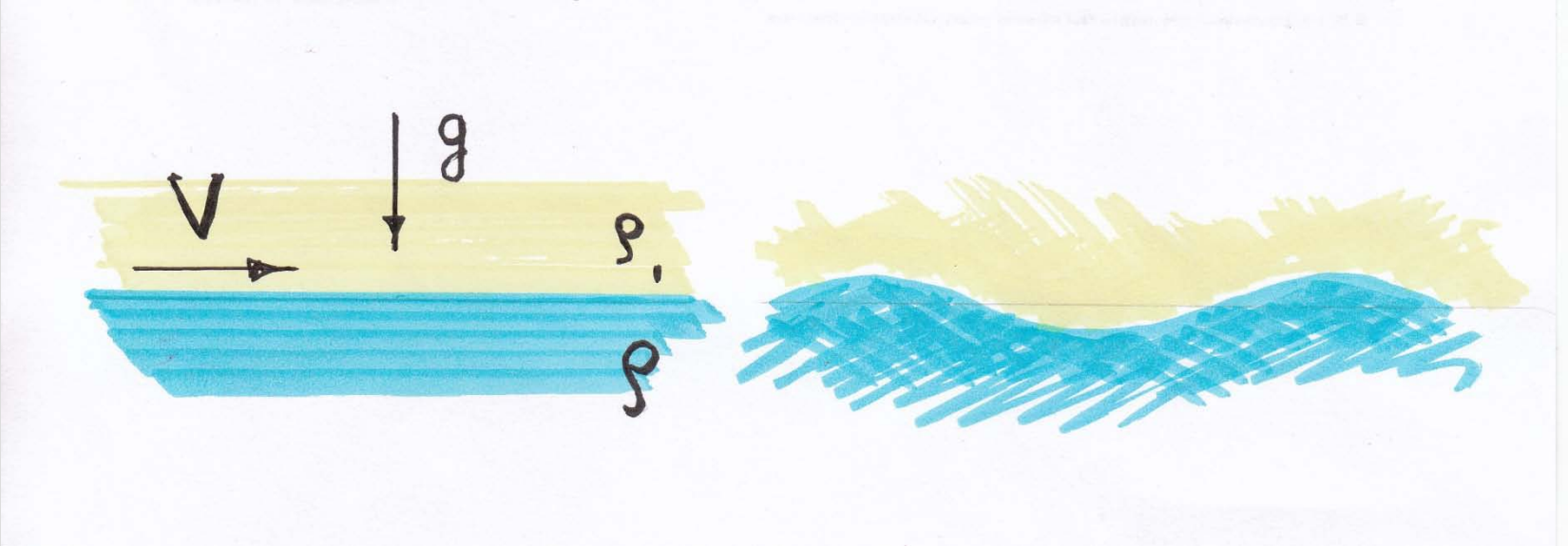
Instability and periodic reconstruction of the vapor-liquid interface

V.Shikin, ISSP, RAS

Outline.

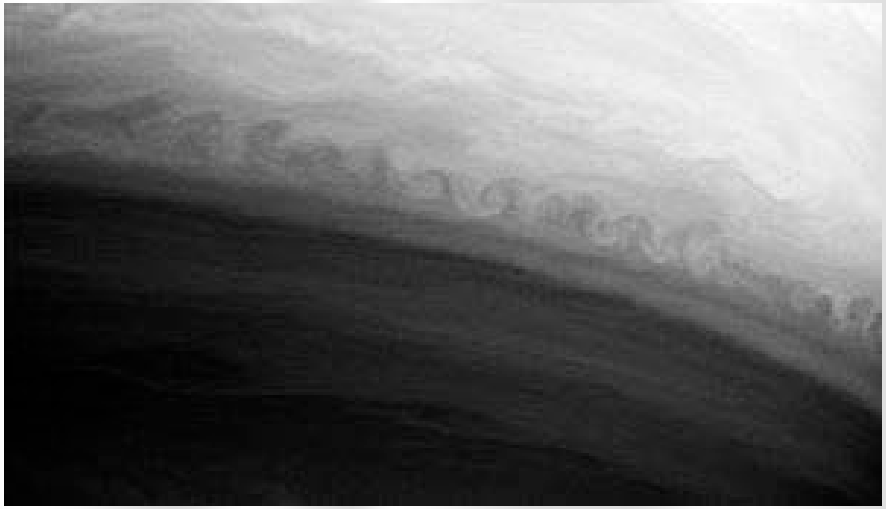
- 1. Conventional instabilities
- 2. Self-limited instabilities
- 3. Resume

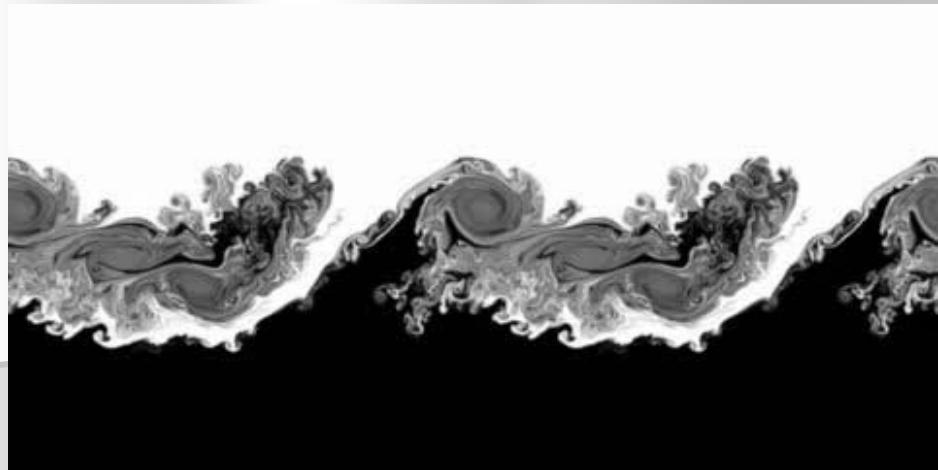
Kelvin-Helmholtz instability

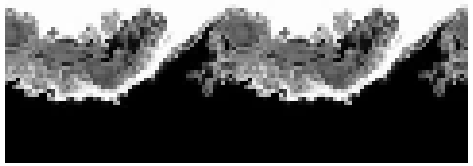


$$\omega = k\frac{\rho_1 V}{(\rho+\rho_1)} \pm \left[\frac{kg(\rho-\rho_1)}{(\rho+\rho_1)} - \frac{k^2\rho\rho_1 V^2}{(\rho+\rho_1)^2} + \frac{\alpha k^3}{(\rho+\rho_1)}\right]^{1/2}$$

$$V^4 \leq \frac{4\alpha g(\rho-\rho_1)(\rho+\rho_1)^2}{\rho^2\rho_1^2}$$







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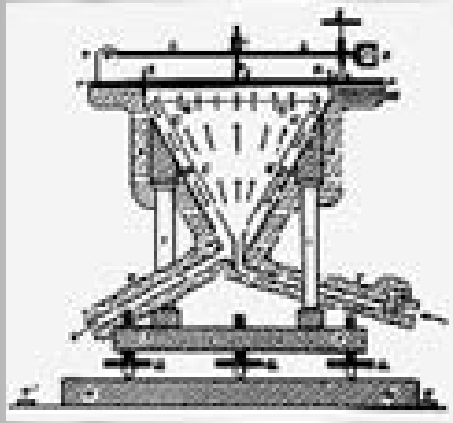
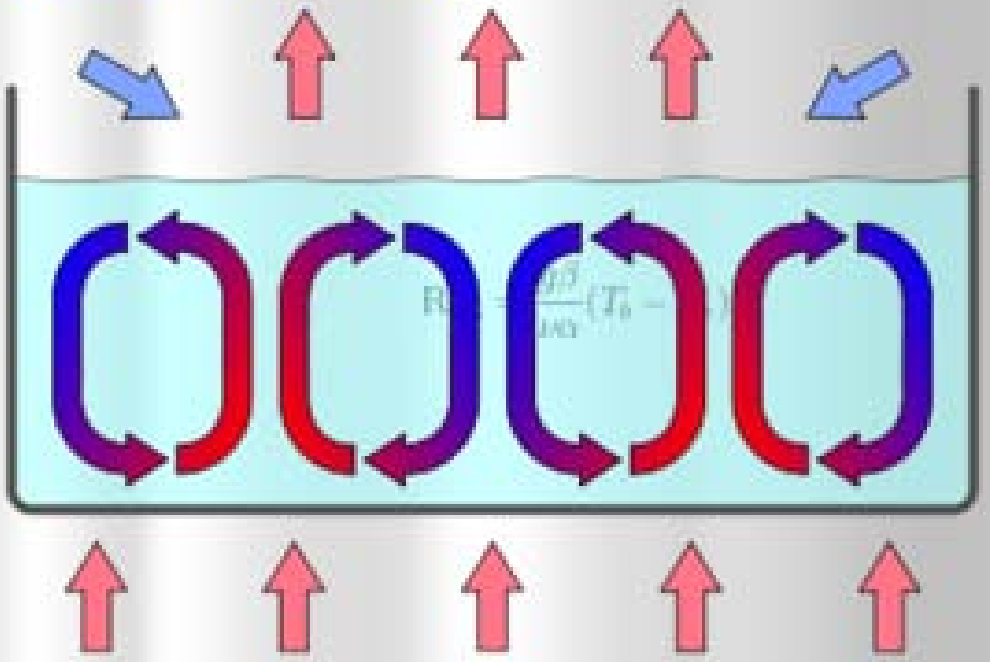
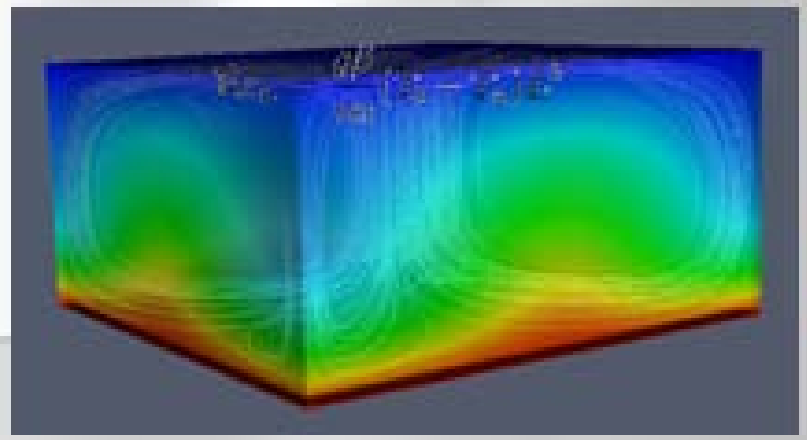
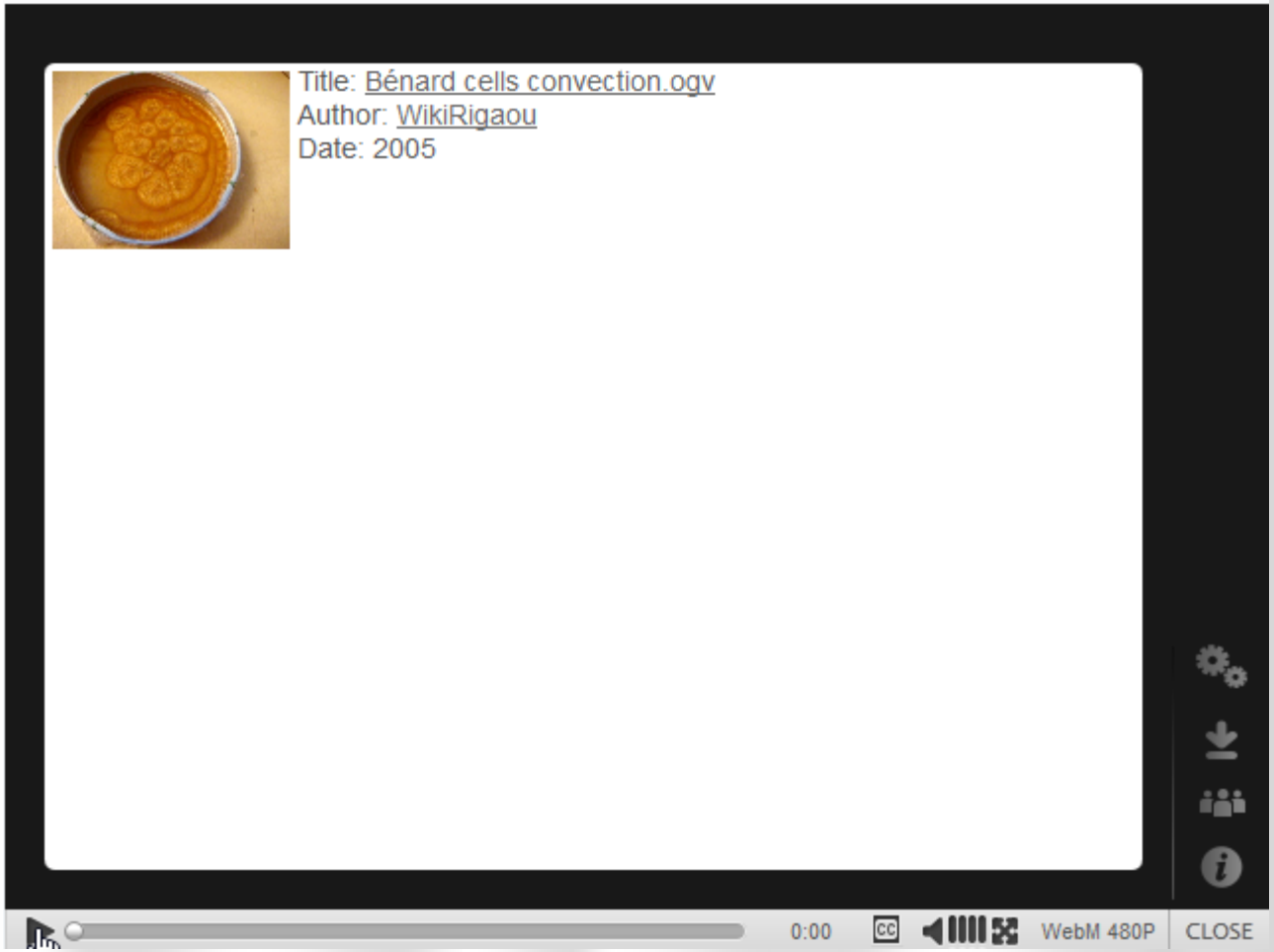


Benard instability



$$\mathrm{Ra}_L = \frac{g\beta}{\nu\alpha}(T_b - T_u)L^3$$

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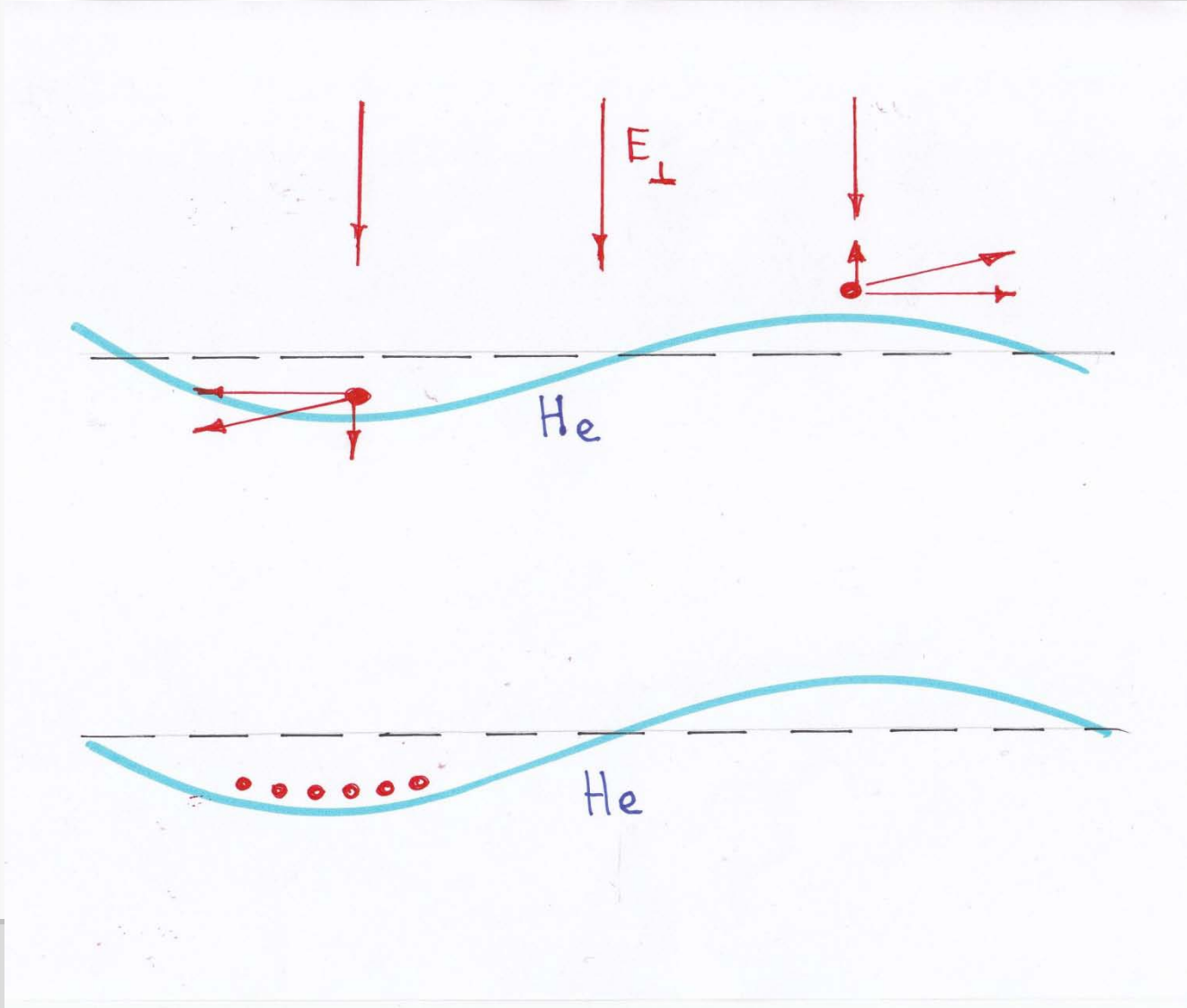
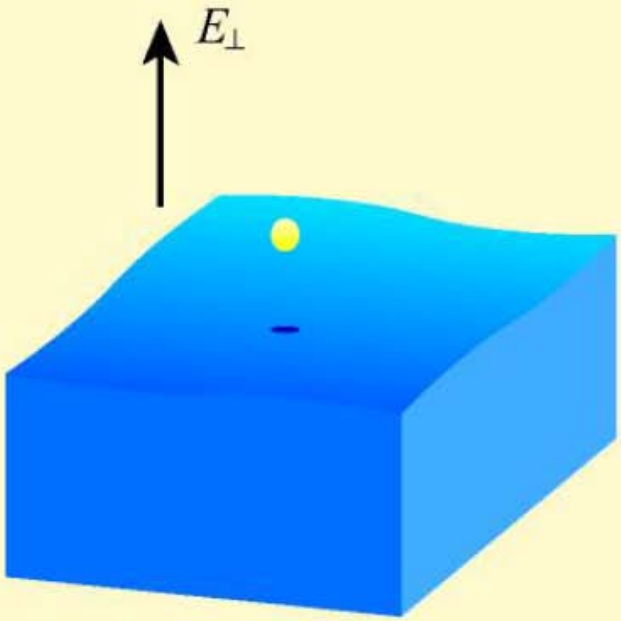
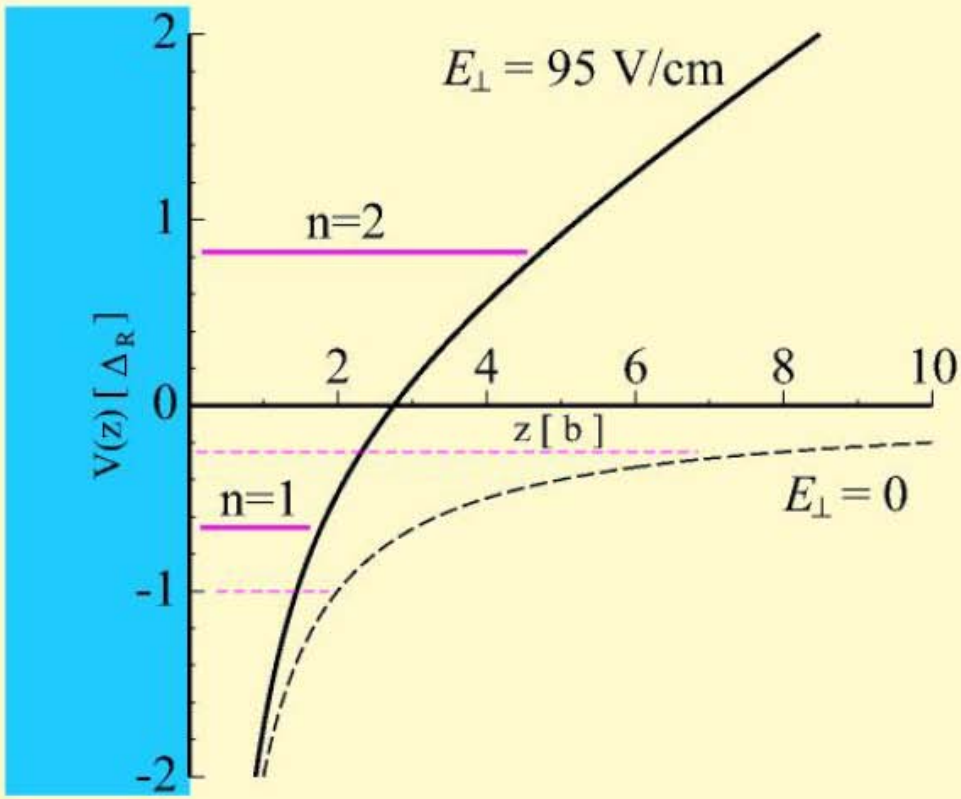
Self-limited instability for charged helium surface.



Surface states



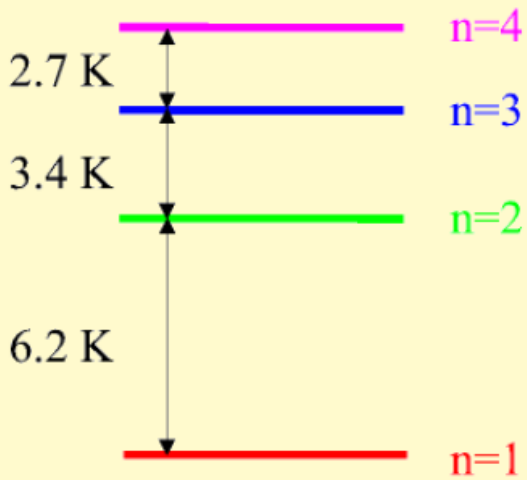


$$V(z) = -\frac{\Lambda e^2}{z} + eE_\perp z$$

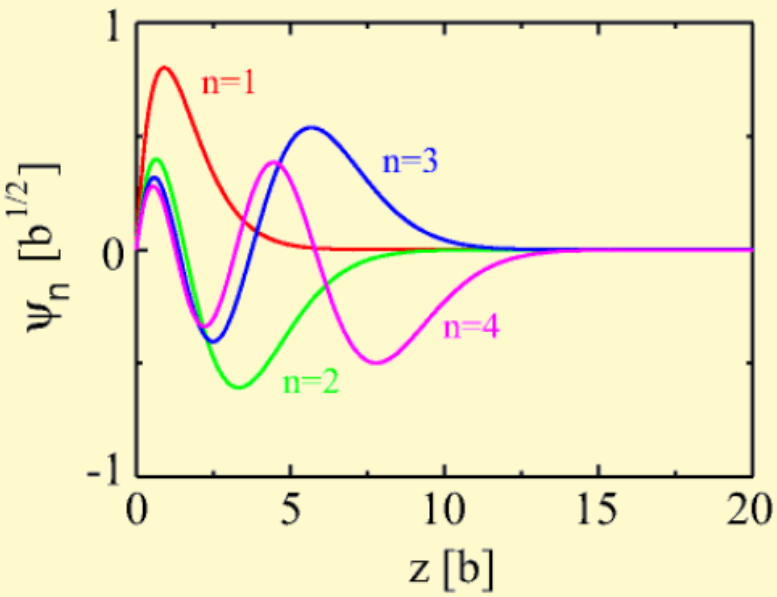
$$\Lambda = \frac{\epsilon - 1}{4(\epsilon + 1)}$$

Wave functions

$$\left[-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial z^2} - \frac{\Lambda e^2}{z} + eE_\perp z\right]\psi_n(z) = \epsilon_n \psi_n(z)$$

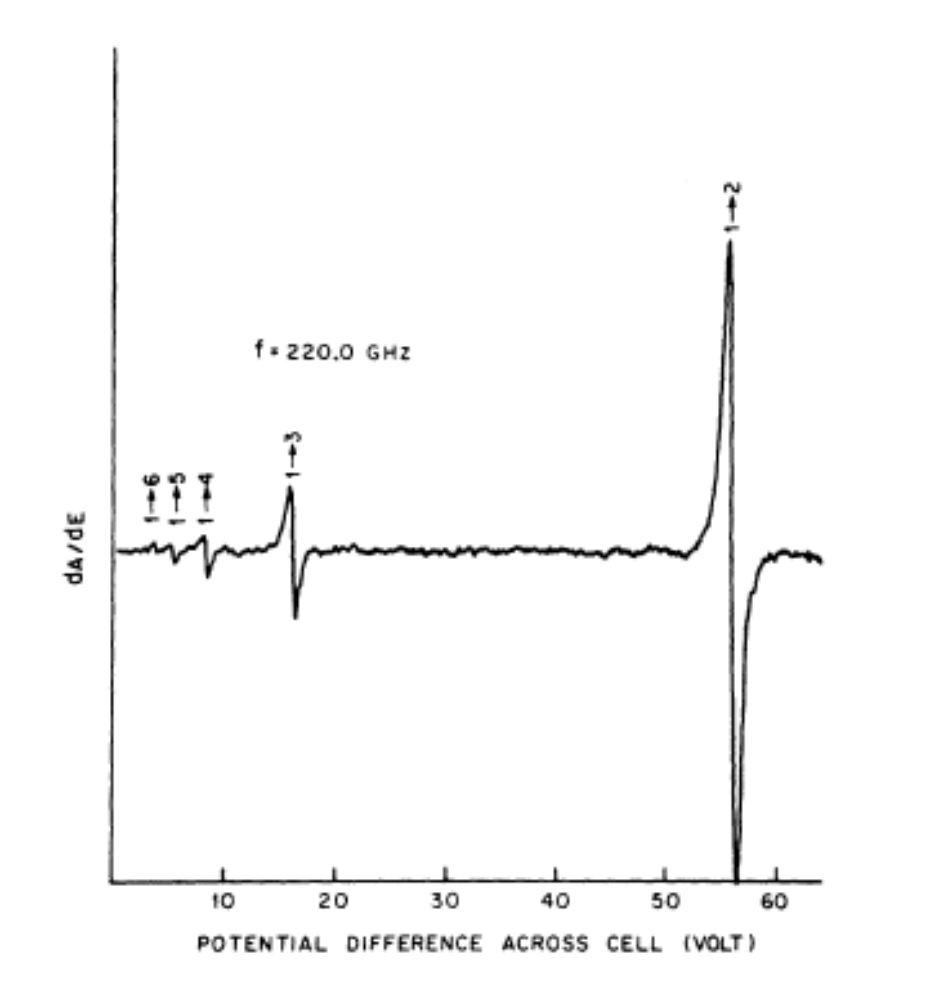


$E_\perp$= 95 V/cm

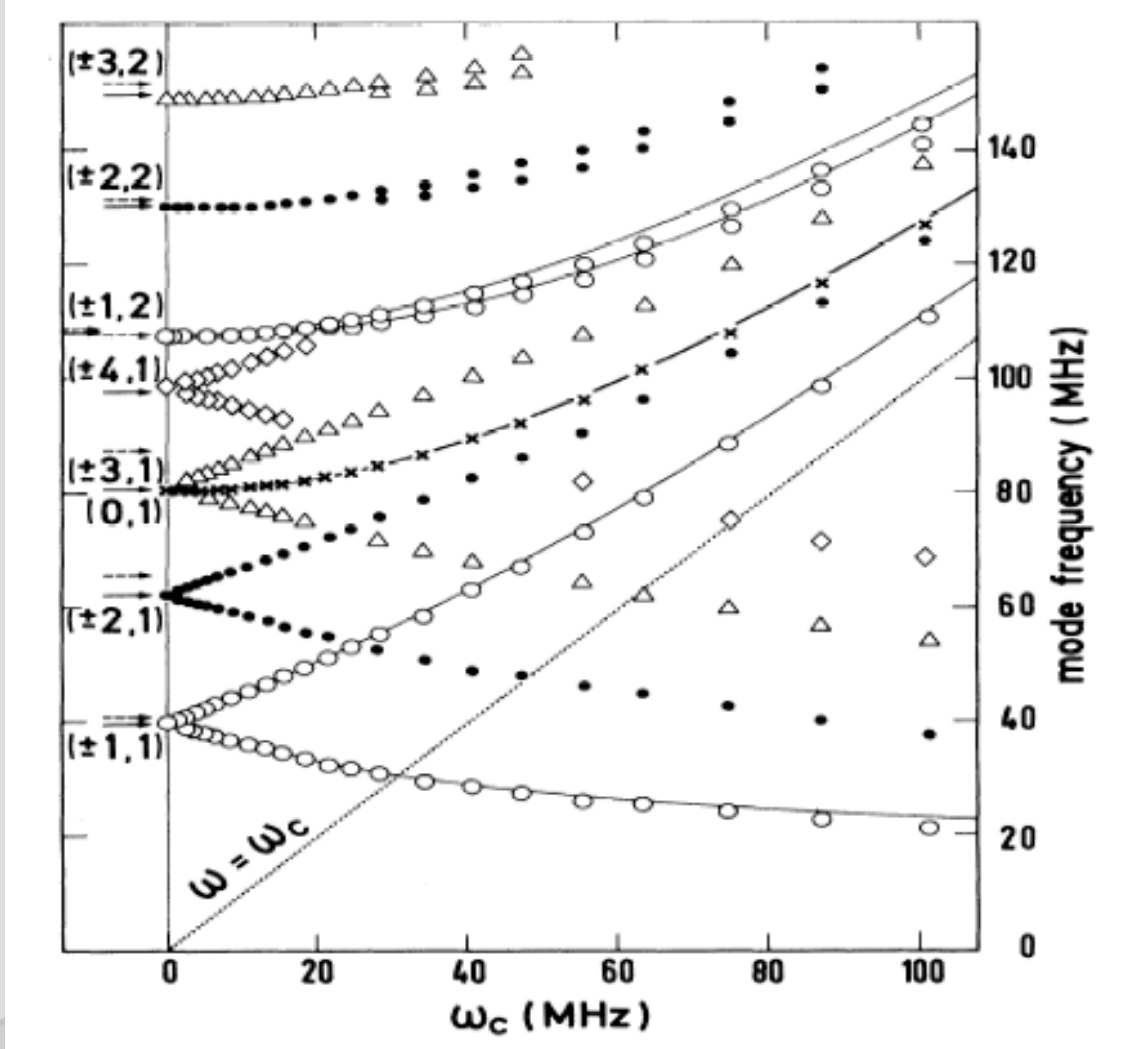


Spectroscopy of electrons in image-potential–induced surface states outside liquid helium

C. C. Grimes, T. R. Brown, Michael L. Burns, and C. L. Zipfel
Bell Laboratories, Murray Hill, New Jersey 07974
(Received 4 August 1975)



Magnetoplasmons



Phonon-Ripplon Coupling and the Two-Dimensional Electron Solid on a Liquid-Helium Surface

Daniel S. Fisher and B. I. Halperin

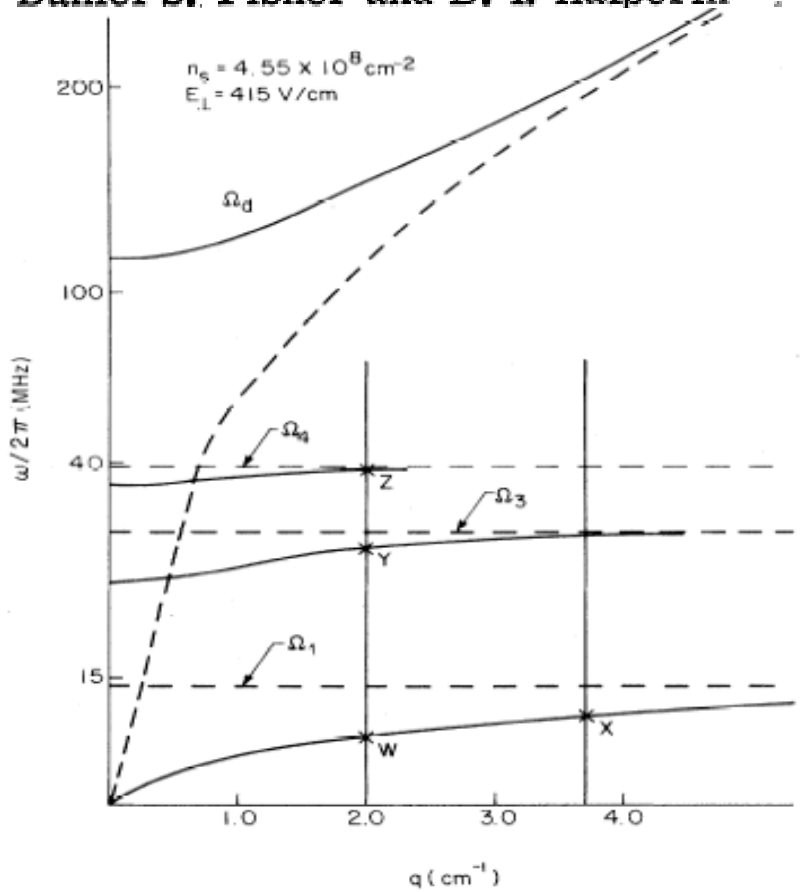


FIG. 1. Schematic of the dispersion relation of the longtitudinal coupled modes (solid curves). The dashed lines show the uncoupled mode spectra and the vertical lines represent the wave vectors excited in the experiment. The resonances are labeled as in Ref. 3.

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Evidence for a Liquid-to-Crystal Phase Transition in a Classical, Two-Dimensional Sheet of Electrons

C. C. Grimes and G. Adams
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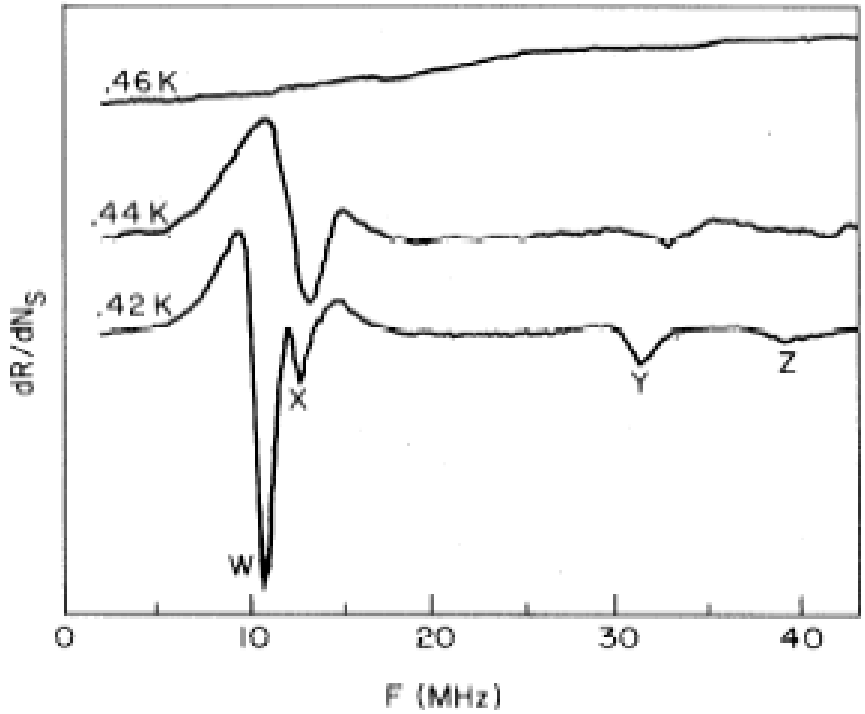

FIG. 1. Experimental traces displaying the sudden appearance with decreasing temperature of coupled plasmon-ripplon resonances. The resonances only appear below 0.457 K where the sheet of electrons has crystallized into a triangular lattice.

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Phase diagrame

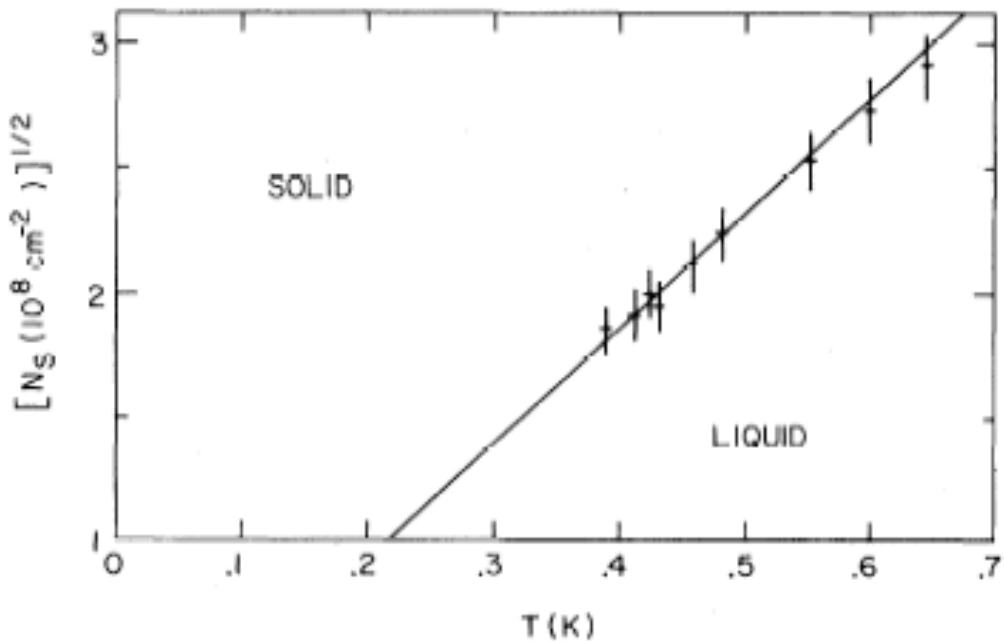


FIG. 2. Portion of the solid-liquid phase boundary for a classical, two-dimensional sheet of electrons. The data points denote the melting temperatures measured at various values of the electron areal density, N_s. Along the line, the quantity Γ, which is a measure of the ratio of potential energy to kinetic energy per electron, is 137.

Dispersion law and exp data for a charged helium surface

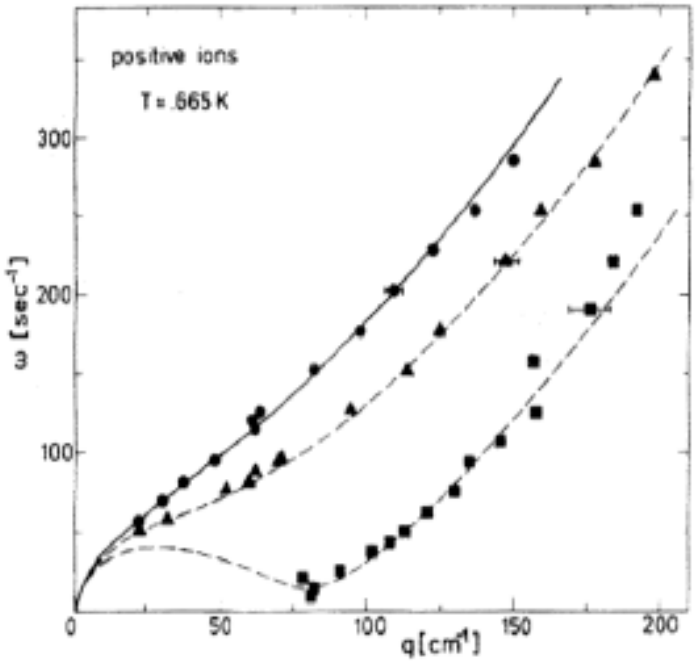
$$\omega^2 = \frac{k}{\rho}\left[\rho g + \alpha k^2 - k\frac{E_+^2 + E_-^2}{4\pi}\right]$$

$$\omega(k) = 0, \quad \frac{\partial \omega^2}{\partial k} = 0.$$

$$\kappa^2 = \frac{\rho g}{\alpha}$$

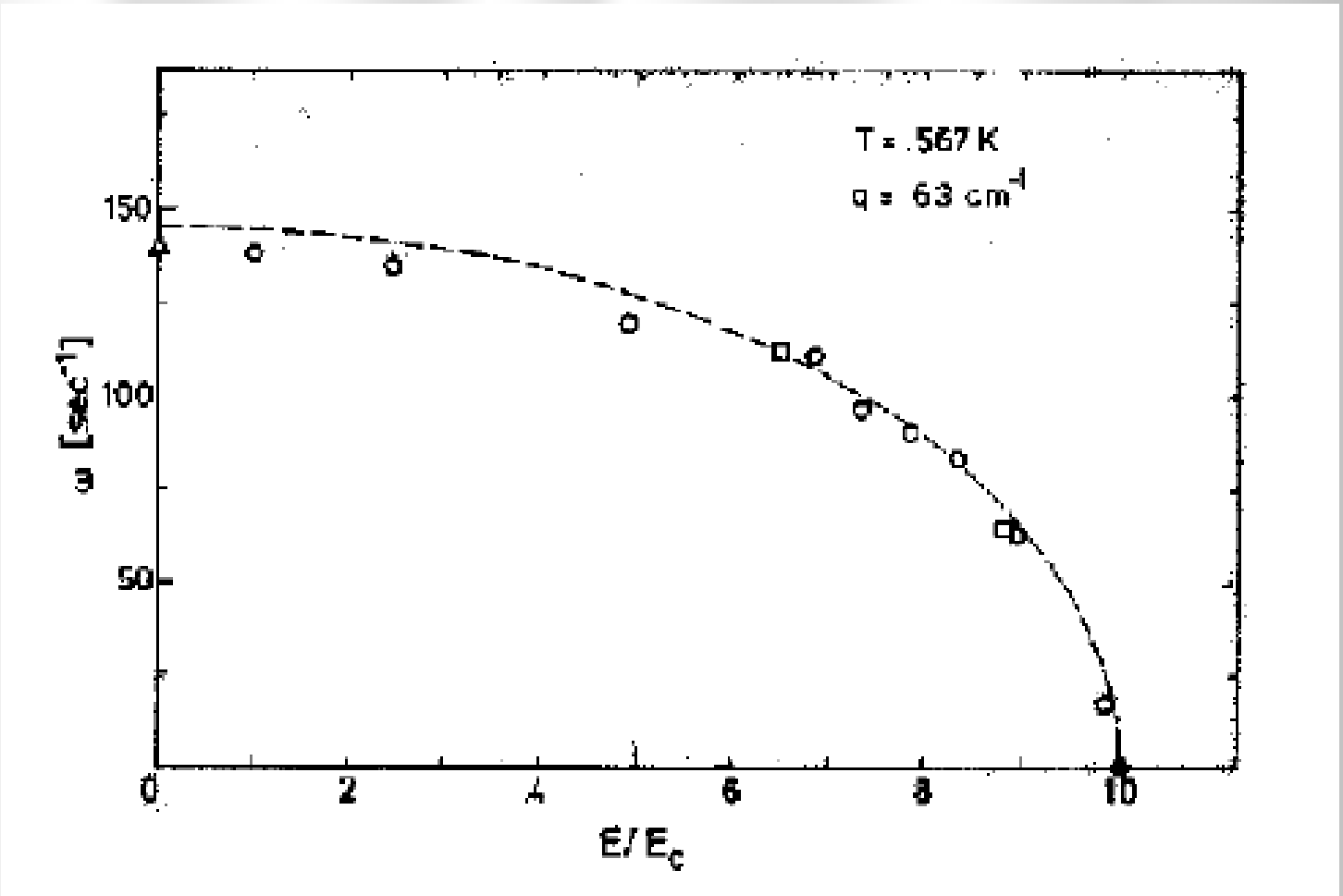
$$(n_s^{max})^2 = \frac{\kappa\alpha}{2\pi e^2}$$

$$E_+^{max} = 4\pi e n_s^{max}$$



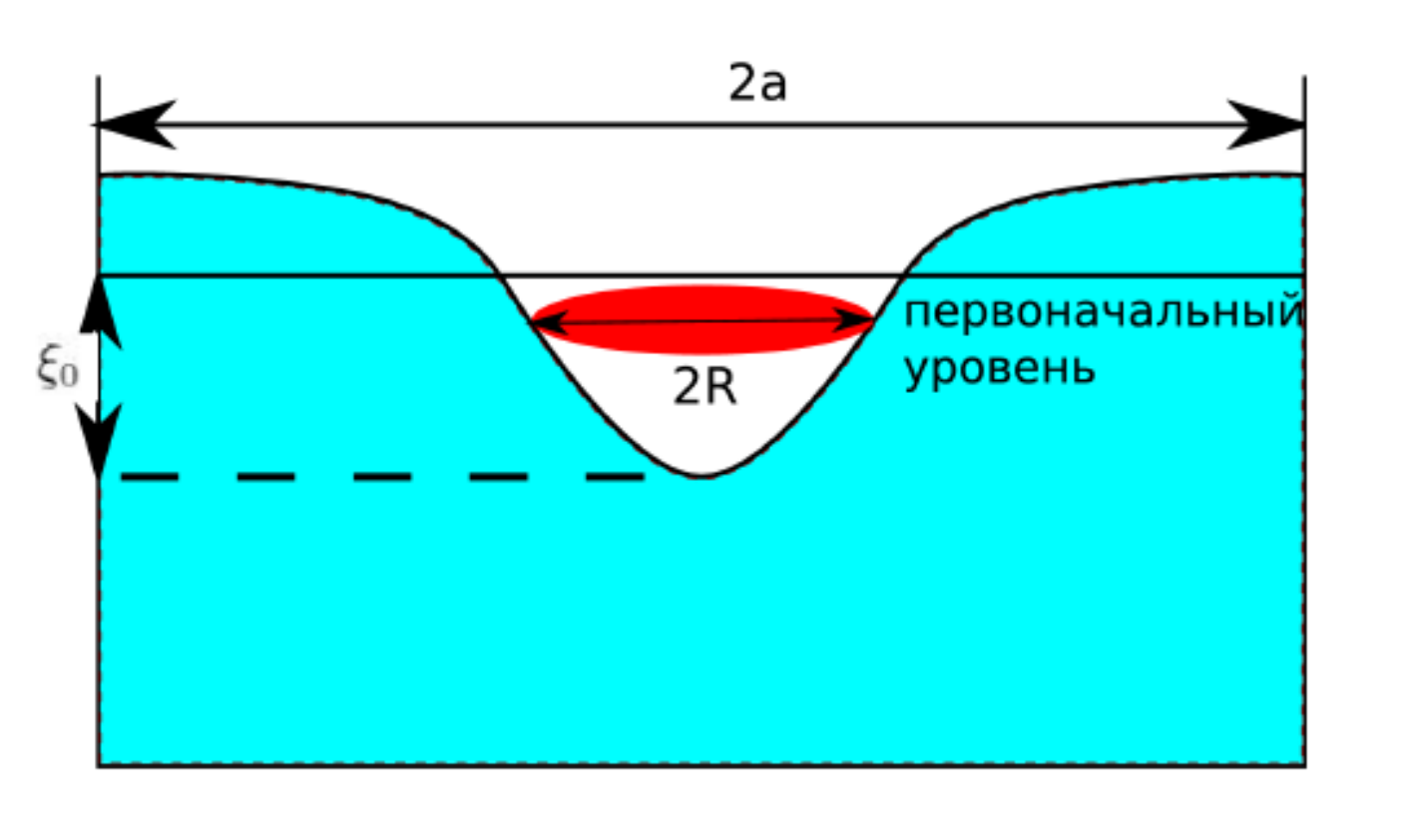
Закон дисперсии риплонов на поверхности раздела фаз He^{3}-He^{4}; пунктирные линии - теория, эксперимент - данные для E/E_{c}= 0.12, 0.71, 0.99.

Dispersion law minimum versus pressing electric field



Interferograme of charged helium surface just below and above critical field

Individual multi electron dimple

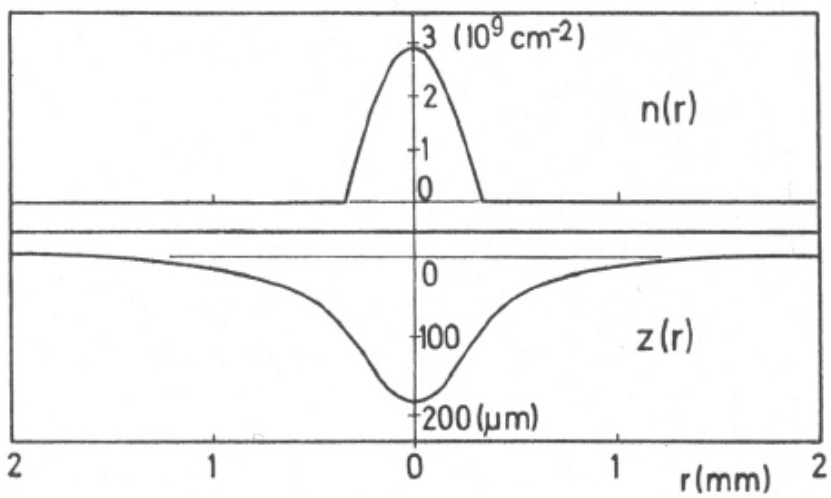


Total charged dimple energy

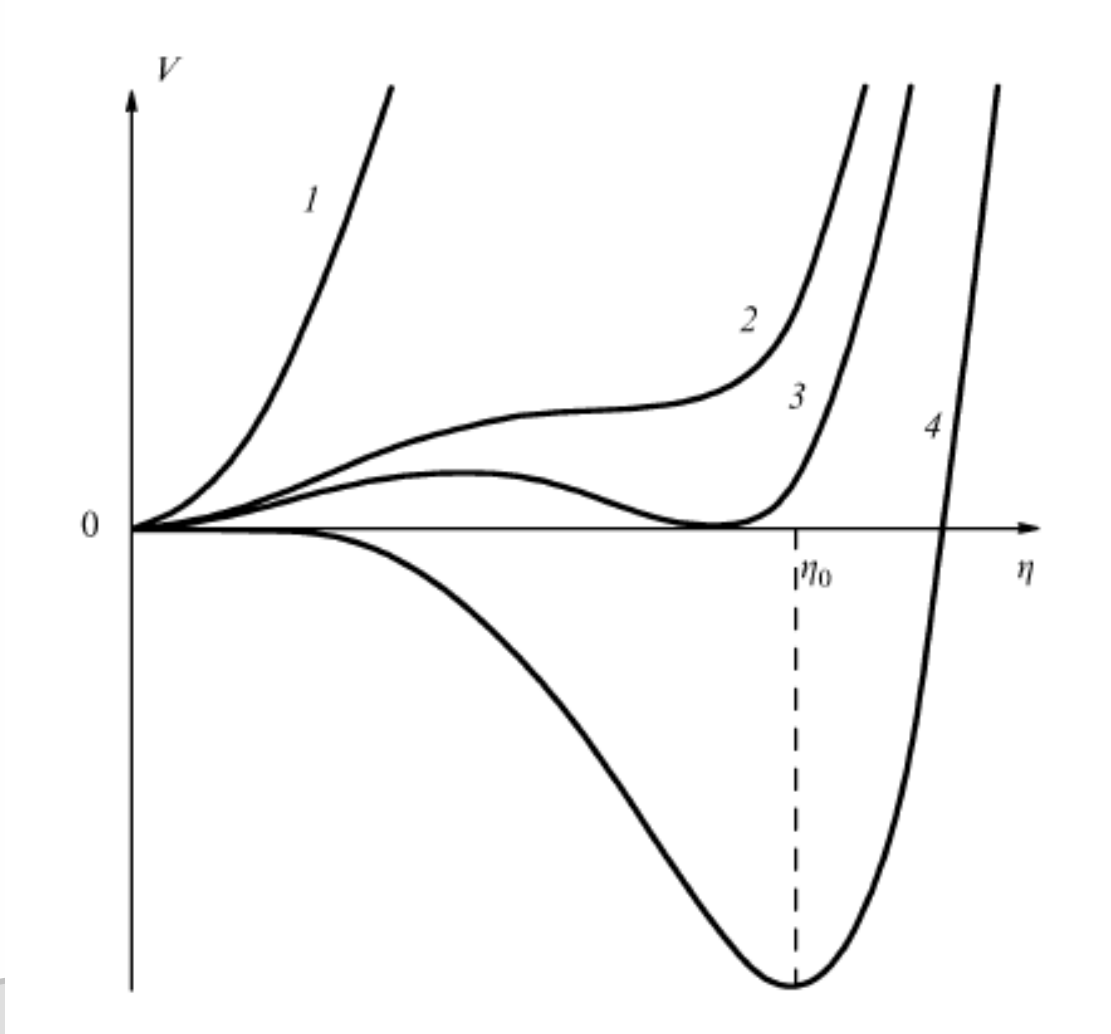
$$W = \int d^2r \left[\frac{\alpha}{2}[(\nabla\xi)^2 + \kappa^2\xi^2] + eE_\perp n(r)\xi + e^2 \int d^2r' \frac{n(r)n(r')}{|r - r'|} \right]$$

$$W = \frac{Q^2 E_\perp^2}{8\pi\alpha} \exp\left(\frac{\kappa^2 R^2}{2}\right) Ei\left(-\frac{\kappa^2 R^2}{2}\right) + V_c(R).$$

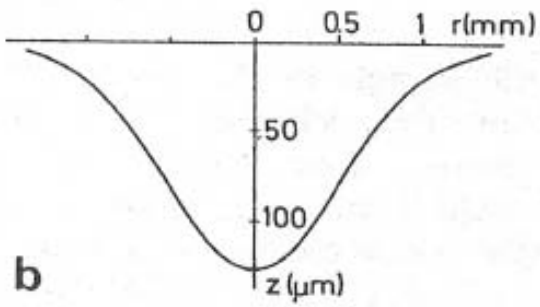
$$n(r) = \frac{N}{\pi R^2} \exp\left(-\frac{r^2}{R^2}\right) \qquad V_c(R) = C_0 Q^2/R,$$

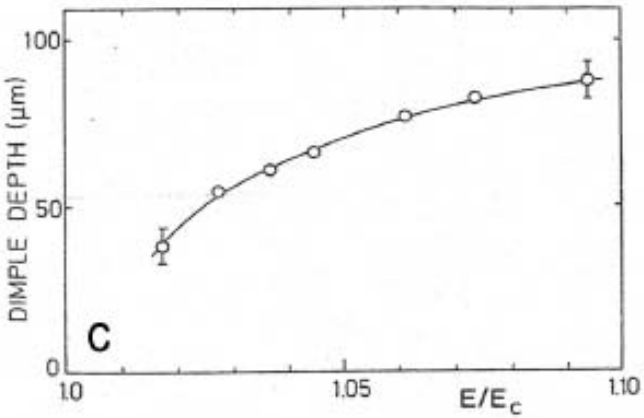


Total multi electron dimple energy W versus of core radius R for different pressing electric fields

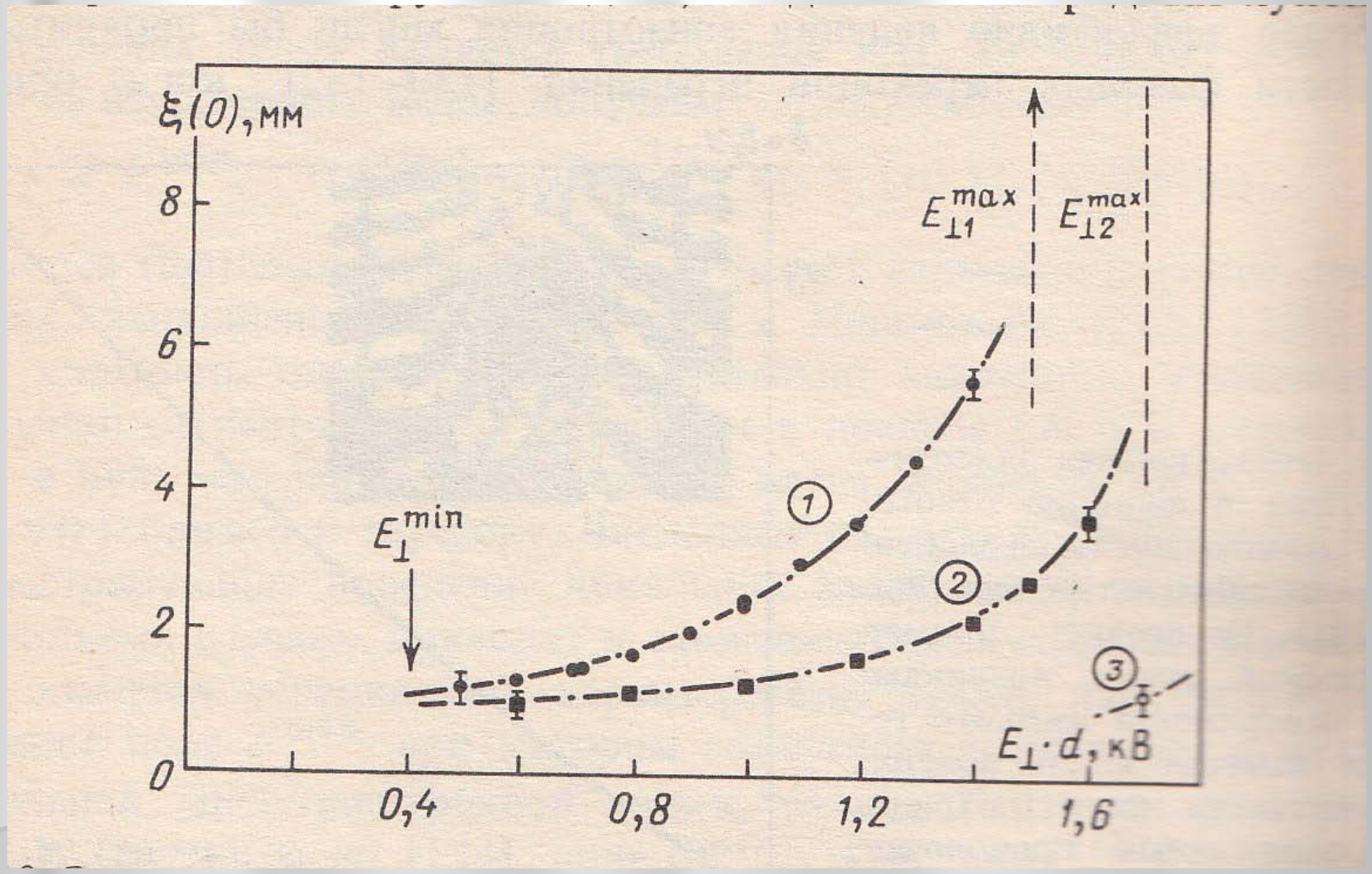


Single multielectron dimple profile

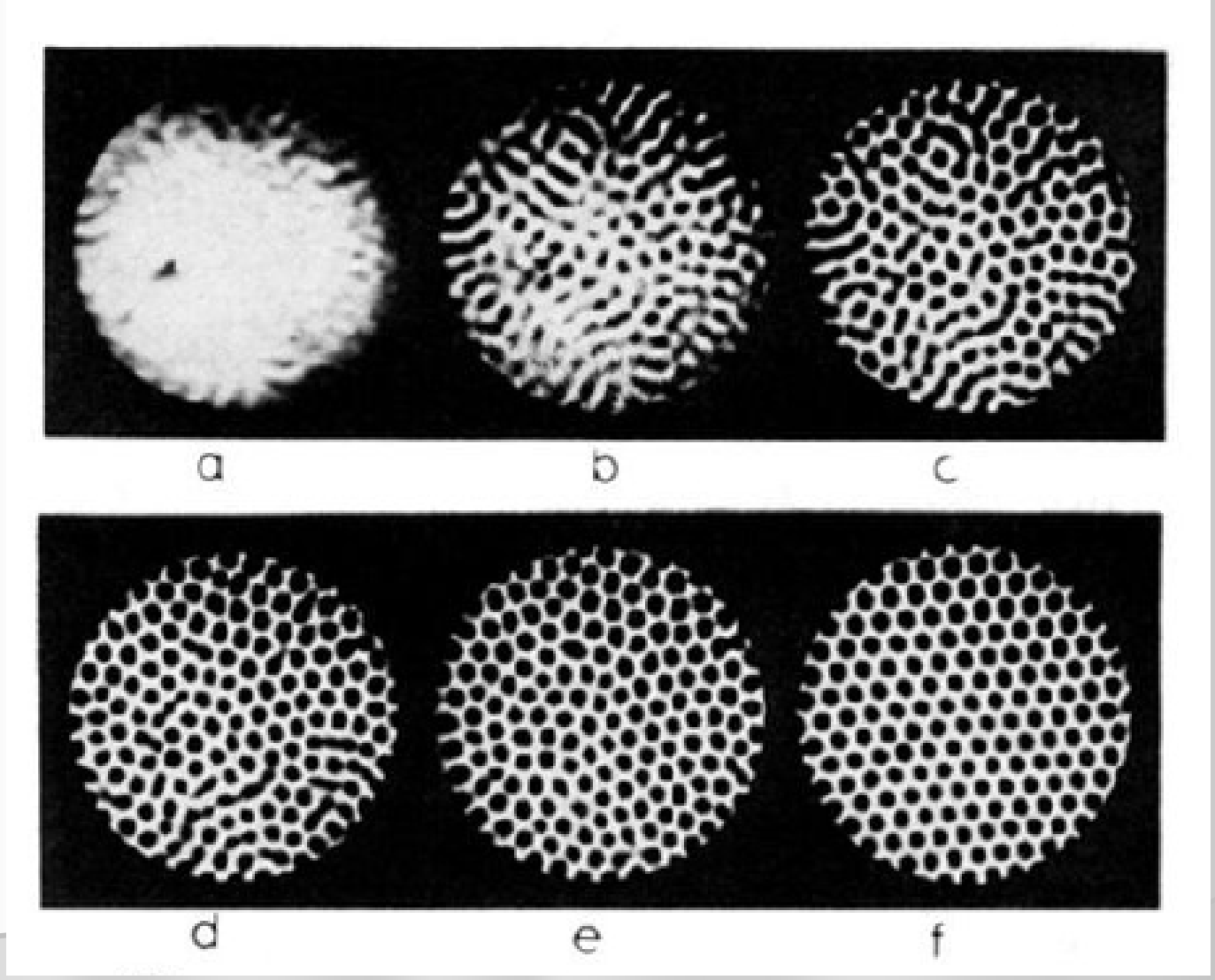




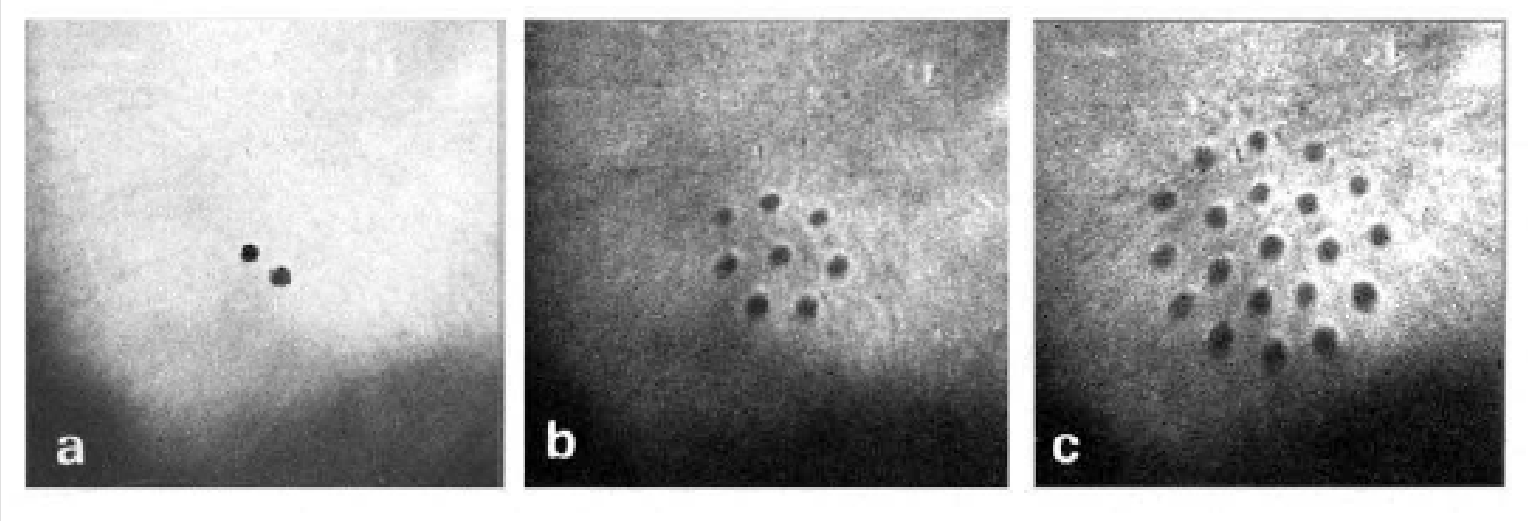
Dimple depth versus E_{perp}



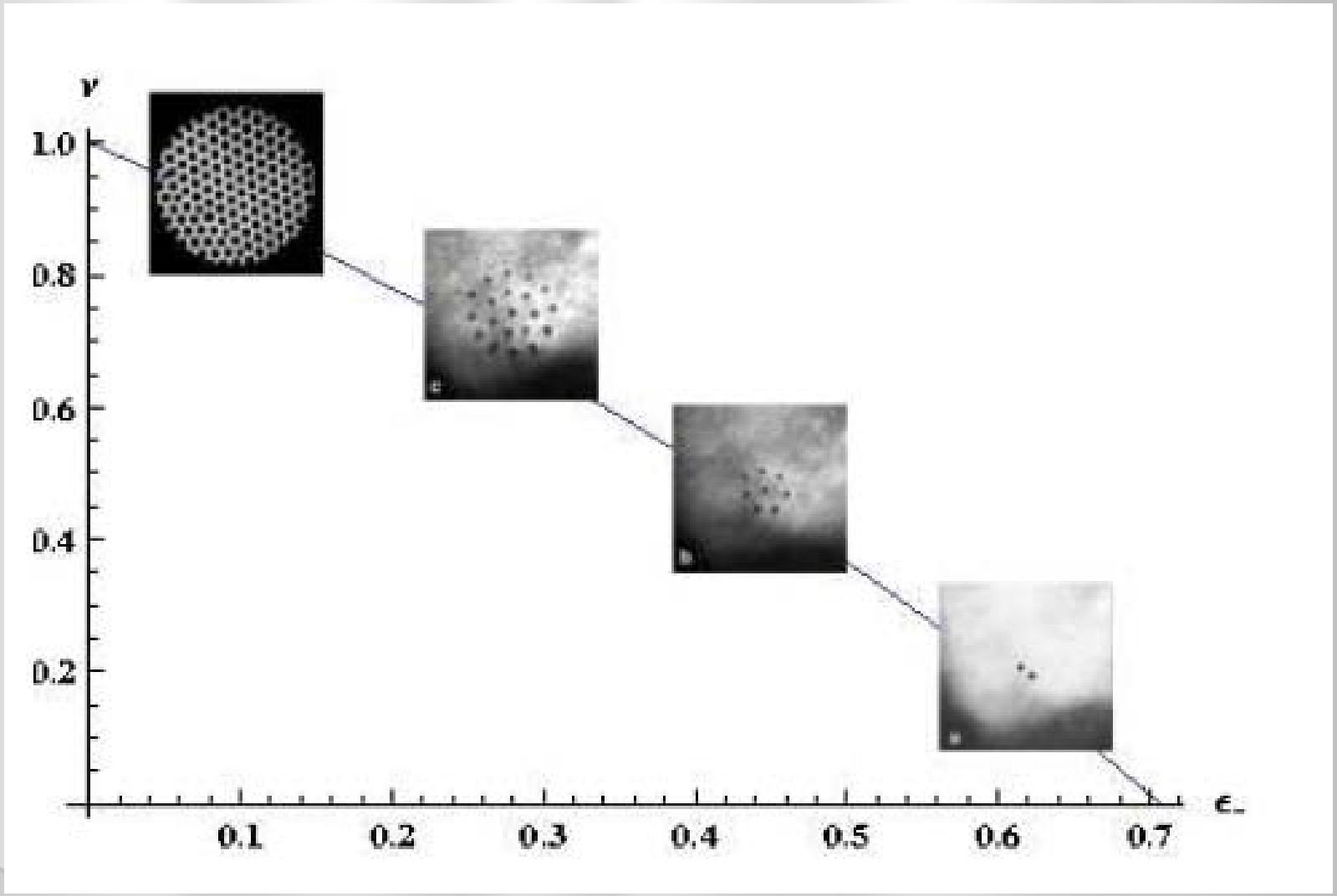
Time evolution of corrugated state



Dimple “company” versus filling factor



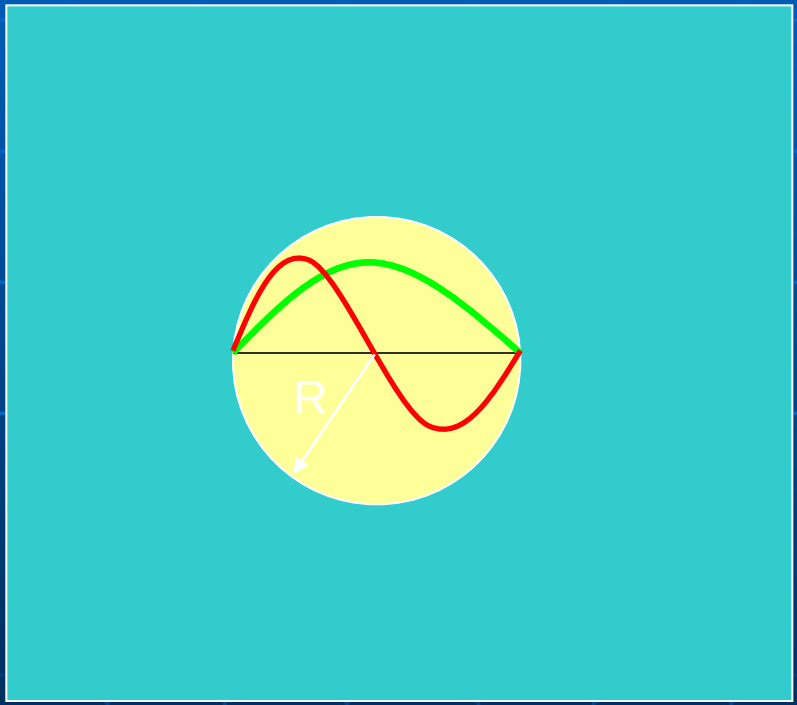
Общая фазовая диаграмма



Resume.

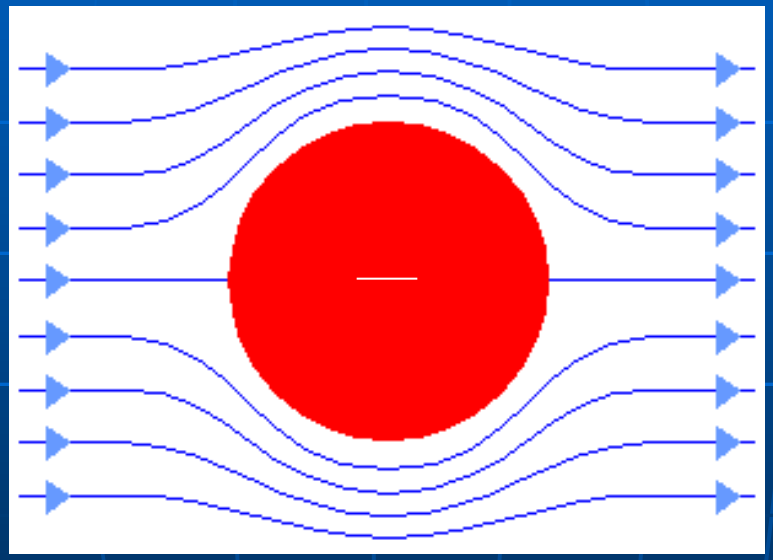
- 1. Instability of the charged helium surface is really self-limited.
- 2. There are some additional quite impressive examples of self-limited instability.

Single electron bubble wave function



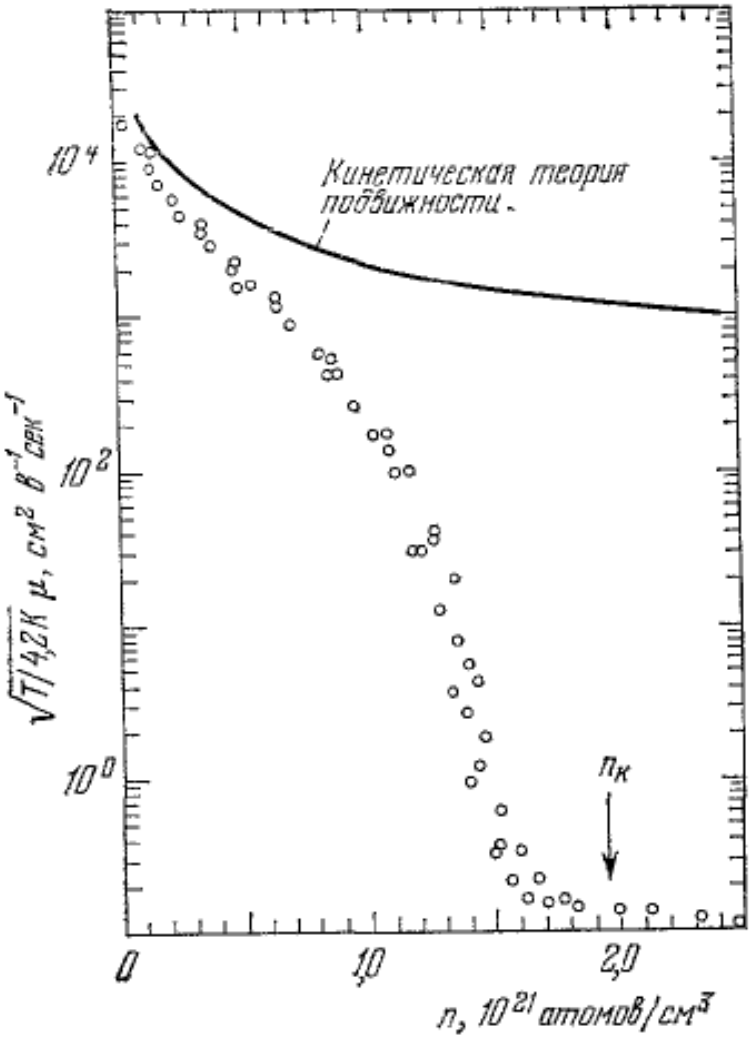
Single electron bubble geometry

$$R_e \simeq 17A$$

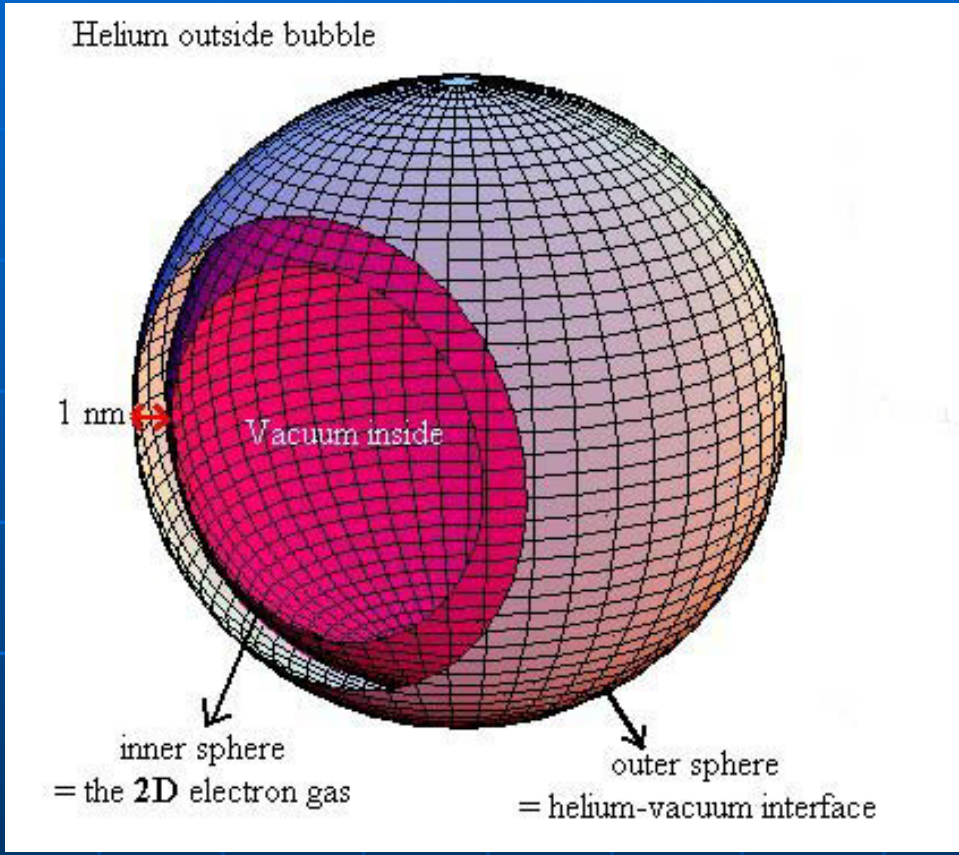


$$M_{ass} = \frac{2}{3}\pi R_e^3 \rho_l \simeq 200 m_4$$

Free electron mobility versus of helium gas density



Individual multi electron bubble

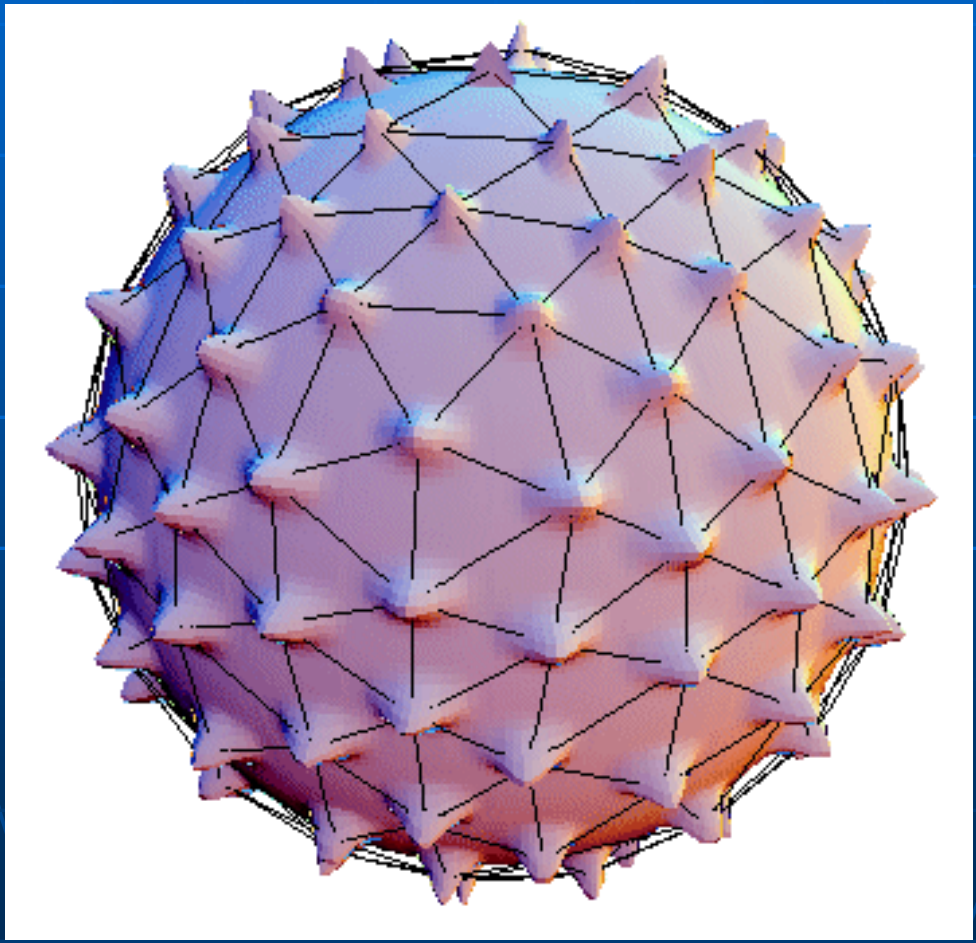


$$W = \frac{Q^2}{R} + 4\pi R^2 \sigma$$

$$\frac{\partial W}{\partial R} = 0 \quad \text{или} \quad R^3 = \frac{Q^2}{8\pi\sigma}$$

Такой bubble неустойчив ?

Multi-bubble in presence of Coulomb crystallisation



Set-up for multi bubbles preparation

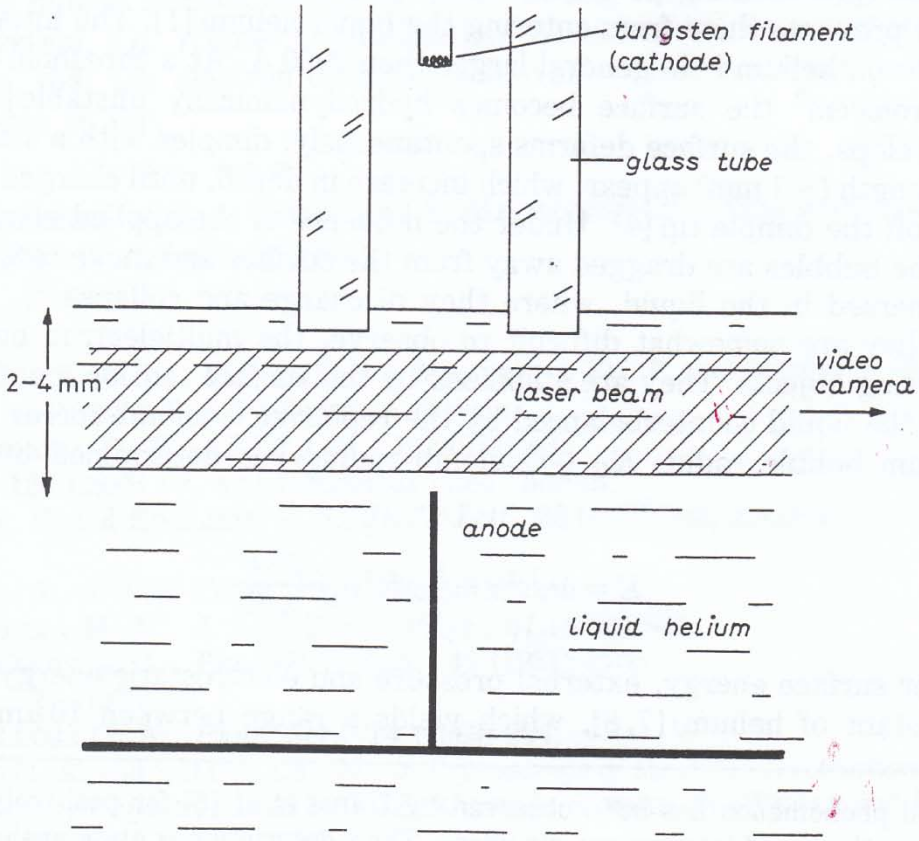
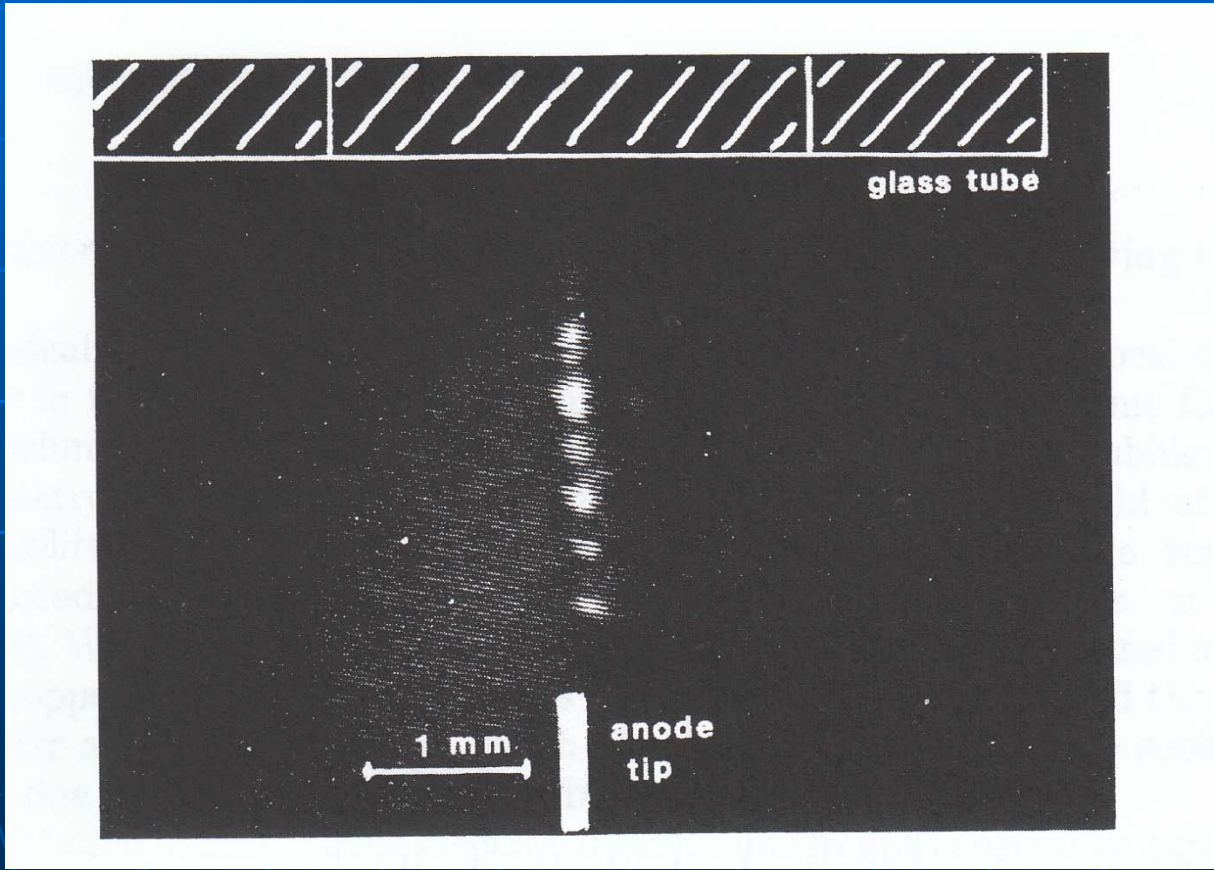
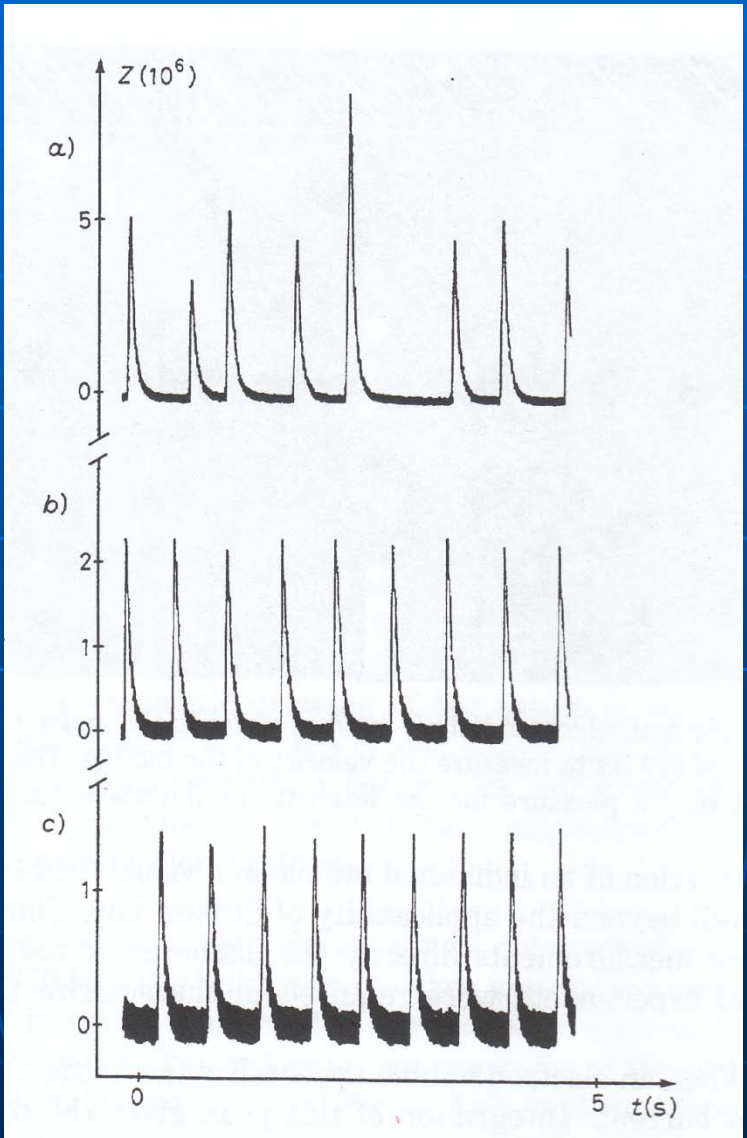


Fig. 1. – Schematic set-up of the experiment.

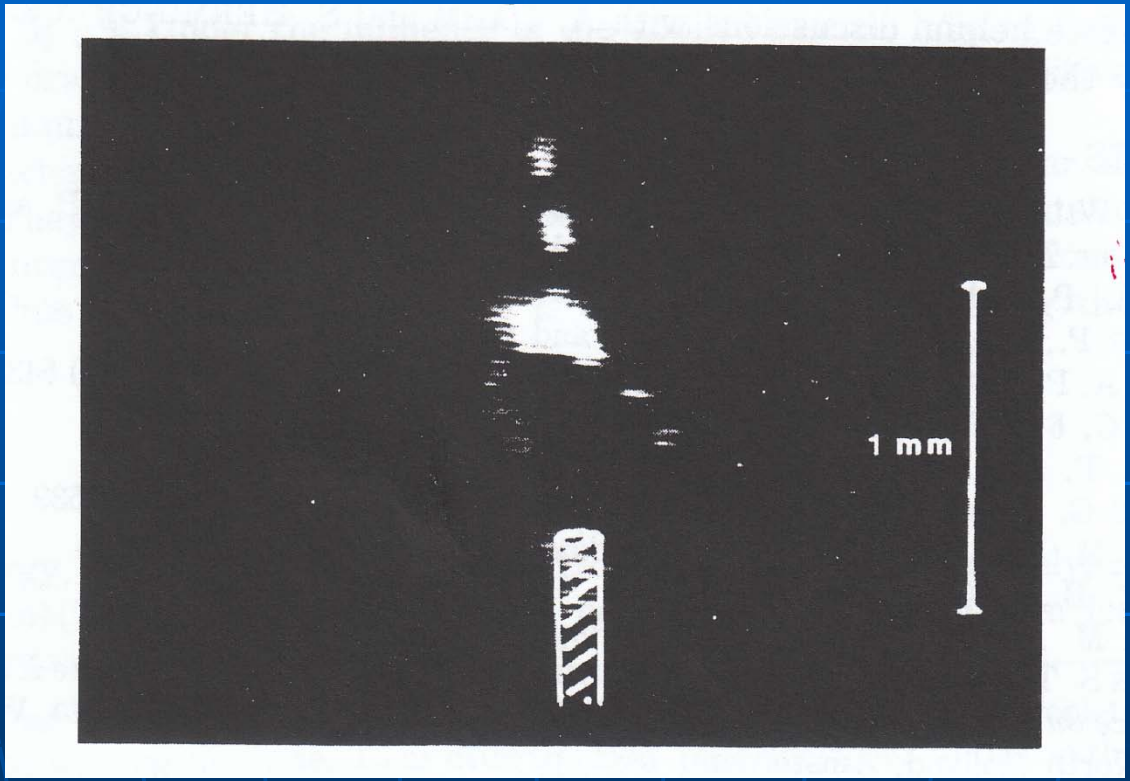
Multi bubble visible picture



Anode current peaks from the bubbles



Instability phenomena



Charged vortexes rings

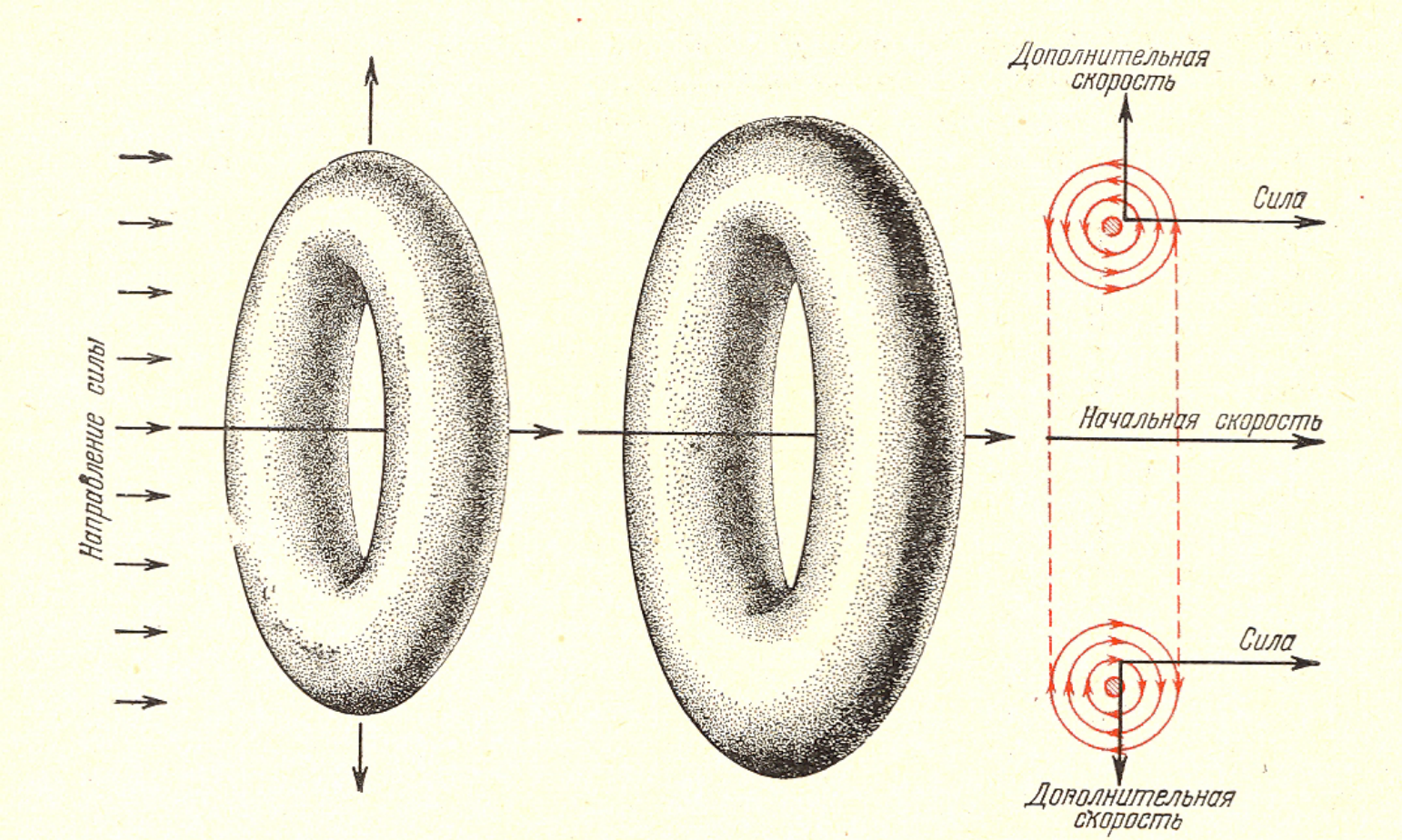
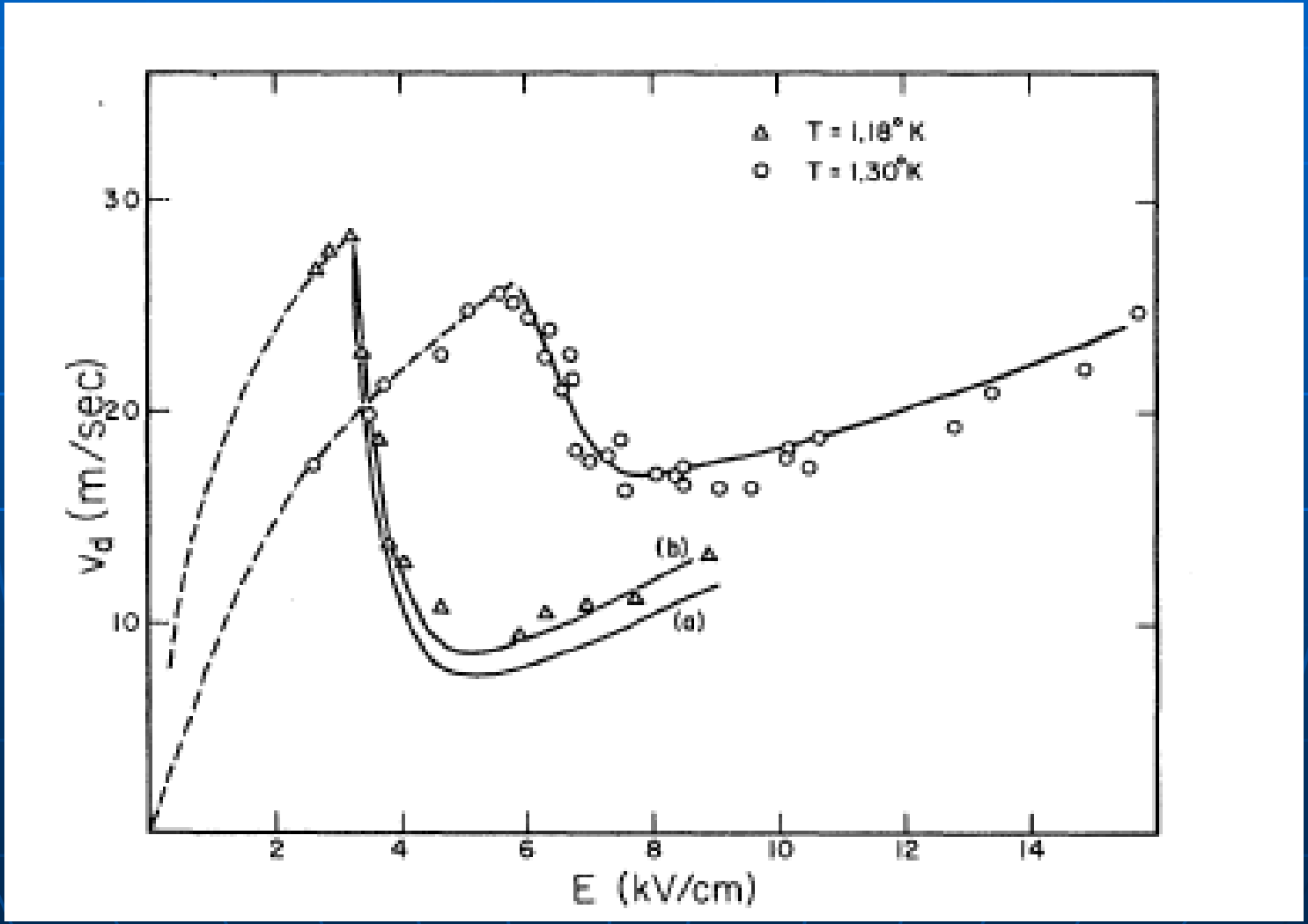
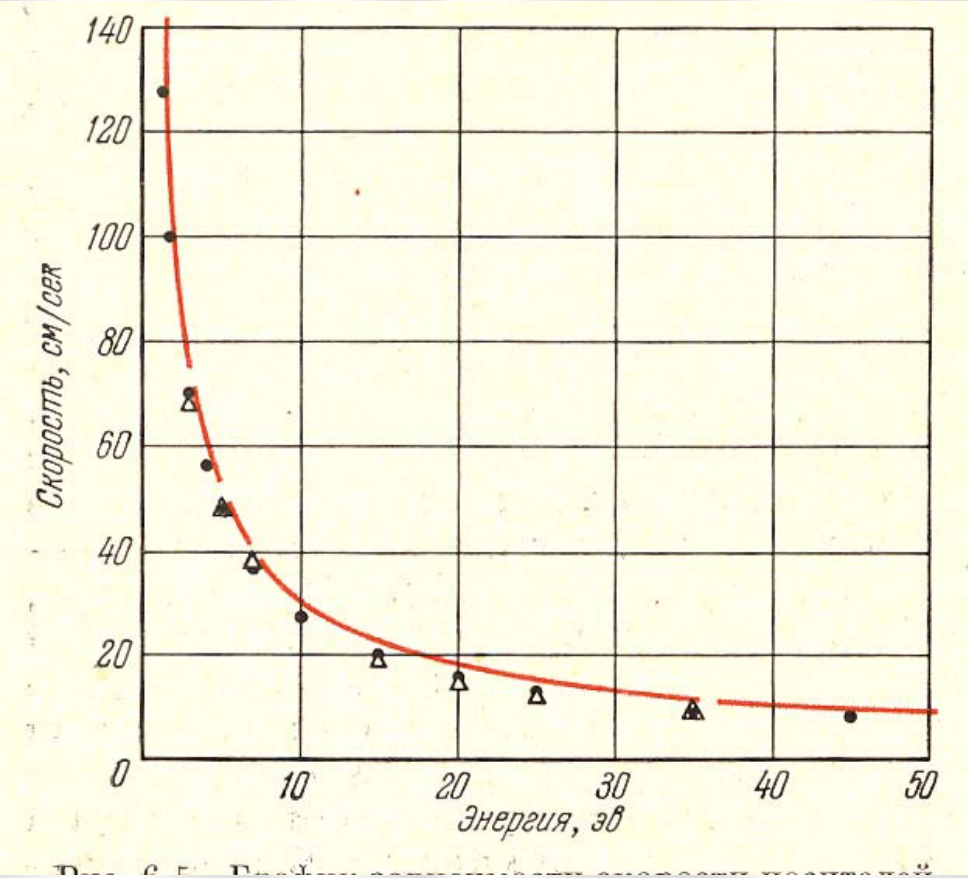


Рис. 6.7. Расширение кольцевого вихря под действием электрической силы, перпенди-

Drift velocity versus driving electric field



Vortex ring velocity versus energy of this cluster



Structure of individual incompressible stripe in QEH

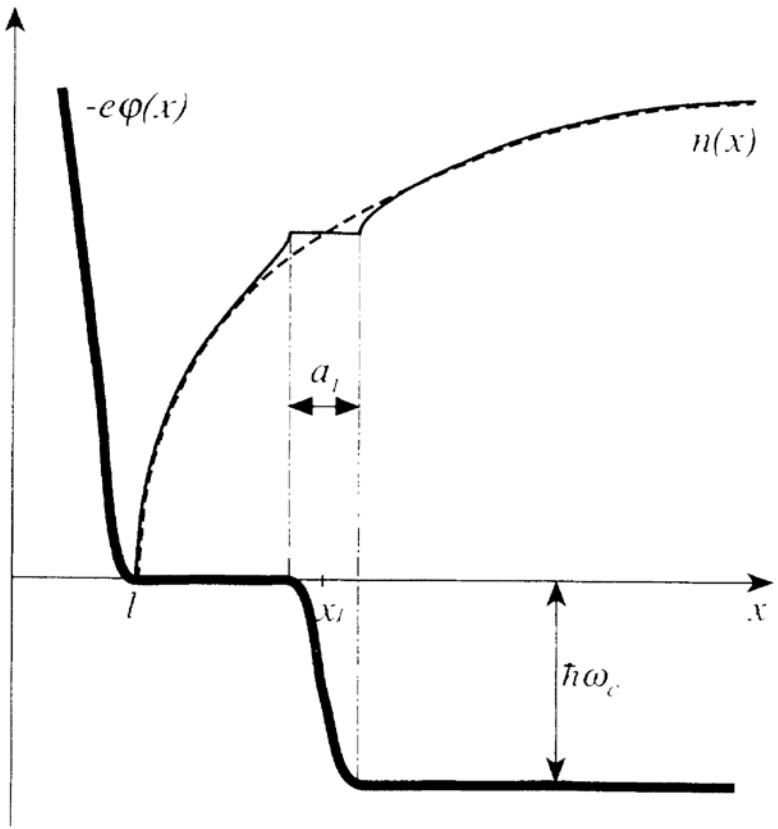
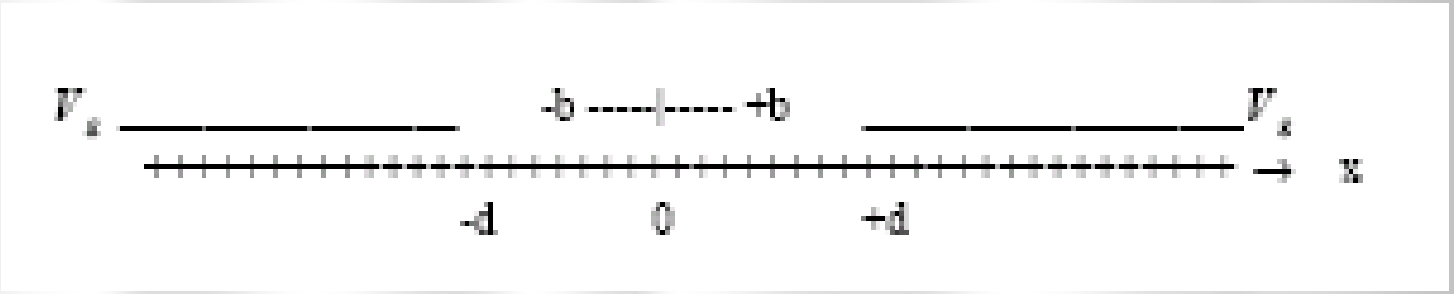


FIG. 3. 2DEG edge at magnetic field corresponding to the bulk filling factor $\nu_0 = 1.5$. The dashed line is the electron density at zero magnetic field. The solid line is the electron density, and the thick line is the electrostatic energy at $\nu_0 = 1.5$.

Electrostatics for 1D channel

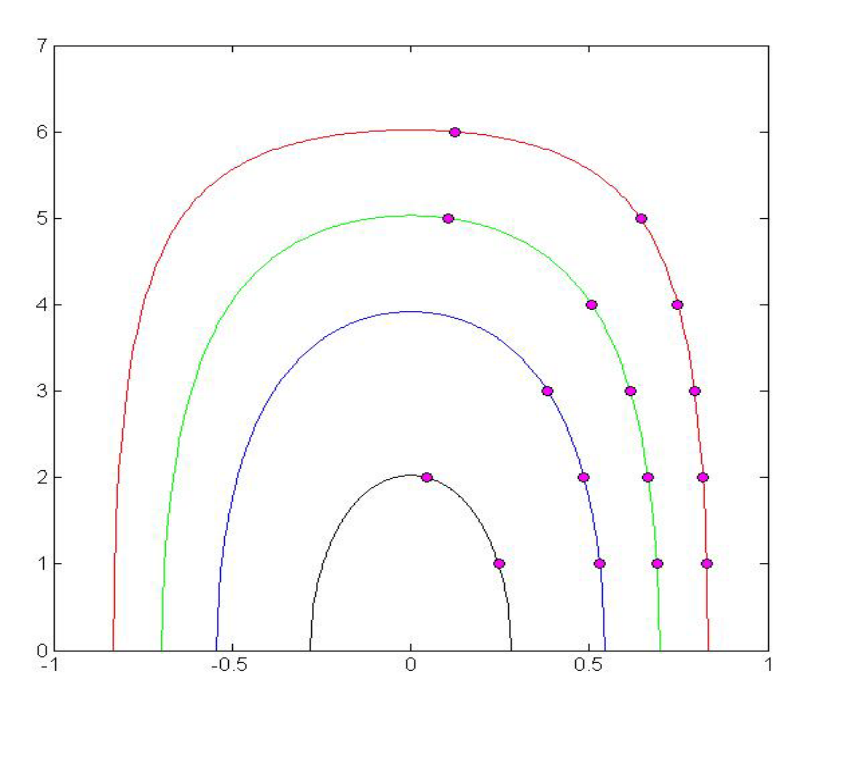


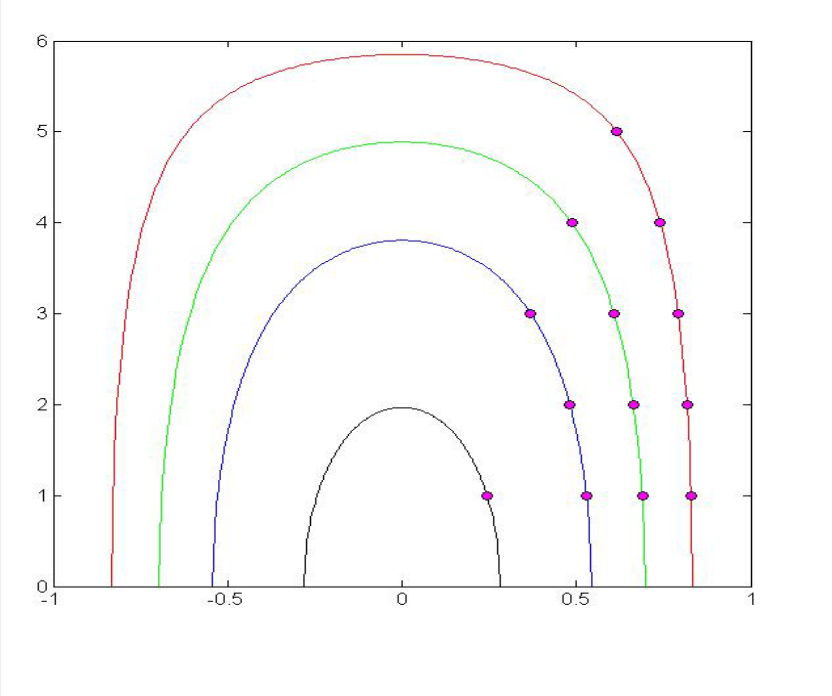
$$E_x(\zeta) = Re\left[\left(\frac{\zeta^2 - b^2}{d^2 - \zeta^2}\right)^{1/2}\right]\frac{2\pi e n_s}{\kappa}$$

$$E_z(\zeta) = Im\left[\left(\frac{\zeta^2 - b^2}{d^2 - \zeta^2}\right)^{1/2} - i\right]\frac{2\pi e n_s}{\kappa}$$

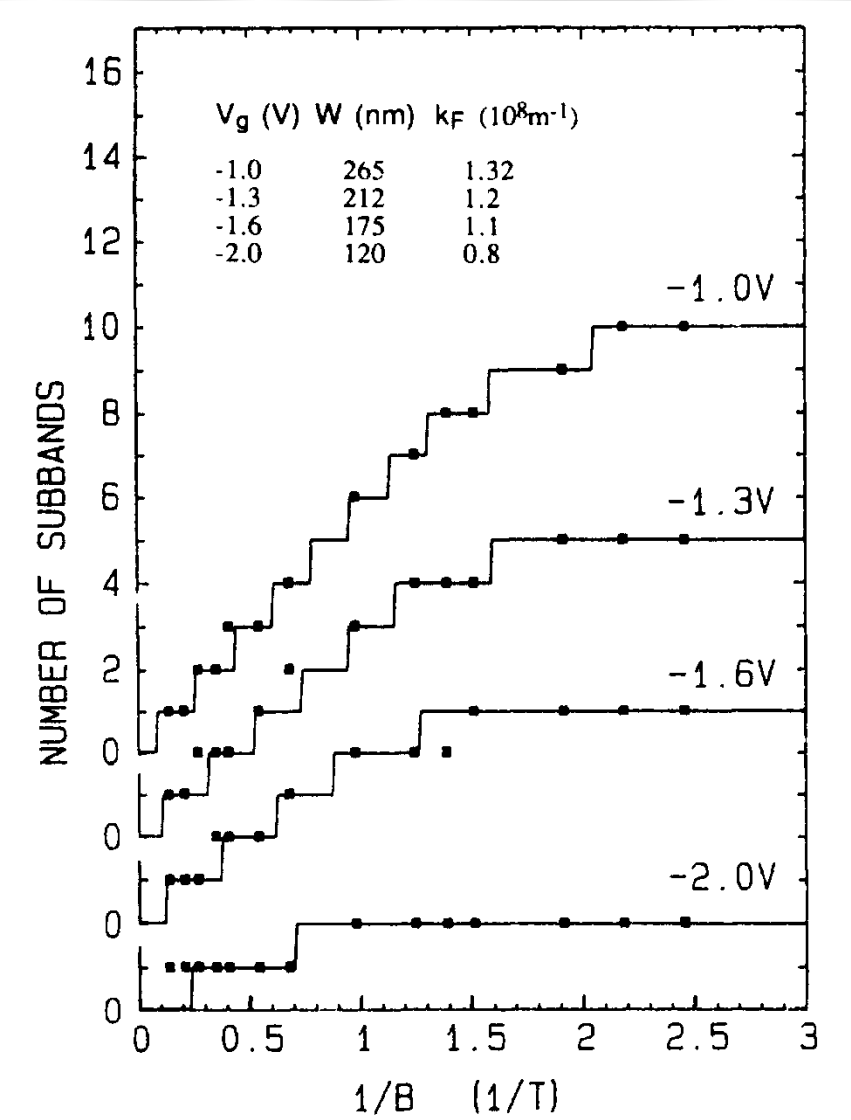
$$\zeta = x + iz$$

H=1.02.....H=1.05

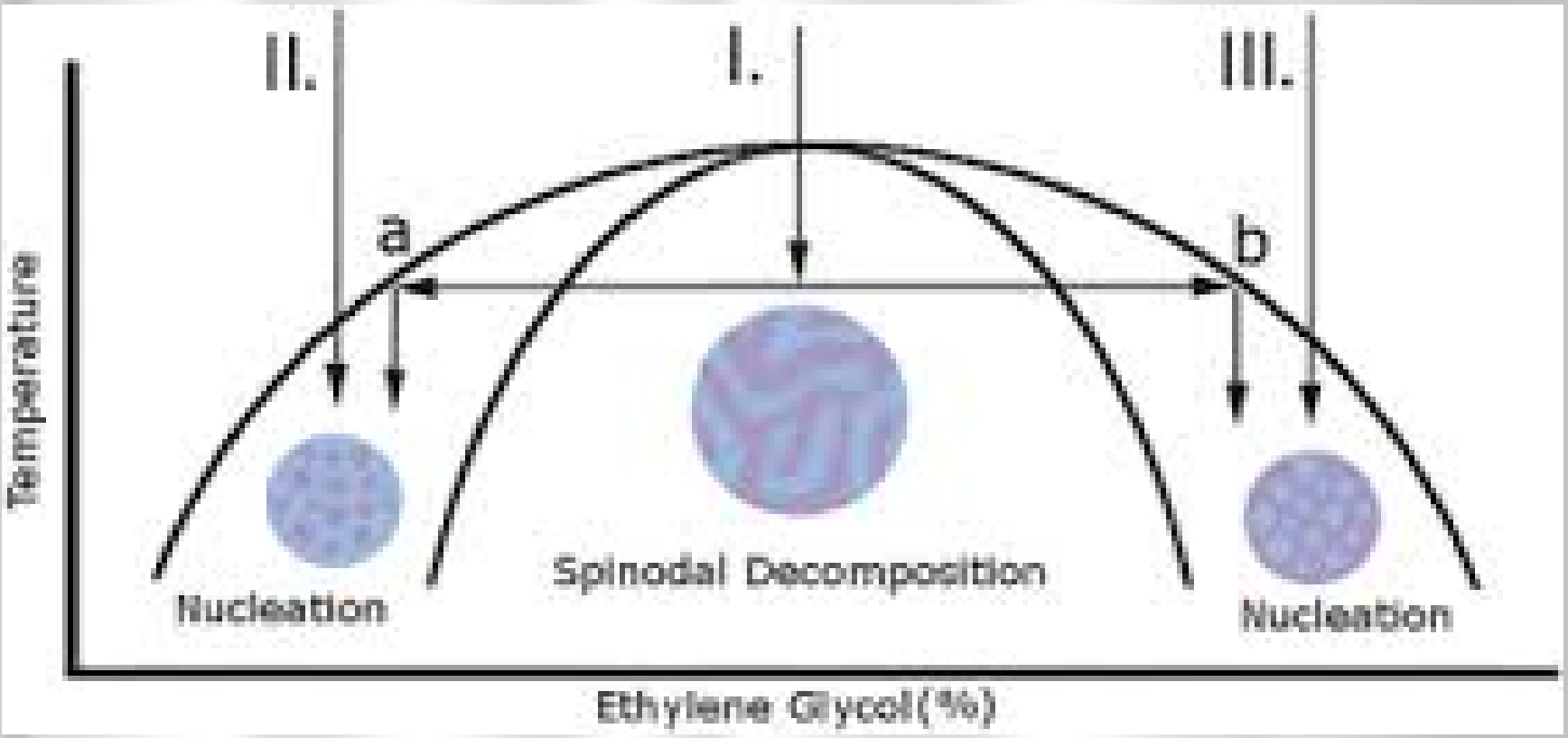




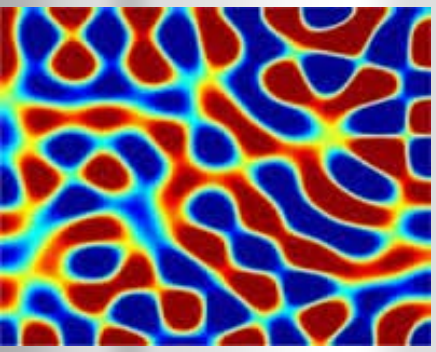
Phys.Rev B 38, (1988), 3625

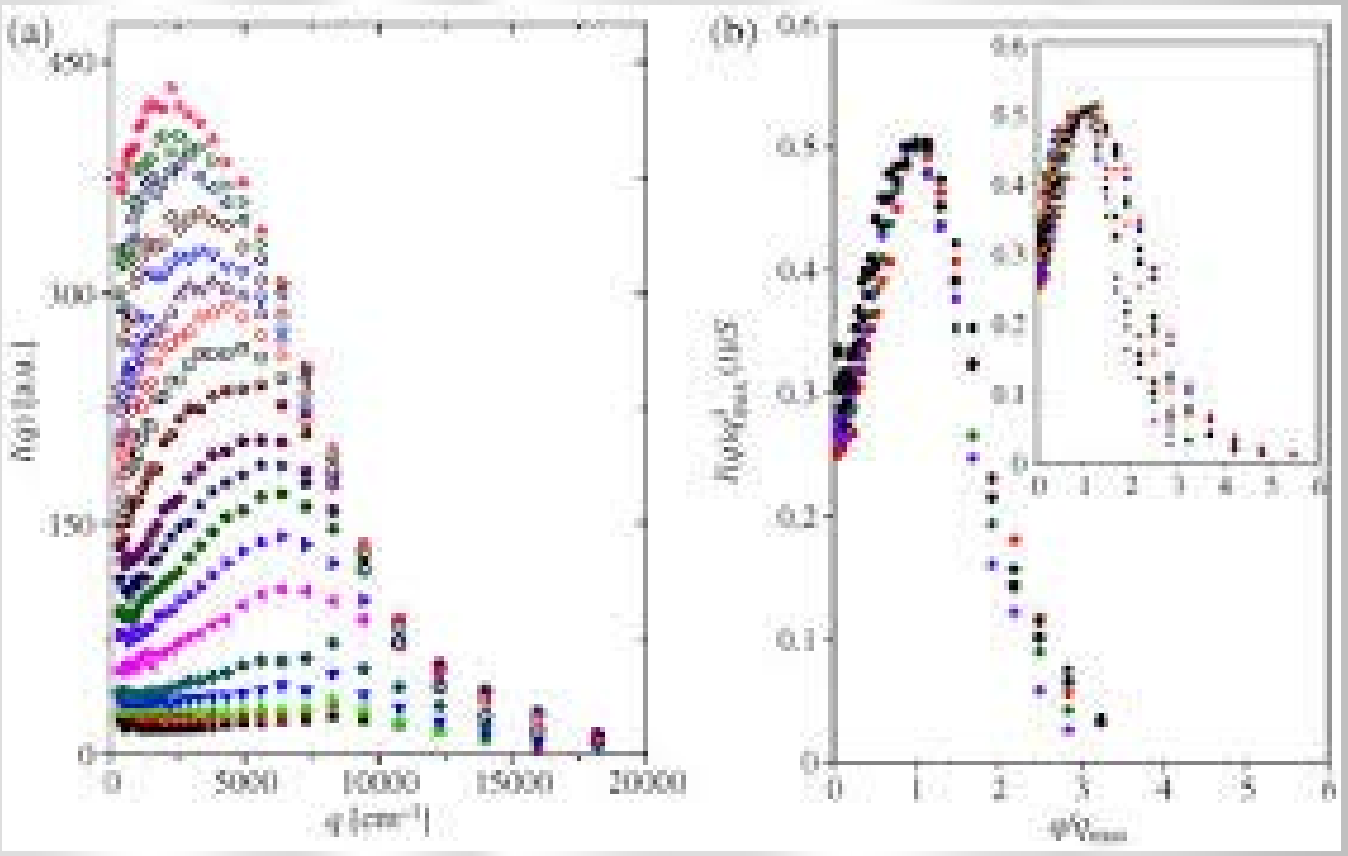


Ethilene-water binary solution



Spinodale instability



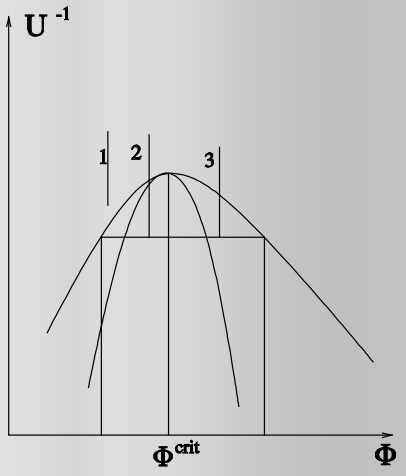

(a)
450
300
150
0
0
5000
10000
15000
20000
q [cm⁻¹]
(b)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6

Binodal and spinodal definitions

$$\mu_1 = \mu_2$$ Binodal line

$$\frac{\partial \delta\mu}{\partial n} = 0$$ Spinodal line

$$\delta\mu = 0$$

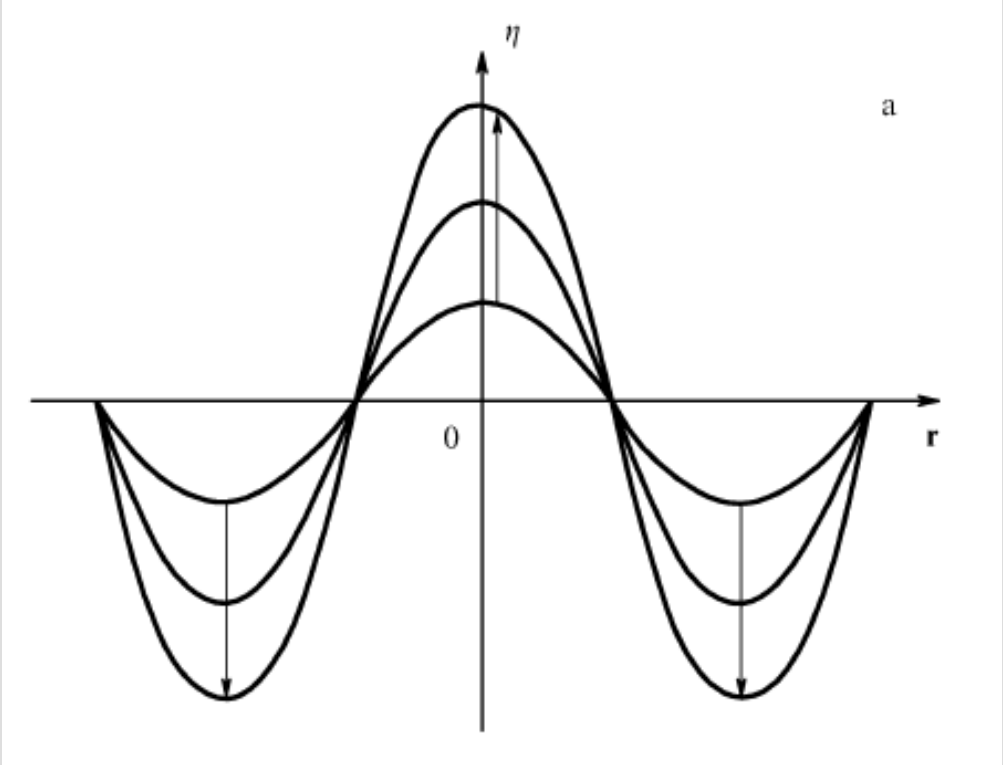


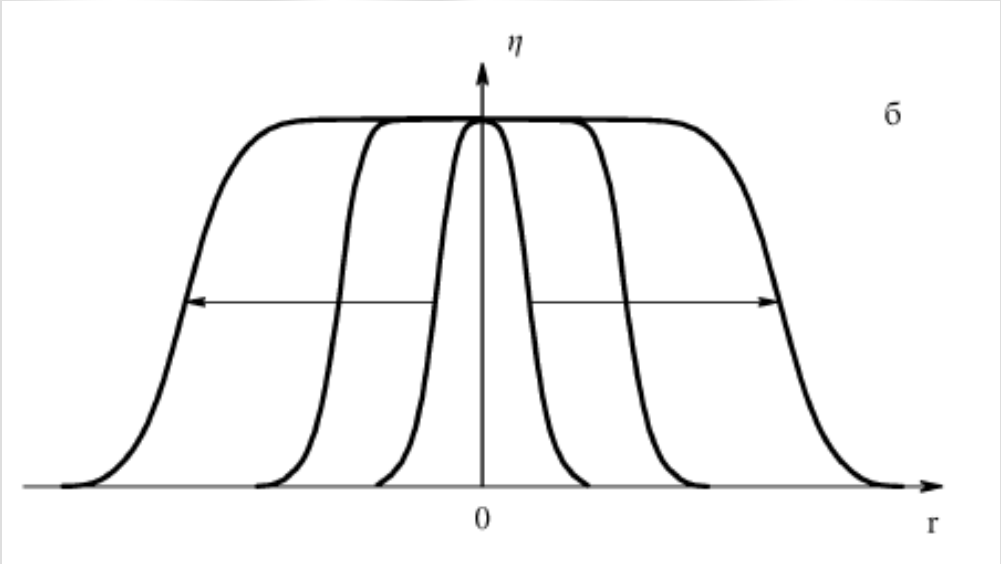
$$\frac{\partial n}{\partial t} + div j = 0$$

$$j = -D\nabla\mu$$

$$\frac{\partial \delta\mu}{\partial n} > 0 \rightarrow \frac{\partial \delta\mu}{\partial n} < 0$$

Diffusion coef. D
has the sign-inversion.


η
a
0
r


η
б
0
r