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The thermal and “cold” ionization mechanism for conductivity of metal vapors in near-critical region

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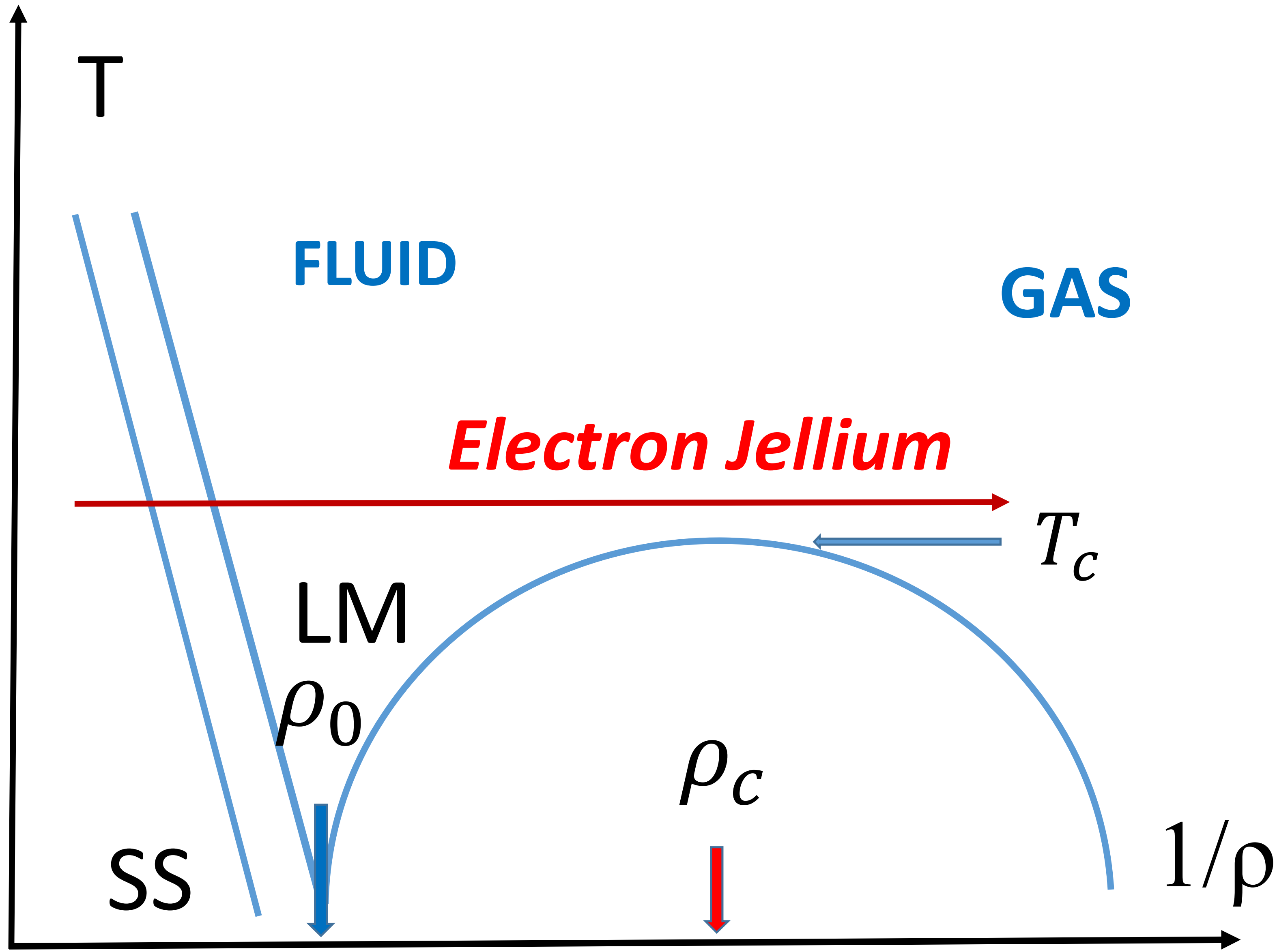
Motivation



Gaseous metal of Likalter

virtual atoms – overlapping by the classically accessible spheres of partially free valence electrons

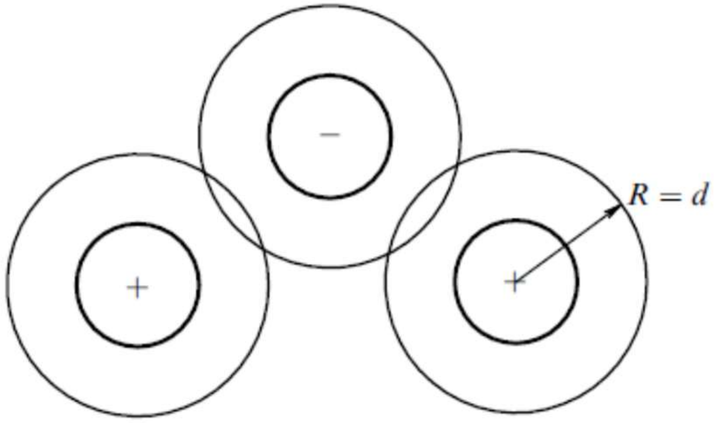
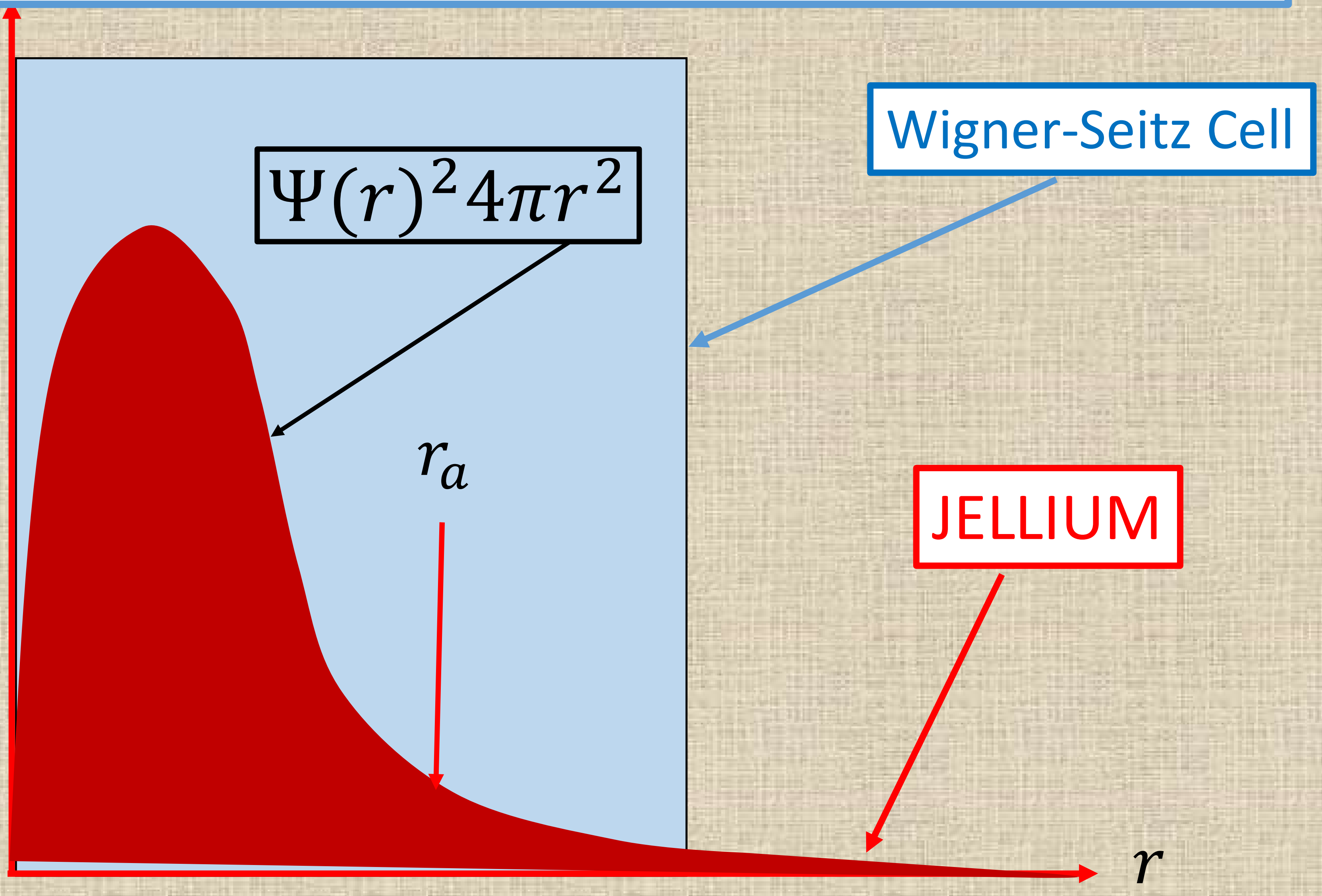


Рис. 1. Заряженные твердые сферы с перекрывающимися оболочками.

the origin of
conduction band

Likalter A.A. “Gaseous metals” Sov. Phys. Usp. **35,** 591 (1992)

ATOMIC GAS + JELLIUM = GASEOUS METAL



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$$R_a = \left(\frac{3}{4\pi n_a}\right)^{1/3}.$$

$$\Psi^{\mathrm{i}}(r) = \sum_{\lambda,p} C_{\lambda,p}\chi_{\lambda,p}(r,\theta,\varphi).$$

$$\alpha_{\mathrm{j}}^{\mathrm{i}} = \int_{y_a}^{\infty} \Psi^{\mathrm{i}}(r)^2 r^2 dr + \frac{y_a^3}{3}\Psi^{\mathrm{i}}(y_a)^2,$$

“cold ionization” degree

where $y_a = R_a/a_0$ is the radius of the atomic Wigner-Seitz cell in atomic units. The total electron density is conserved and the Wigner-Seitz cell is electroneutral.

Degree of “cold ionization” for Al, Be, Cs

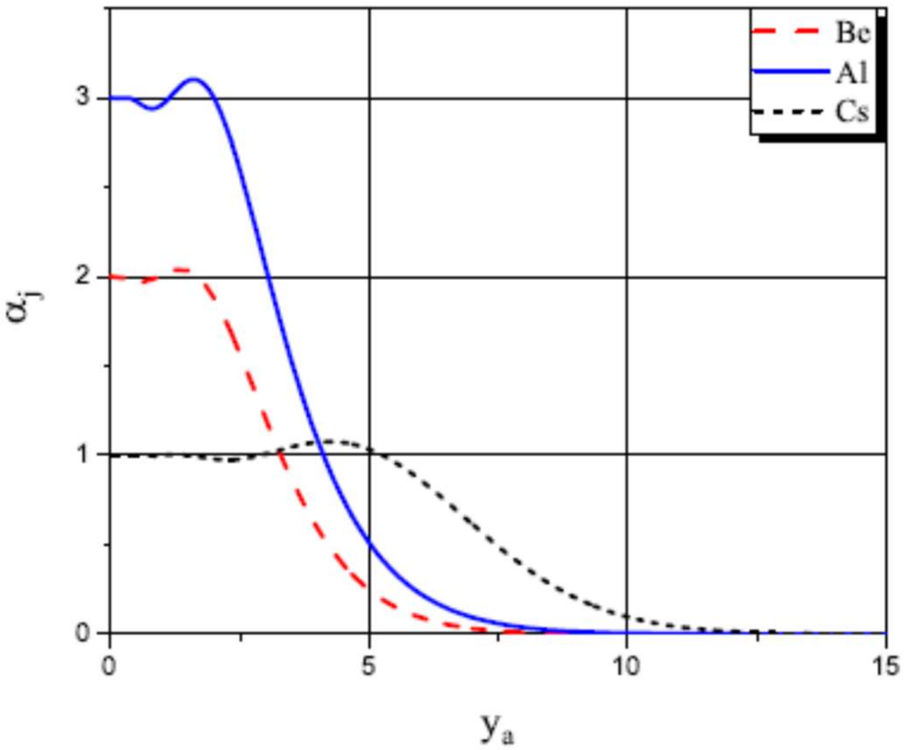


FIG. 1. The degree of ”cold ionization” for Be, Al, Cs depending on y_a — radius of the Wigner-Seitz cell in atomic units.

$$\rho \rightarrow n_a \rightarrow y_a \rightarrow n_j = \alpha_j n_a \rightarrow \sigma.$$

$$\sigma_j = n_j^{2/3} \frac{q_e^2}{9 \cdot 10^{11}} \frac{2 y_a}{(3\pi^2)^{1/3} \hbar}$$

We can determine the jellium electrons' conductivity by their concentration n_j, related to the density of atoms, and a direct relationship to the density of atoms via y_a – the atomic cell's size in atomic units. Temperature dependence is absent. The dimension of all values is CGSE, and the conductivity's one is in 1/(Ohm cm). To estimate the vapor conductivity for Cs, Al, and Be, it is sufficient to set their density, find α_j from the graphs, and use the formula to calculate the conductivity.

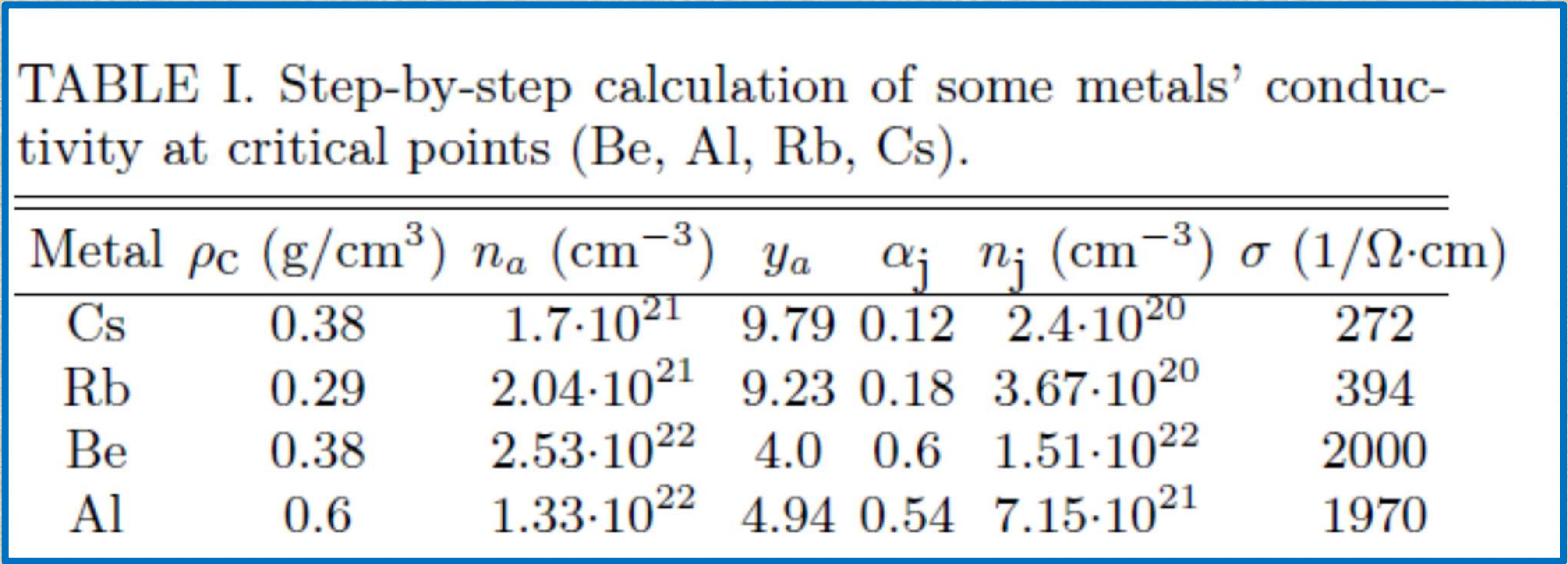


TABLE I. Step-by-step calculation of some metals' conductivity at critical points (Be, Al, Rb, Cs).

Metal	ρ_C (g/cm^3)	n_a (cm^{-3})	y_a	α_j	n_j (cm^{-3})	σ (1/Ω·cm)
Cs	0.38	$1.7 \cdot 10^{21}$	9.79	0.12	$2.4 \cdot 10^{20}$	272
Rb	0.29	$2.04 \cdot 10^{21}$	9.23	0.18	$3.67 \cdot 10^{20}$	394
Be	0.38	$2.53 \cdot 10^{22}$	4.0	0.6	$1.51 \cdot 10^{22}$	2000
Al	0.6	$1.33 \cdot 10^{22}$	4.94	0.54	$7.15 \cdot 10^{21}$	1970

Experimentally measured conductivity values for cesium and rubidium at the critical point are of the order of 250 ± 150 1/(Om cm) [Hensel, 1980]

“3+” model

Gas and liquid binodal

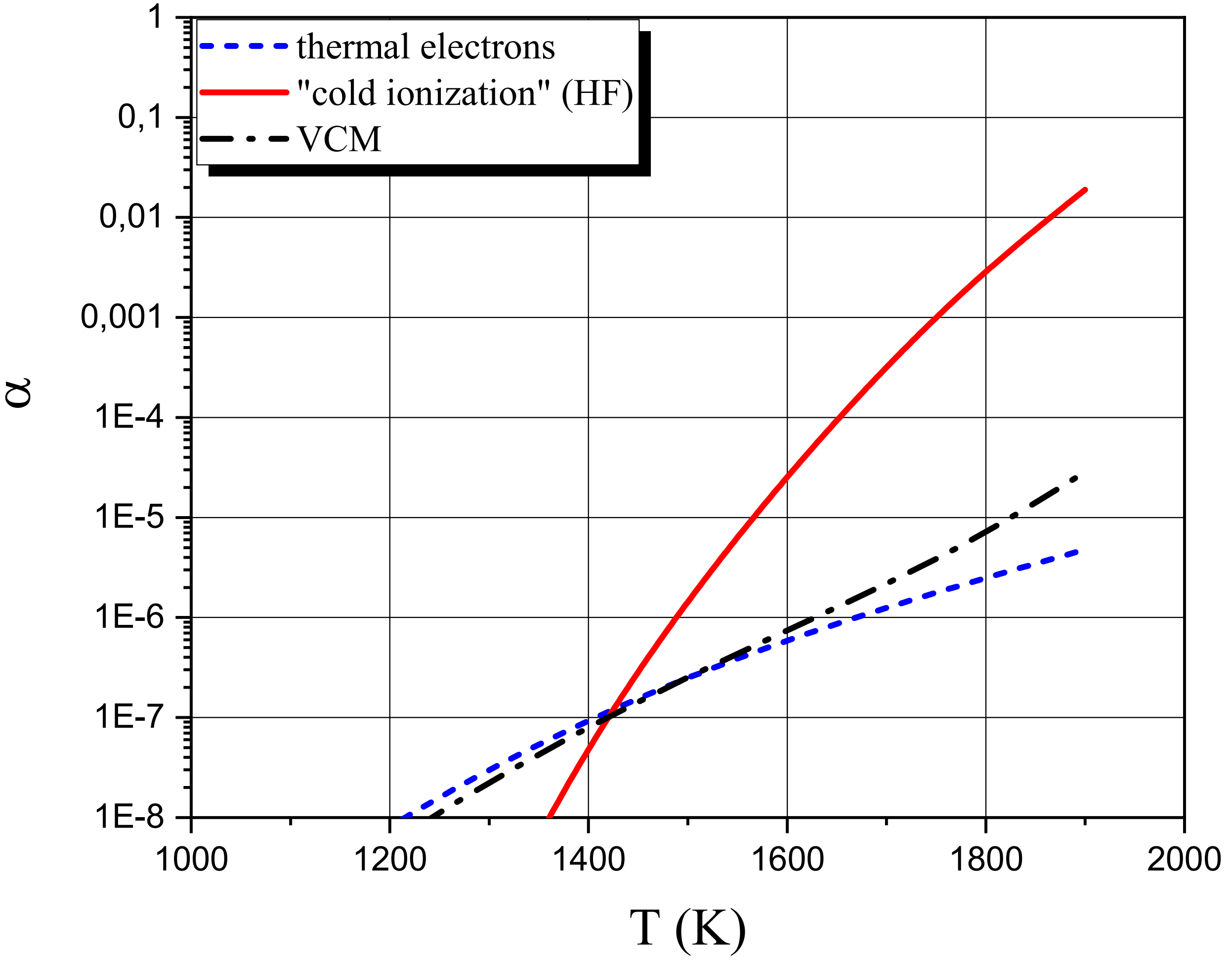
- Thermal electrons
- Jellium

NNA + Cohesion

$$\sigma_F = \frac{4}{3\sqrt{\pi}} \frac{q^2 n_e}{m\, T^{5/2}} \int_0^{\infty} \exp\left(-\frac{E}{T}\right) E^{3/2} \frac{dE}{\left(\nu_{en}(E) + \gamma_S^{-1} \nu_{ei}(E)\right)}$$

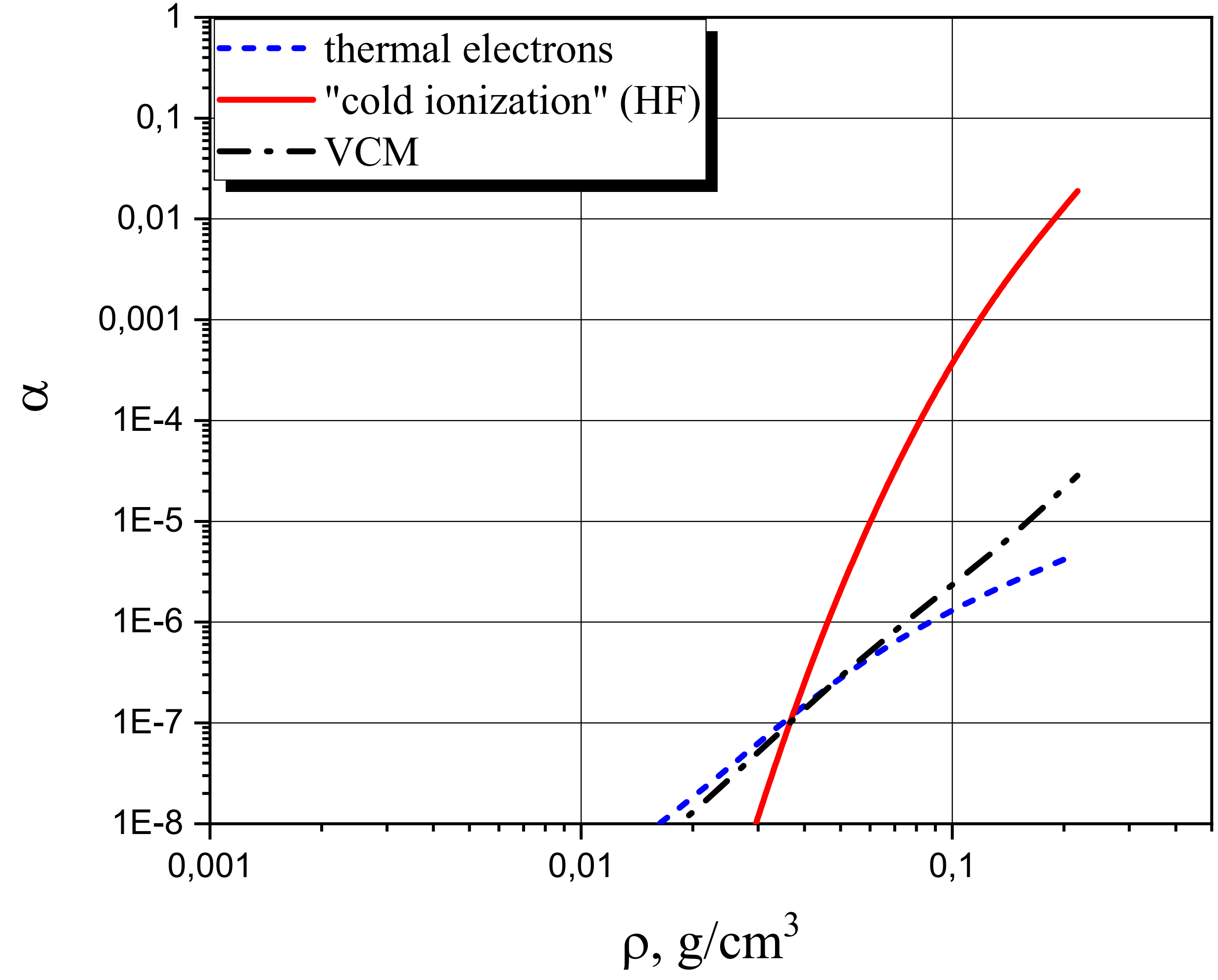
$$\sigma_{\mathrm{RI}} = n_{\mathrm{j}} \frac{e^2}{m} \tau_{\mathrm{RI}}$$

Ionization degree vs temperature along gas branch of binodal



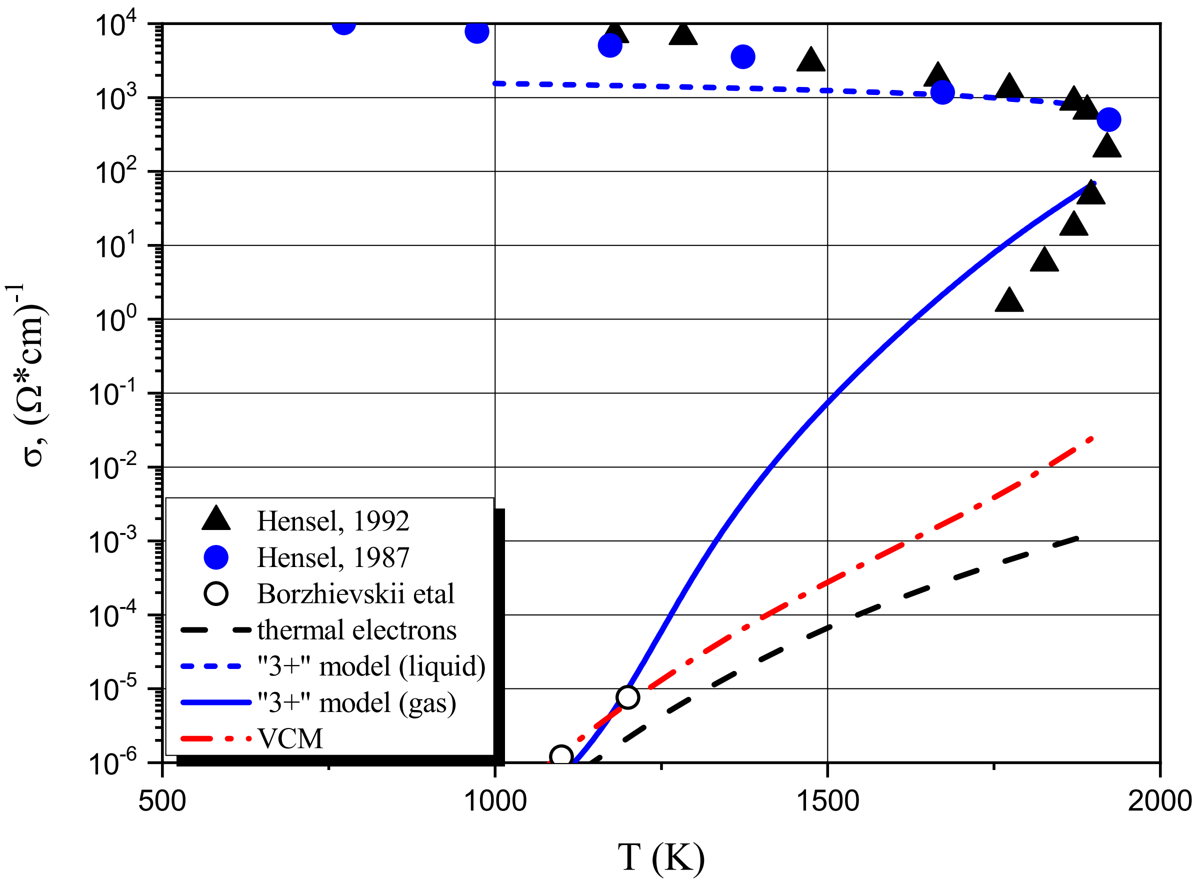
VCM – A.L. Khomkin, A.S. Shumikhin. High Temp. **51**, 594 (2013)

Ionization degree vs density along gas branch of binodal



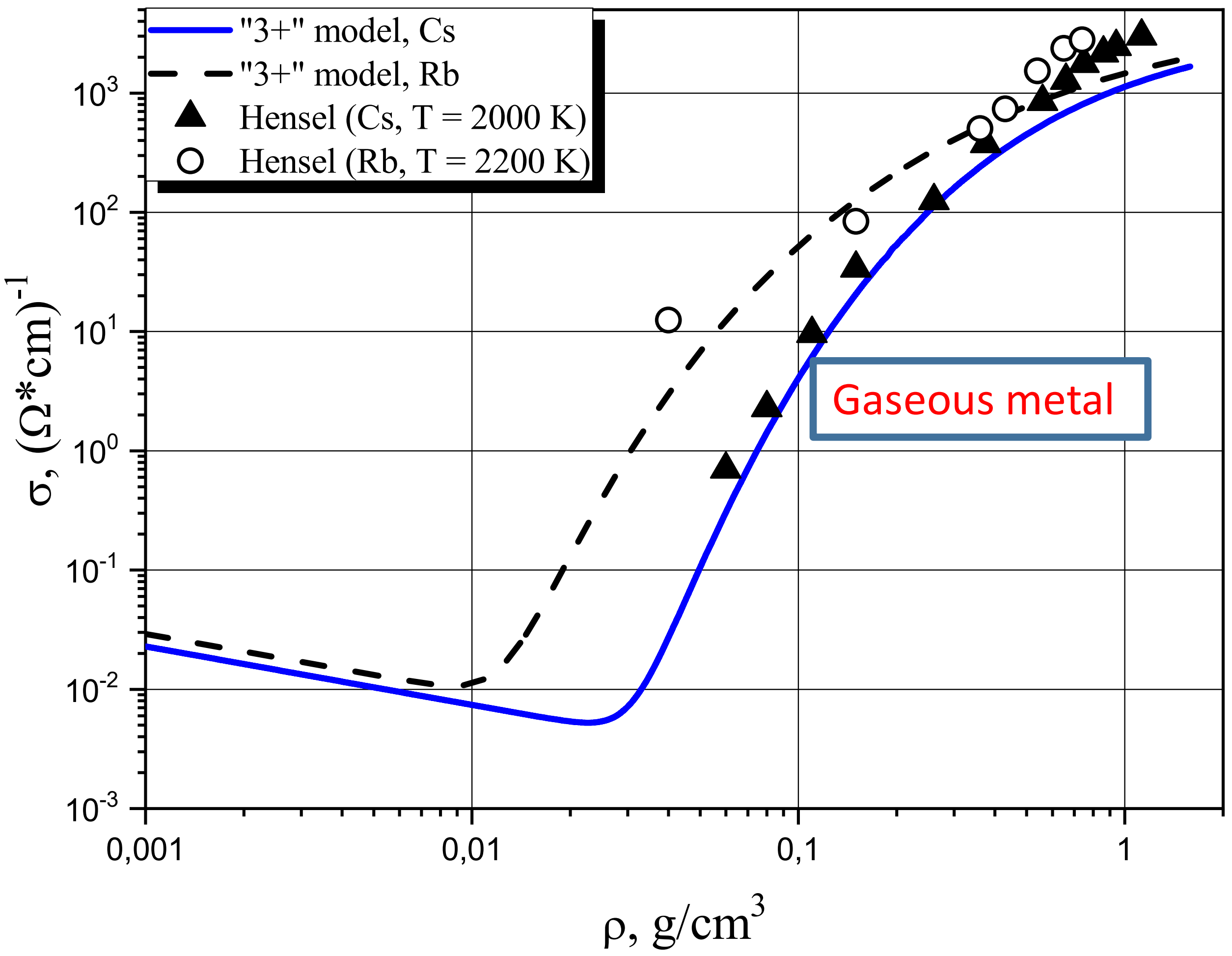
VCM – A.L. Khomkin, A.S. Shumikhin. High Temp. **51**, 594 (2013)

Conductivity of cesium vapors on binodal

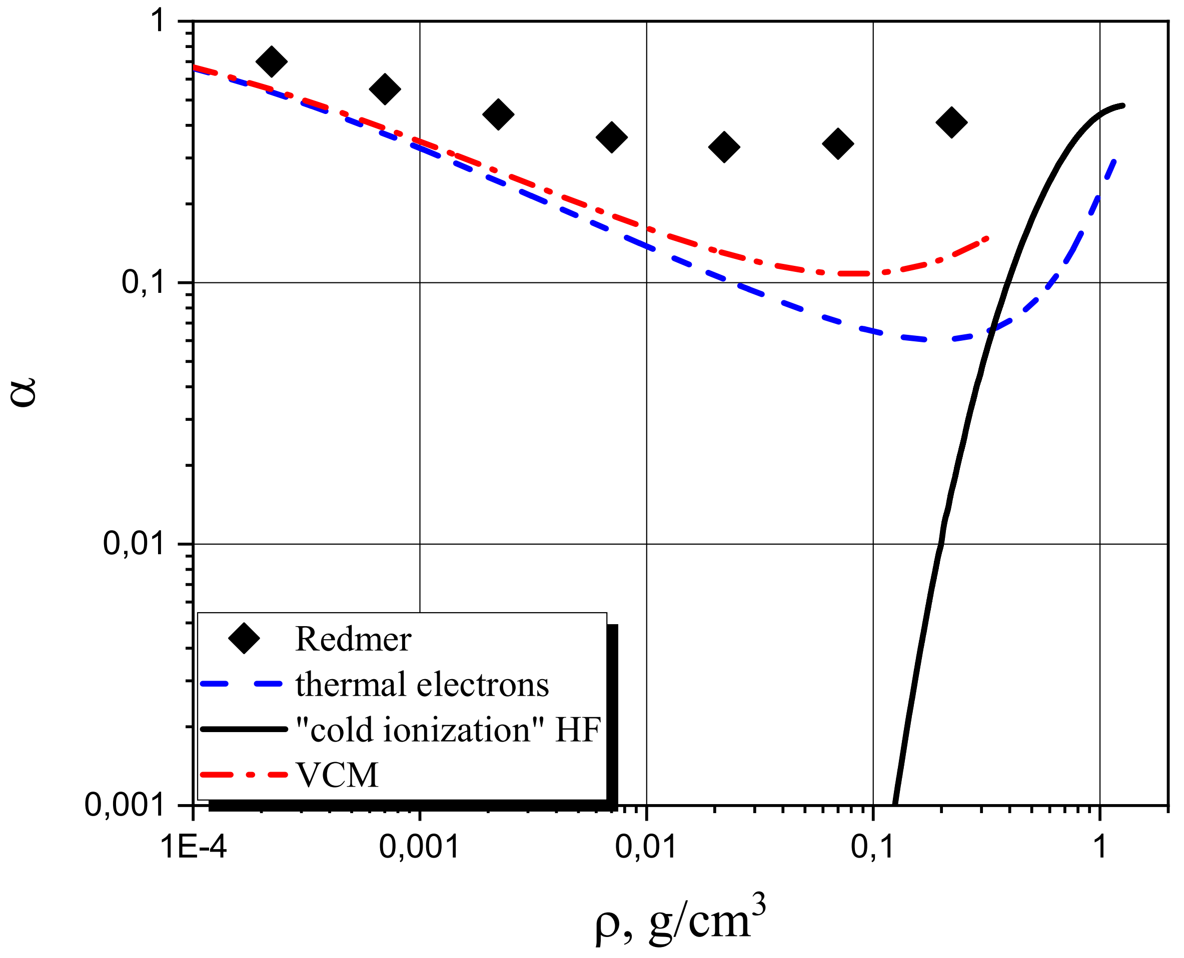


SATURATED VAPORS OF ALKALI METALS – GASEOUS METAL

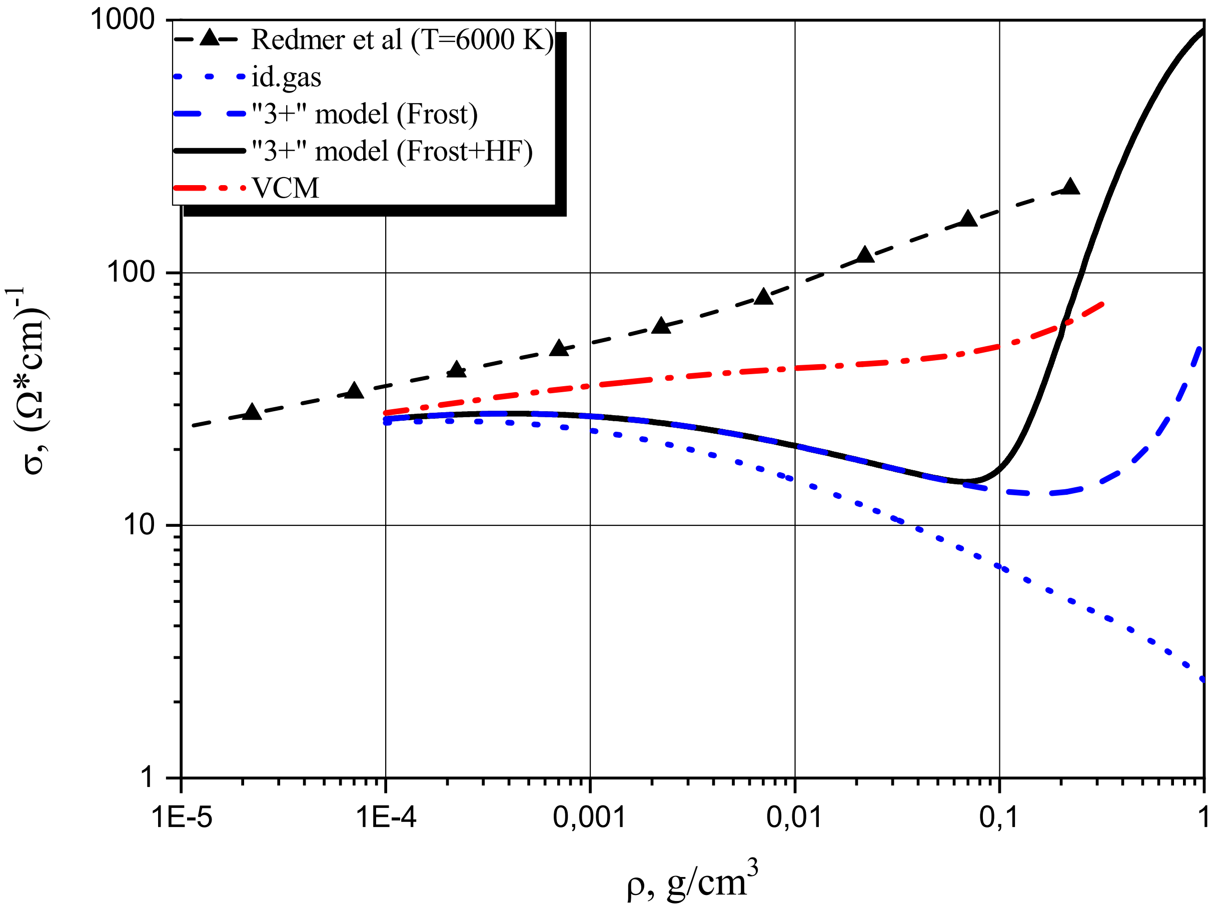
Conductivity of alkali metals vapors (T ≈ 2000 K)



Ionization degree vs density for cesium, T = 6000 K



Conductivity of cesium vapors (T = 6000 K)



VCM – A.L. Khomkin, A.S. Shumikhin. High Temp. **51**, 594 (2013)
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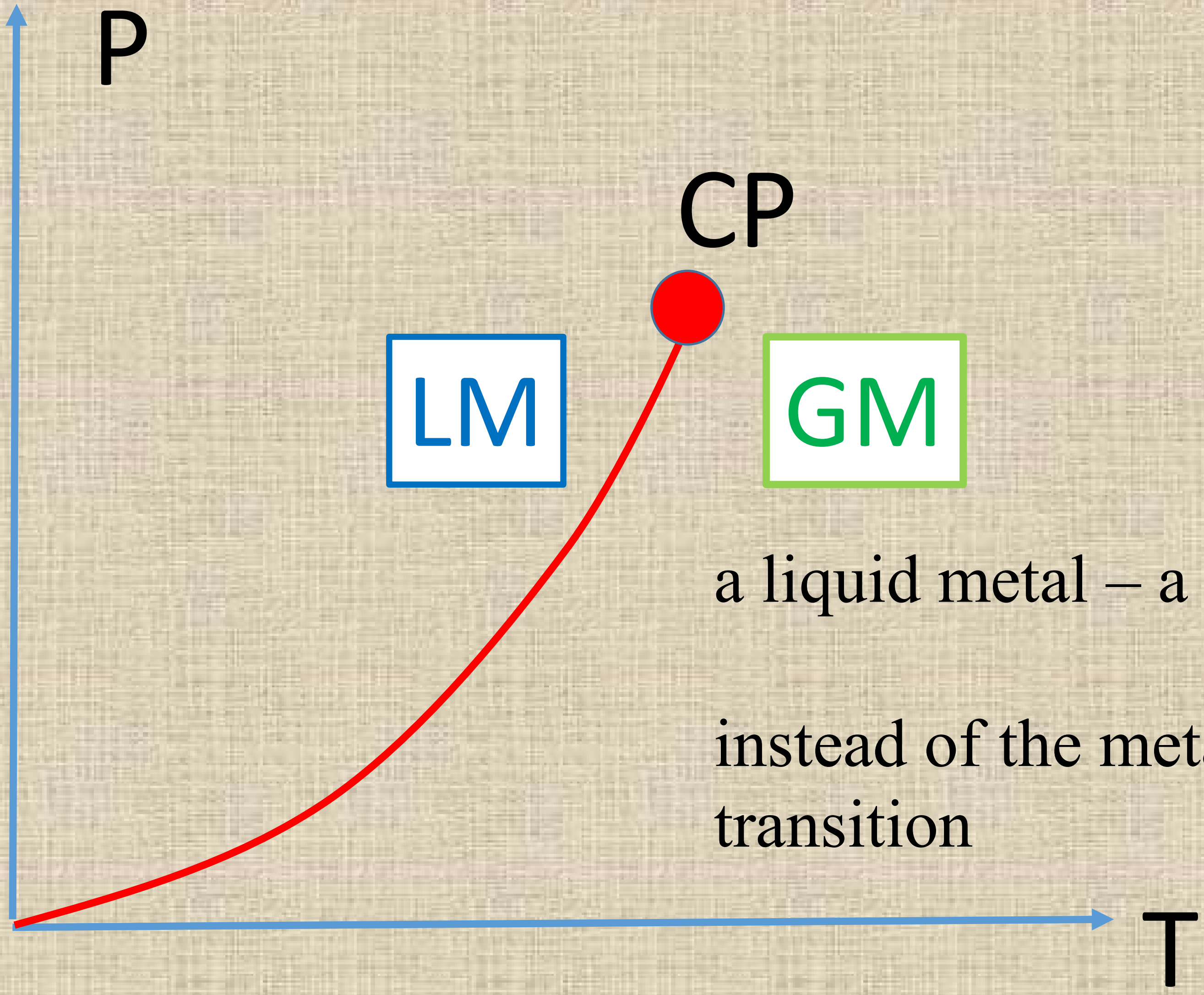

a liquid metal – a gaseous metal

instead of the metal-dielectric transition

CONCLUSIONS

1. The proposed “3+” model allow to calculate composition, equation of state and electrical conductivity within unified approach for plasma fluid of metal vapors.

A distinctive feature of the model: the use of solid–state characteristics to describe the properties of the fluid (gas state): the jellium – the origin of the band structure and the cohesive binding energy of atoms.

2. Atomic gas and Jellium = Gaseous metal. It is not a dielectric state.

3. Liquid metal–gaseous metal phase transition occurs instead of dielectric-metal phase transition.

THANK YOU

FOR YOUR ATTENTION!