Introduction to Incoherent Scatter Radar - Part 3

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With credit and thanks to **Anja Strømme**, Craig Heinselmann, Phil Erickson, Bill Rideout, Josh Semeter, Juha Vierinen

And my advisor: William E. Gordon

Incoherent Scatter Radar

- Radar
- Scatter
- Incoherent - Ion Line

Definition of Incoherent

- Property of being coherent
- Antonym: incoherent
- Incoherent=Random
- Example: The drunk man made no sense. He was incoherent.
- In radar: Incoherent scatter is the process by which radio waves are randomly scattered by electrons in the ionosphere

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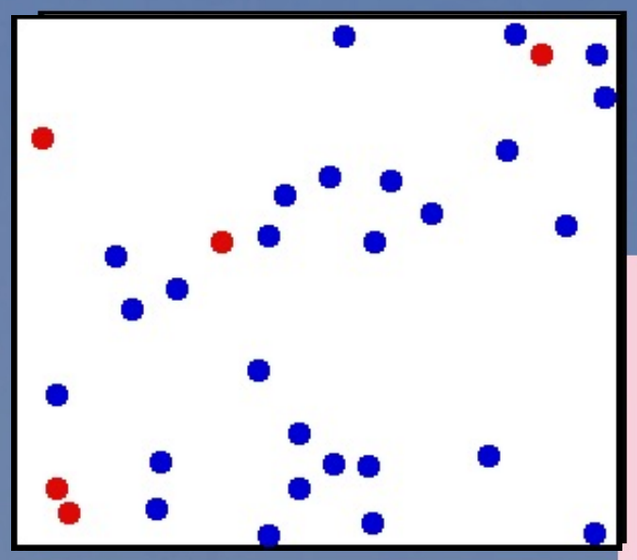
Incoherent scatter is neither incoherent nor incomprehensible

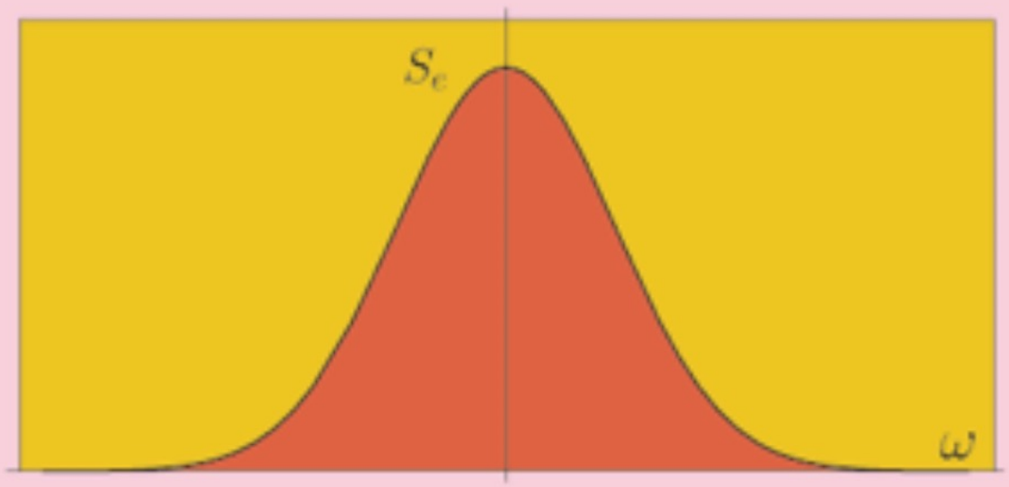
For TRUE incoherent scatter…



no collective interactions

$$S_e(\mathbf{k},\omega) = N_e \left|1 - \frac{\chi_e(\mathbf{k},\omega)}{\epsilon(\mathbf{k},\omega)}\right|^2 \int d\mathbf{v} f_e(\mathbf{v}) \delta(\omega - \mathbf{k}\cdot\mathbf{v}) + N_i \left|\frac{\chi_e(\mathbf{k},\omega)}{\epsilon(\mathbf{k},\omega)}\right|^2 \int d\mathbf{v} f_i(\mathbf{v}) \delta(\omega - \mathbf{k}\cdot\mathbf{v})$$

$$S_e(\mathbf{k},\omega) = N_e \int d\mathbf{v} f_e(\mathbf{v}) \delta(\omega - \mathbf{k}\cdot\mathbf{v})$$



- We only see scattering from the electrons

…but they also tell the story about the ion dynamics…

Collective behavior

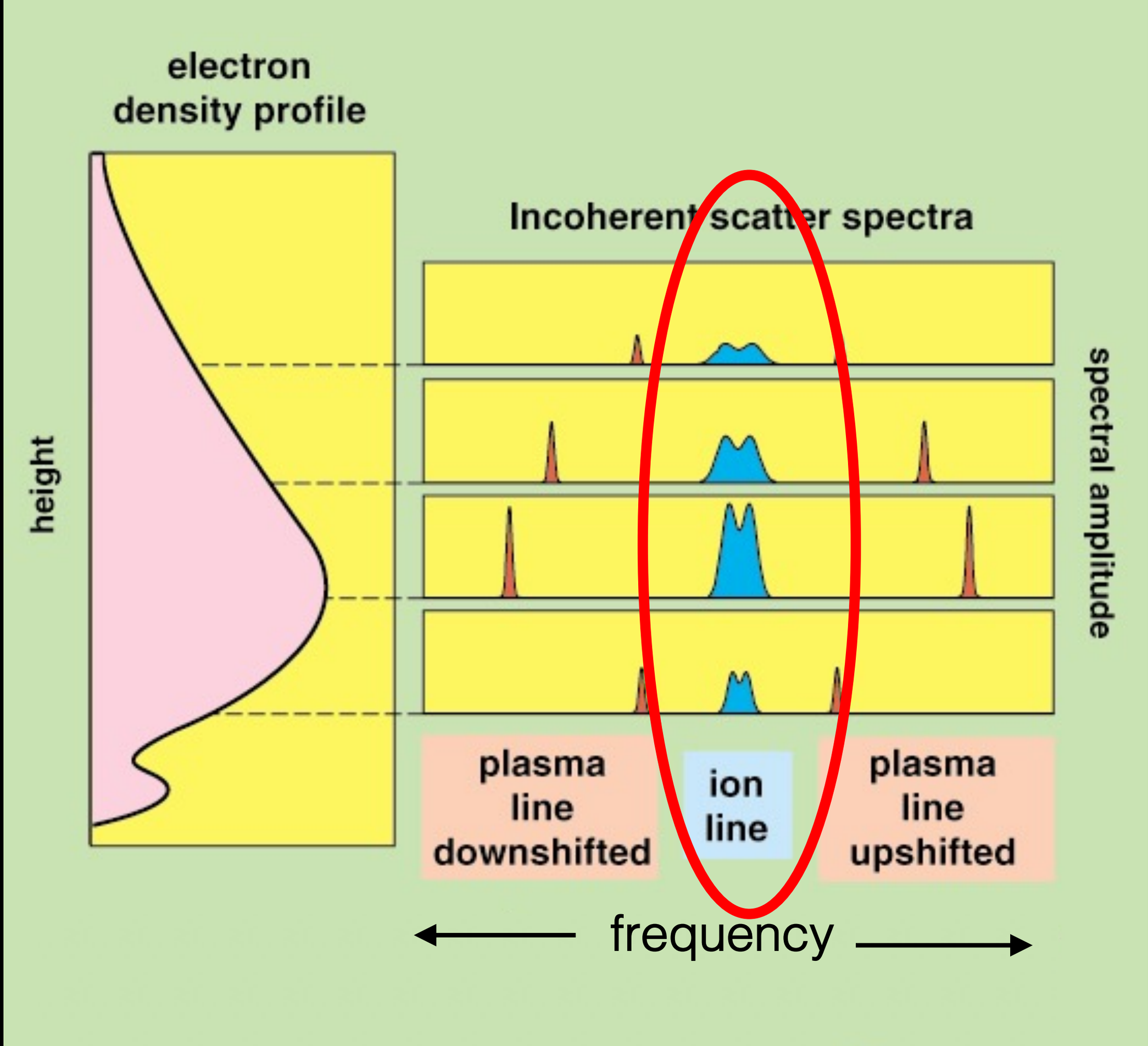
- There are a number of wave modes existing inherently in the ionospheric plasma

→ *Ion acoustic waves*

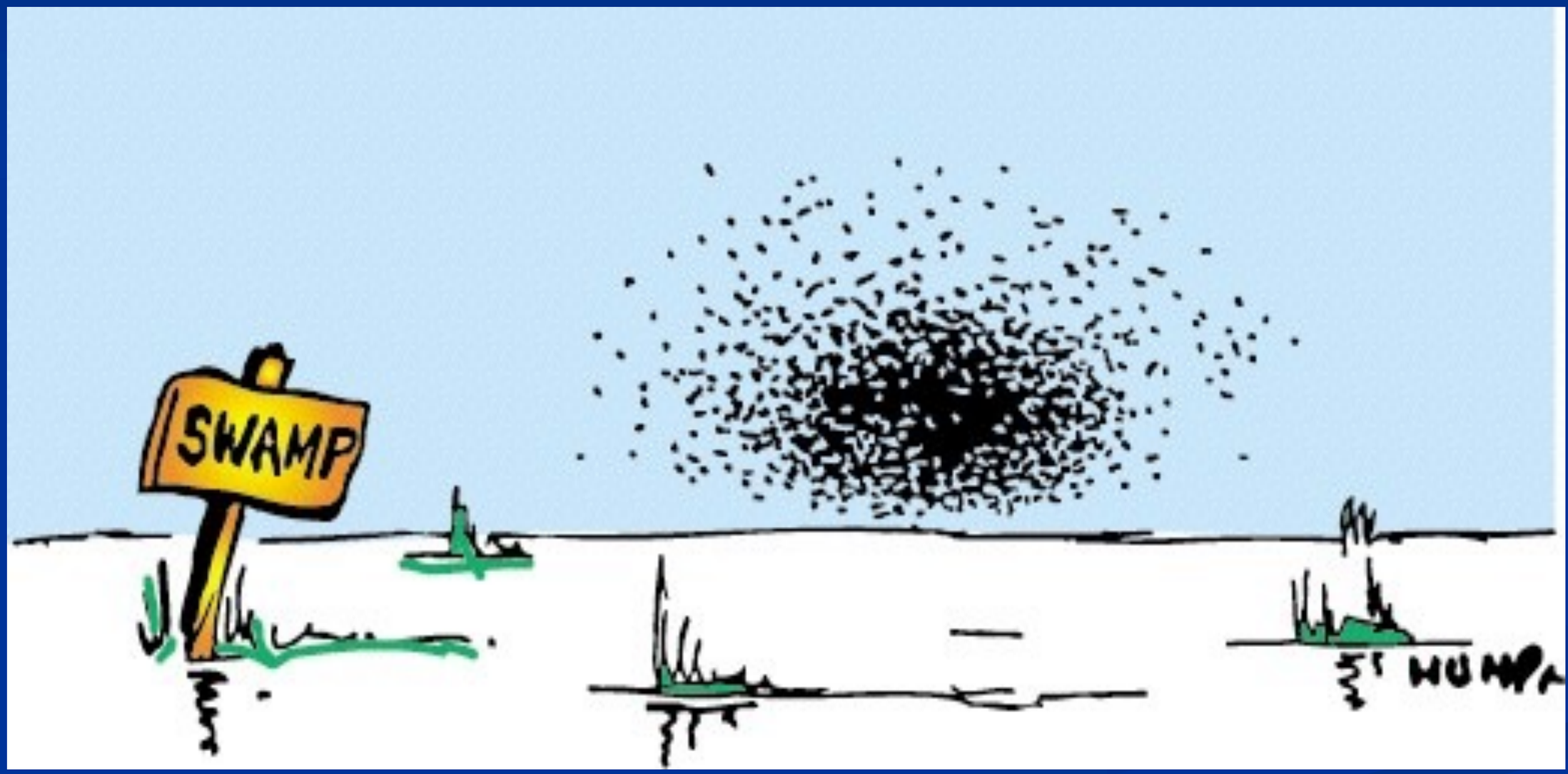
Langmuir waves (plasma frequency)

→ *Debye Spheres (Debye length)*

→ *Landau Damping ……*


electron
density profile
Incoherent scatter spectra
height
spectral amplitude
plasma
line
downshifted
ion
line
plasma
line
upshifted
frequency

Incoherent scattering: the short story



Incoherent scattering: the short story

Debye length dependence

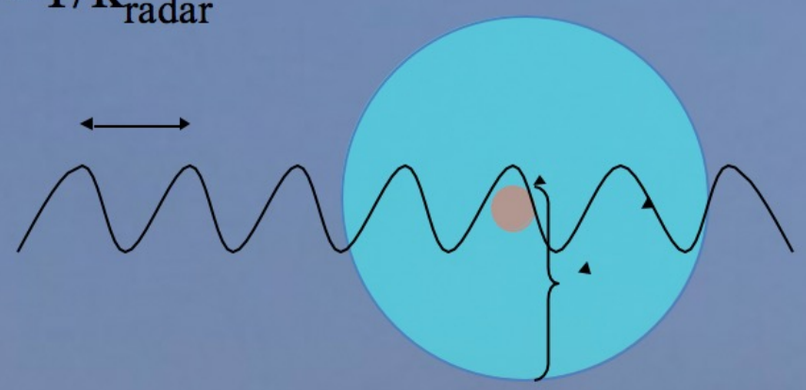
<

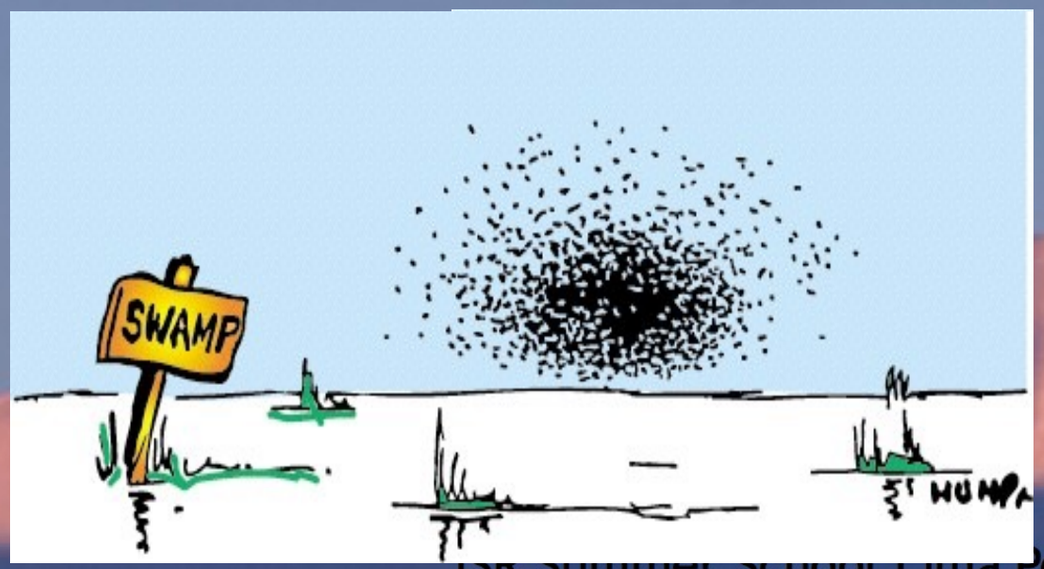
$\lambda_{radar} \propto 1/k_{radar}$

Ion

Electron cloud

Debye length λ_D

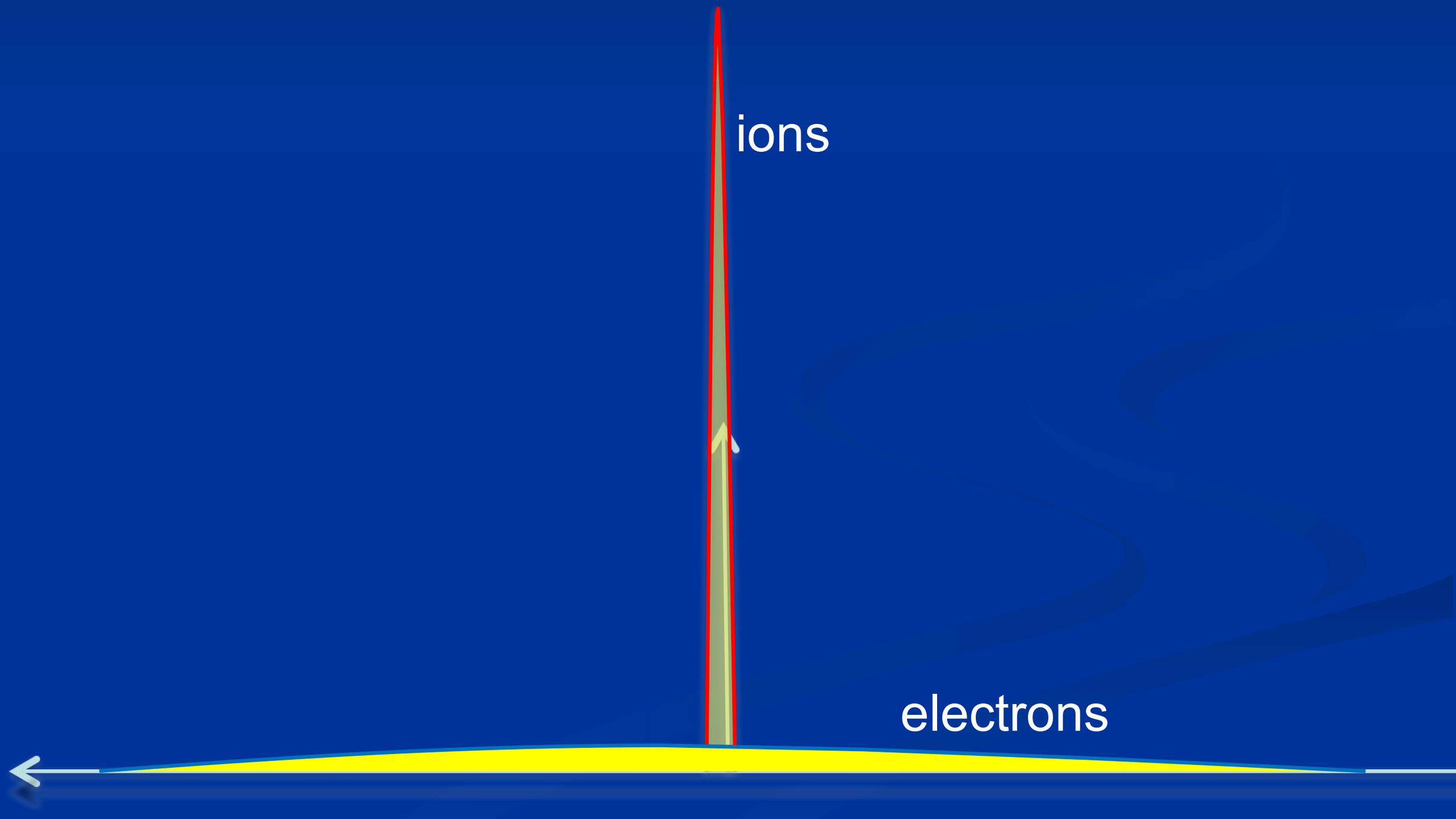




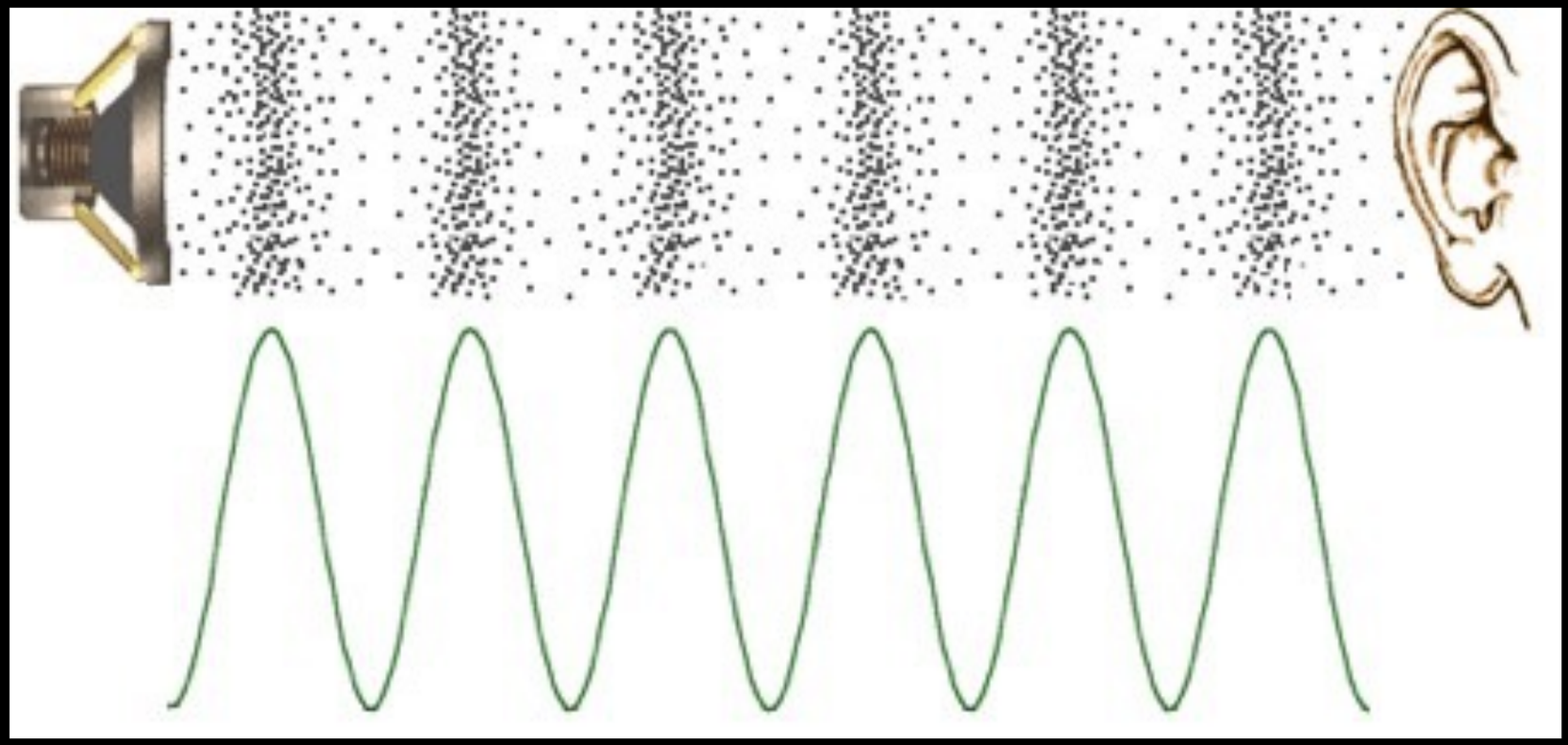
$(\lambda_D / \lambda_{radar})^2 < 1$

- $(k_{radar}\, \lambda_D)^2 < 1$
- ~~No~~ collective interactions

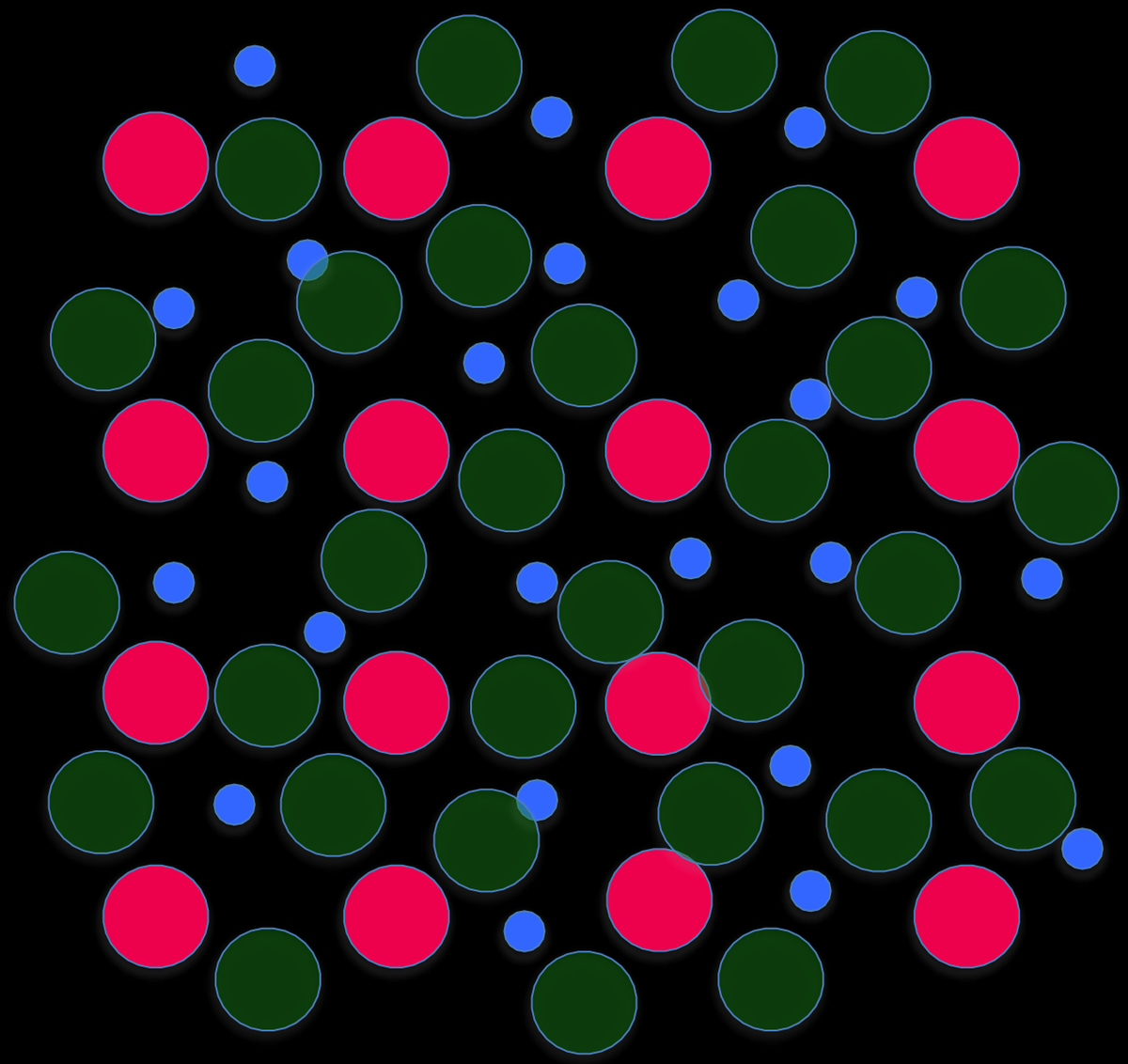
The ionospheric ions acts as slooooow pacers for the electron gas



Ion Acoustic Waves



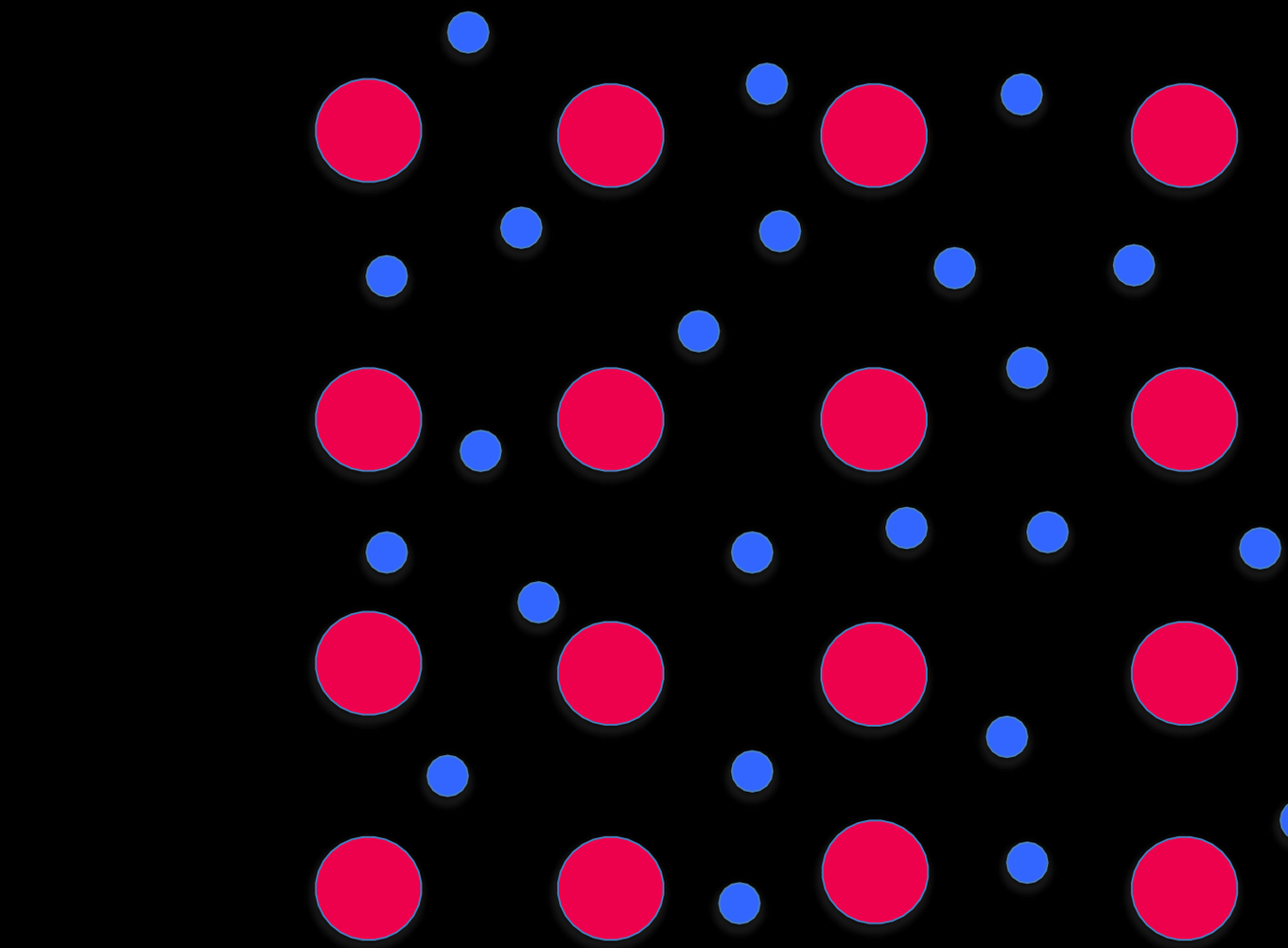
"Pressure" waves in the ion density



Neutrals

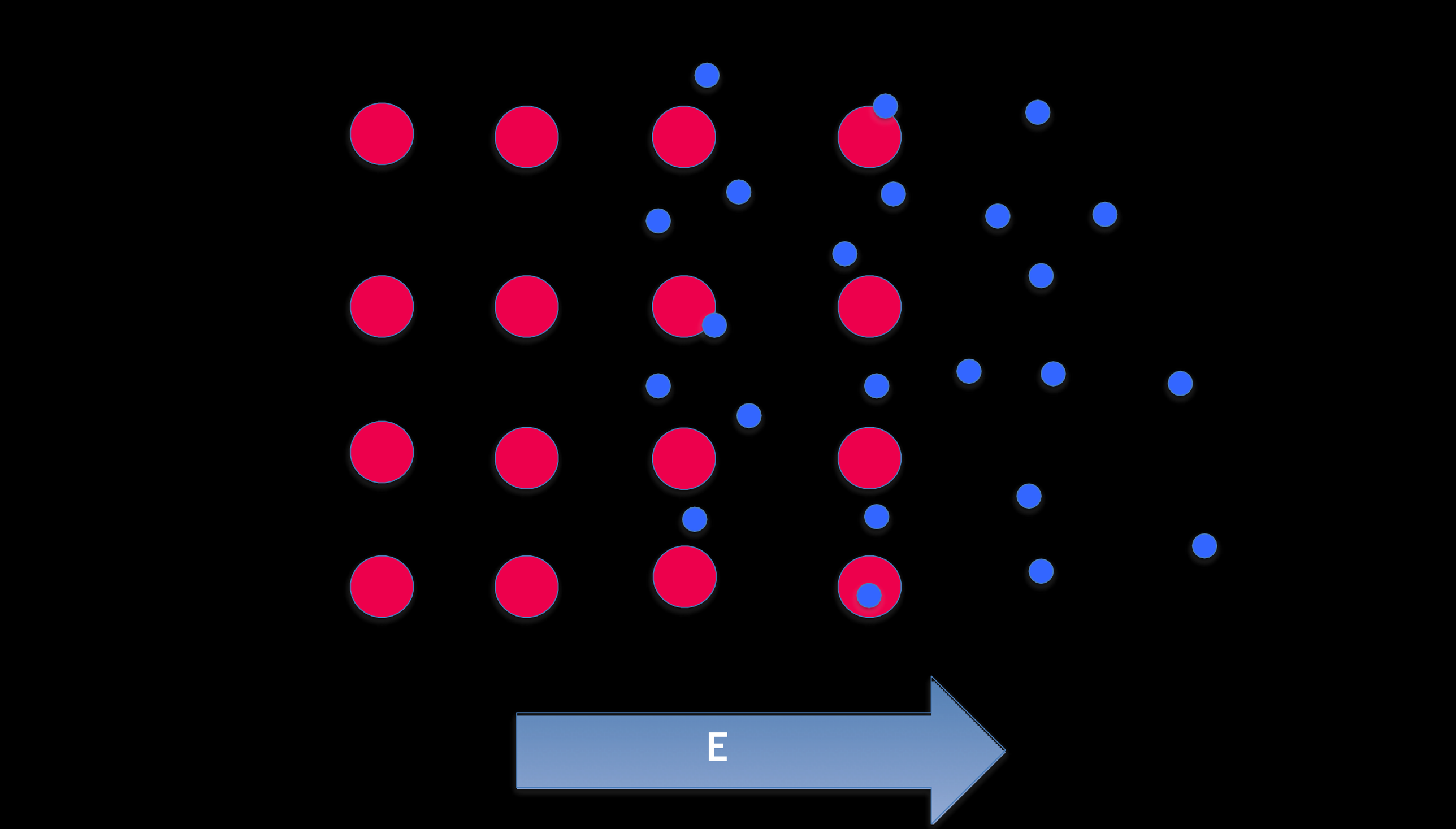
Positive Ions

Electrons



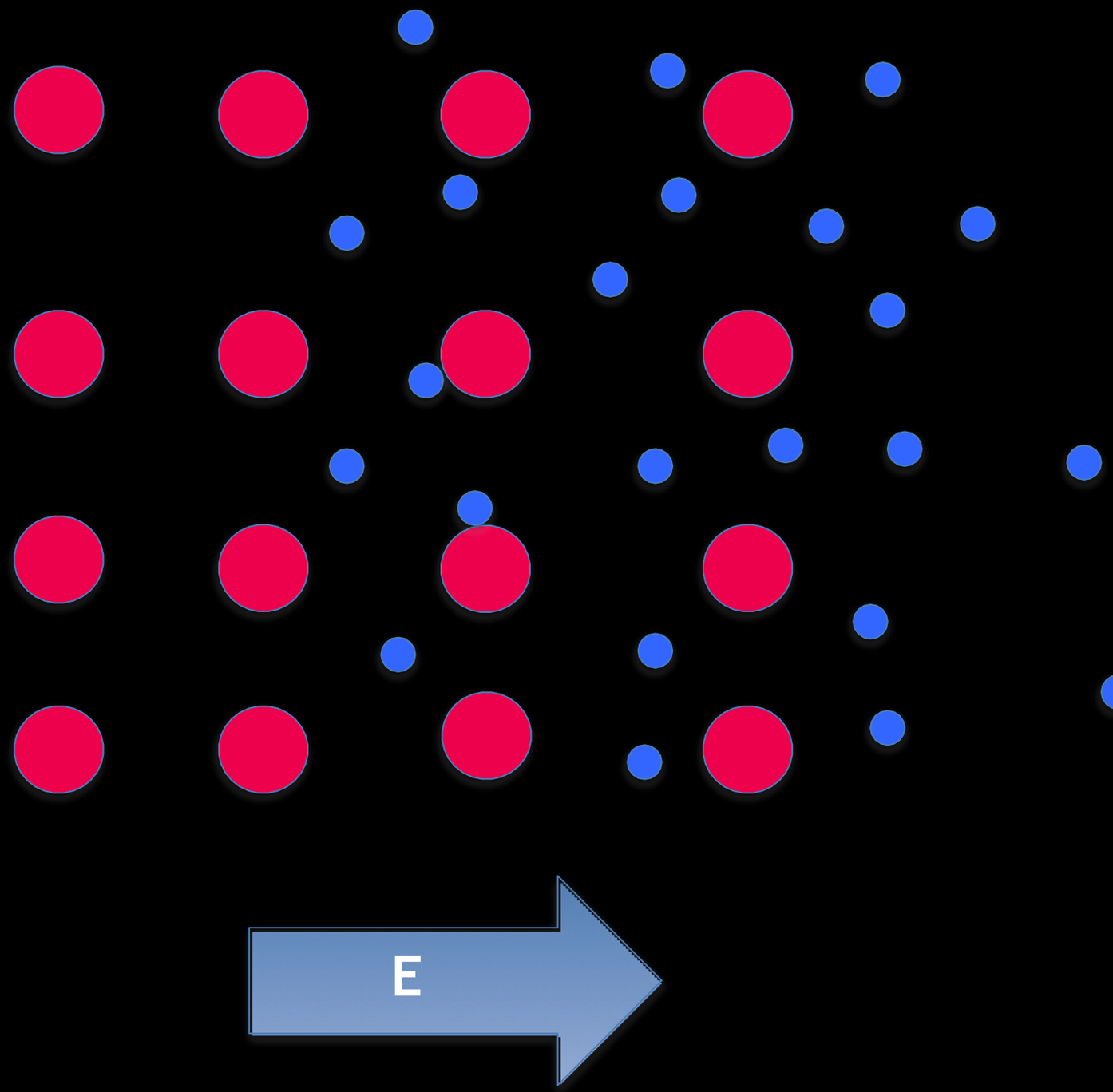
Positive Ions

Electrons



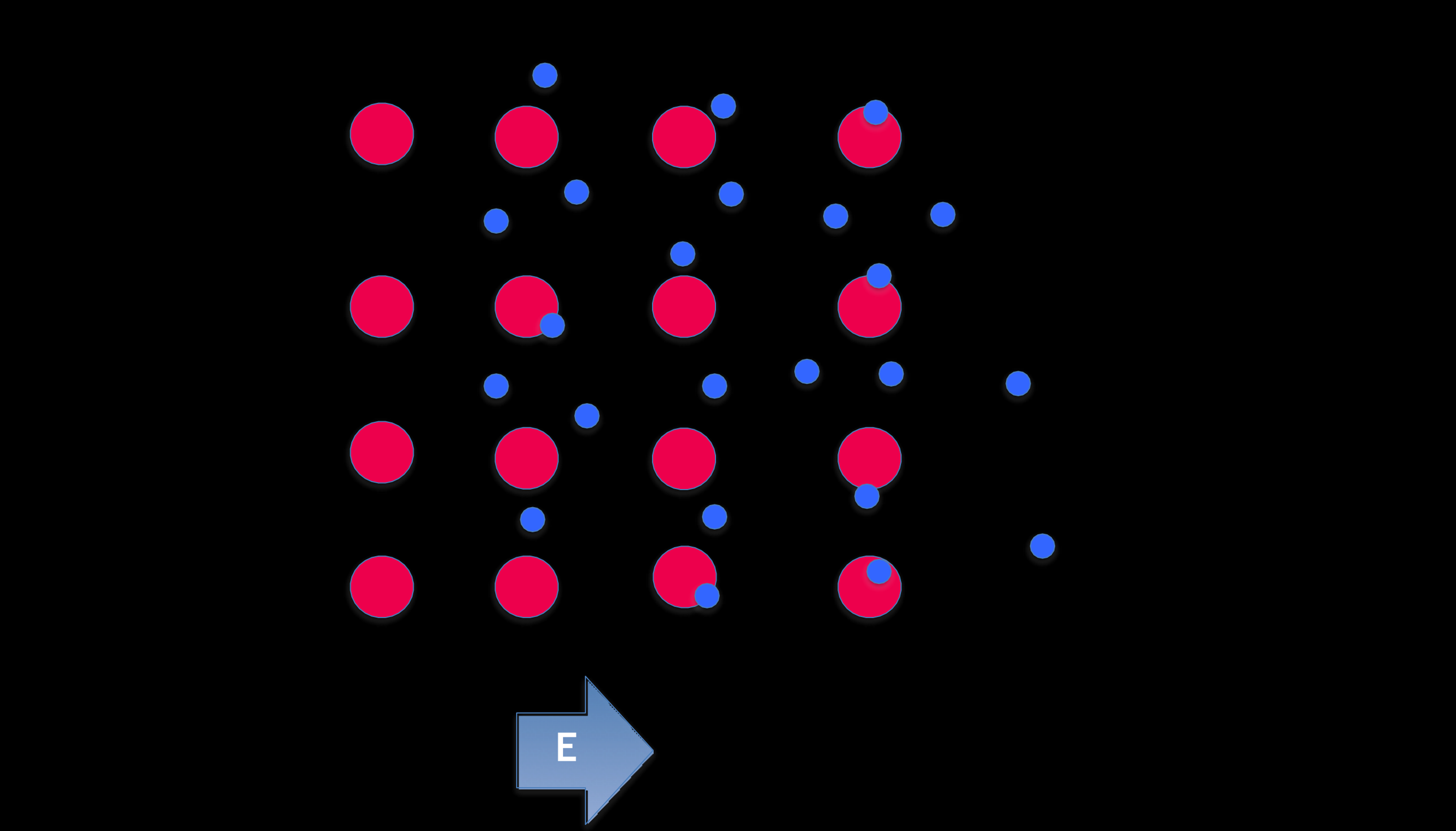
Positive Ions

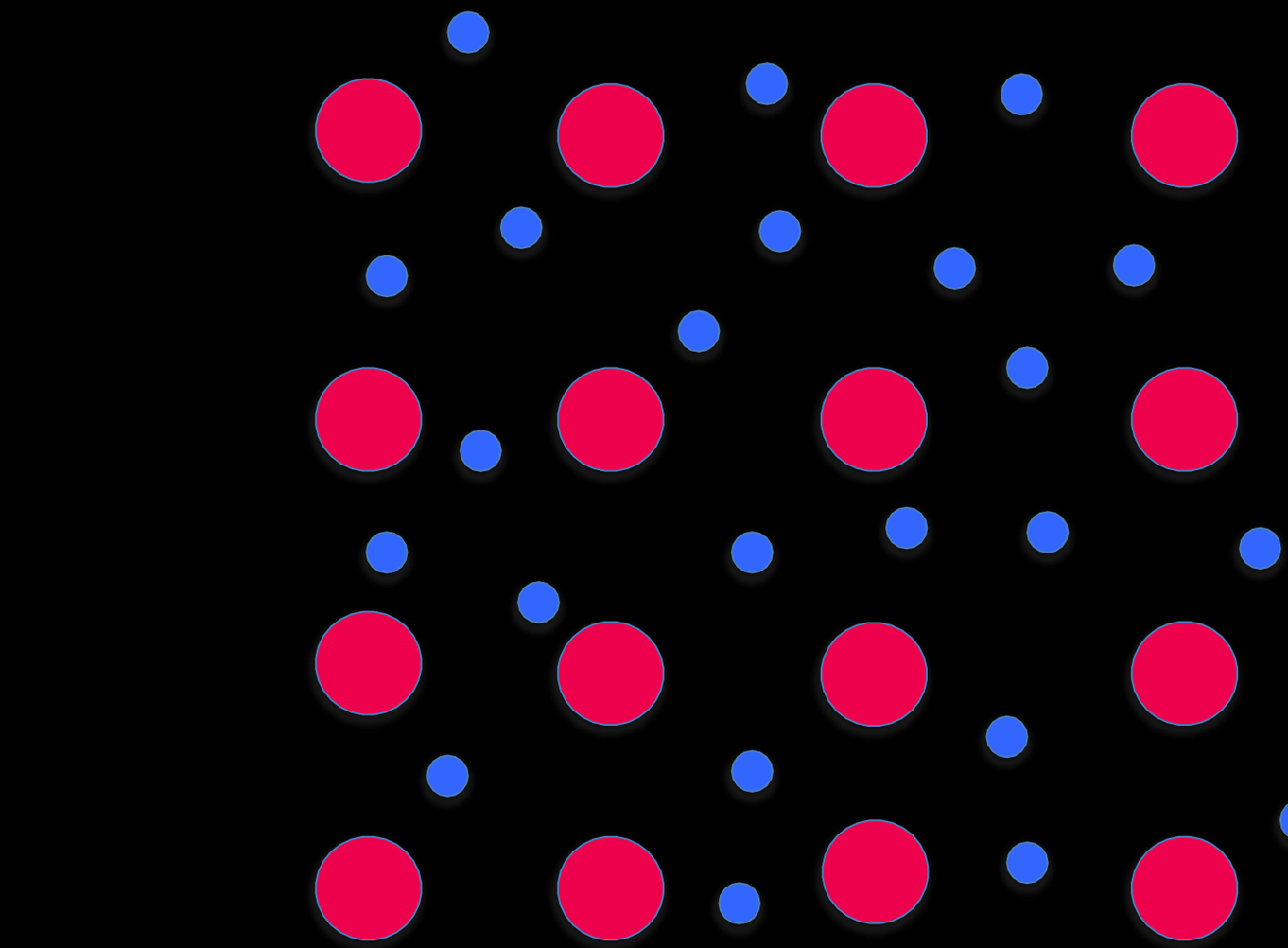
Electrons



Positive Ions

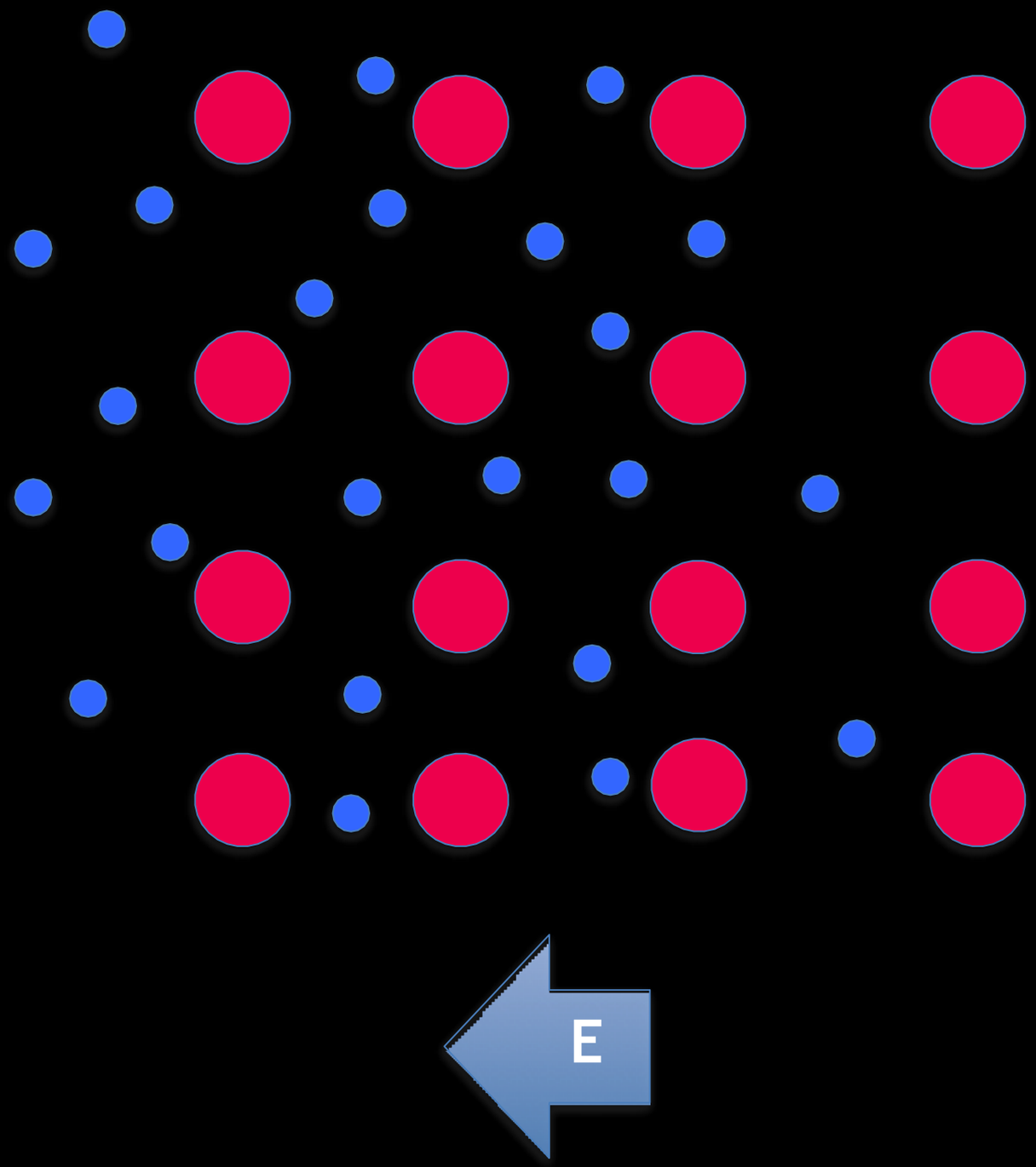
Electrons


E
Positive Ions
Electrons



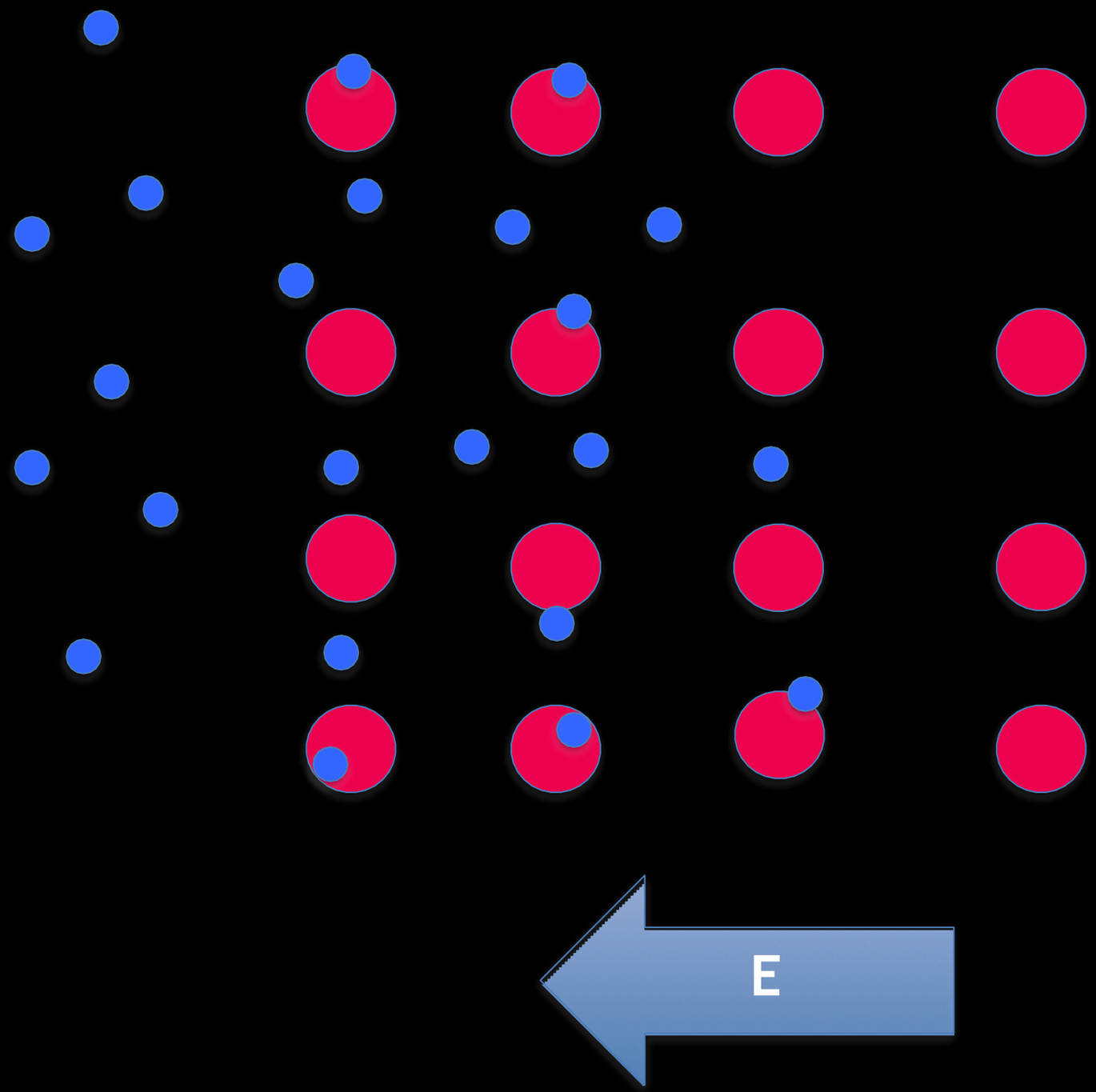
Positive Ions

Electrons



Positive Ions

Electrons



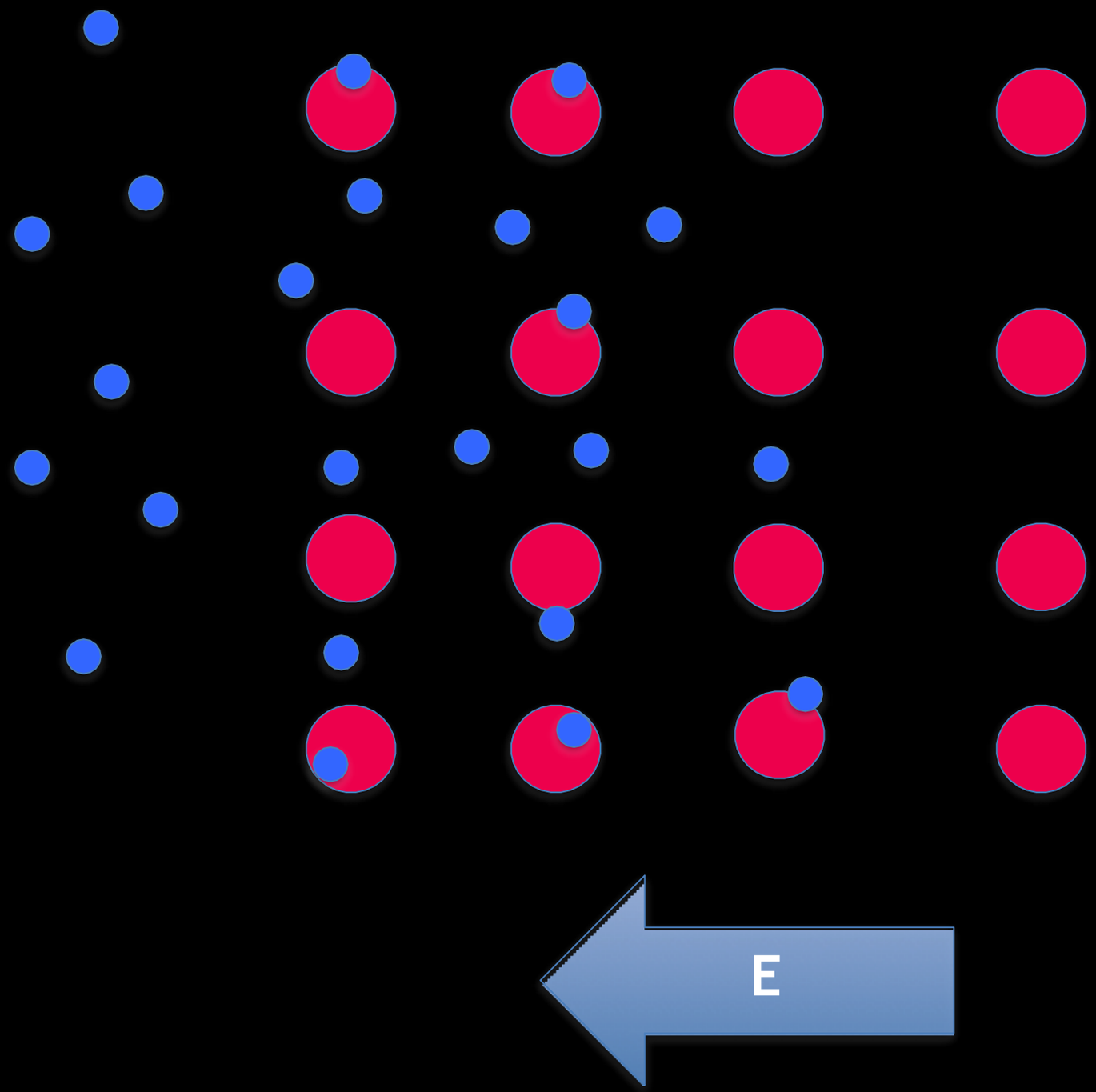
Positive Ions

Electrons

E

Positive Ions

Electrons



Positive Ions

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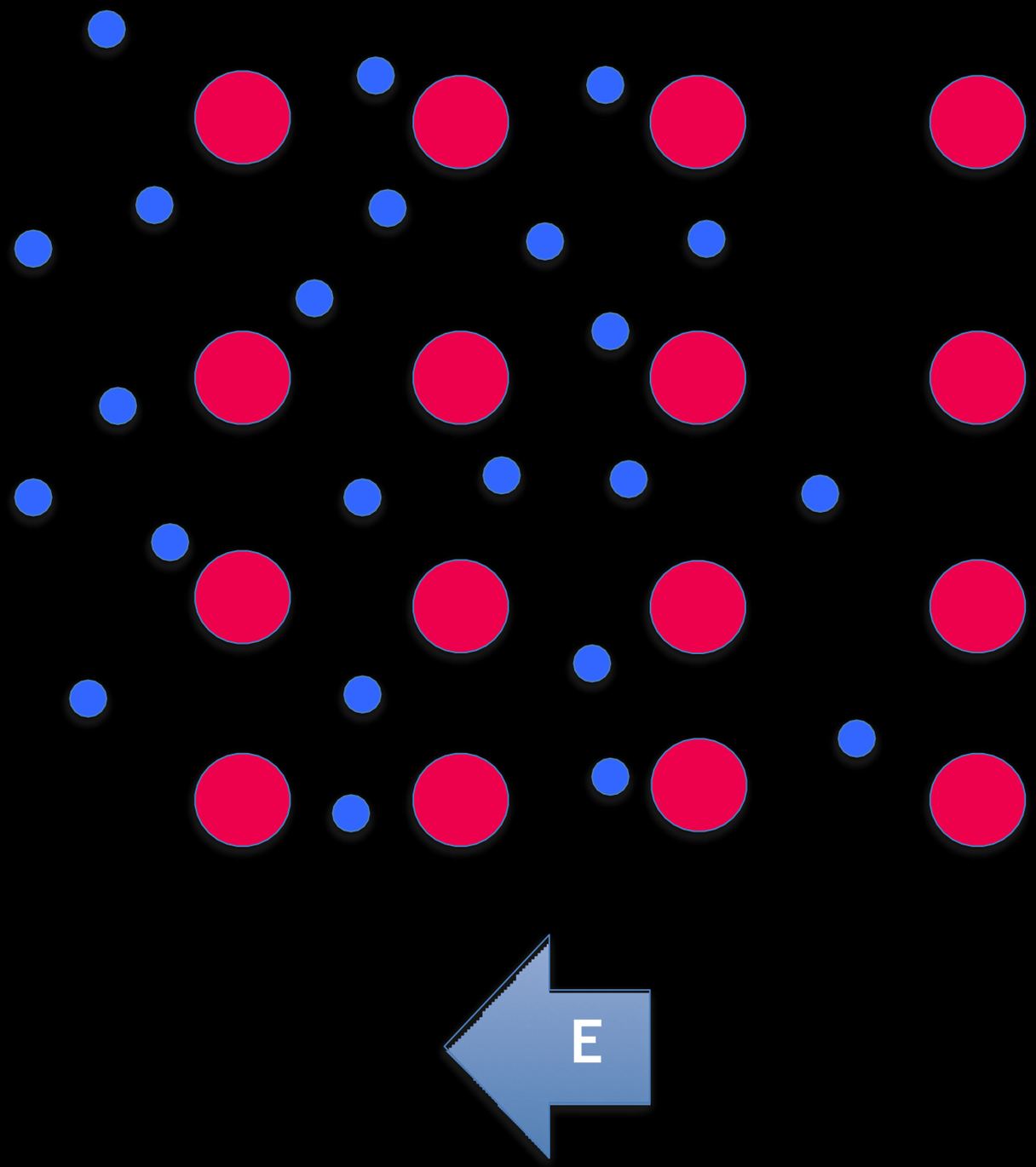

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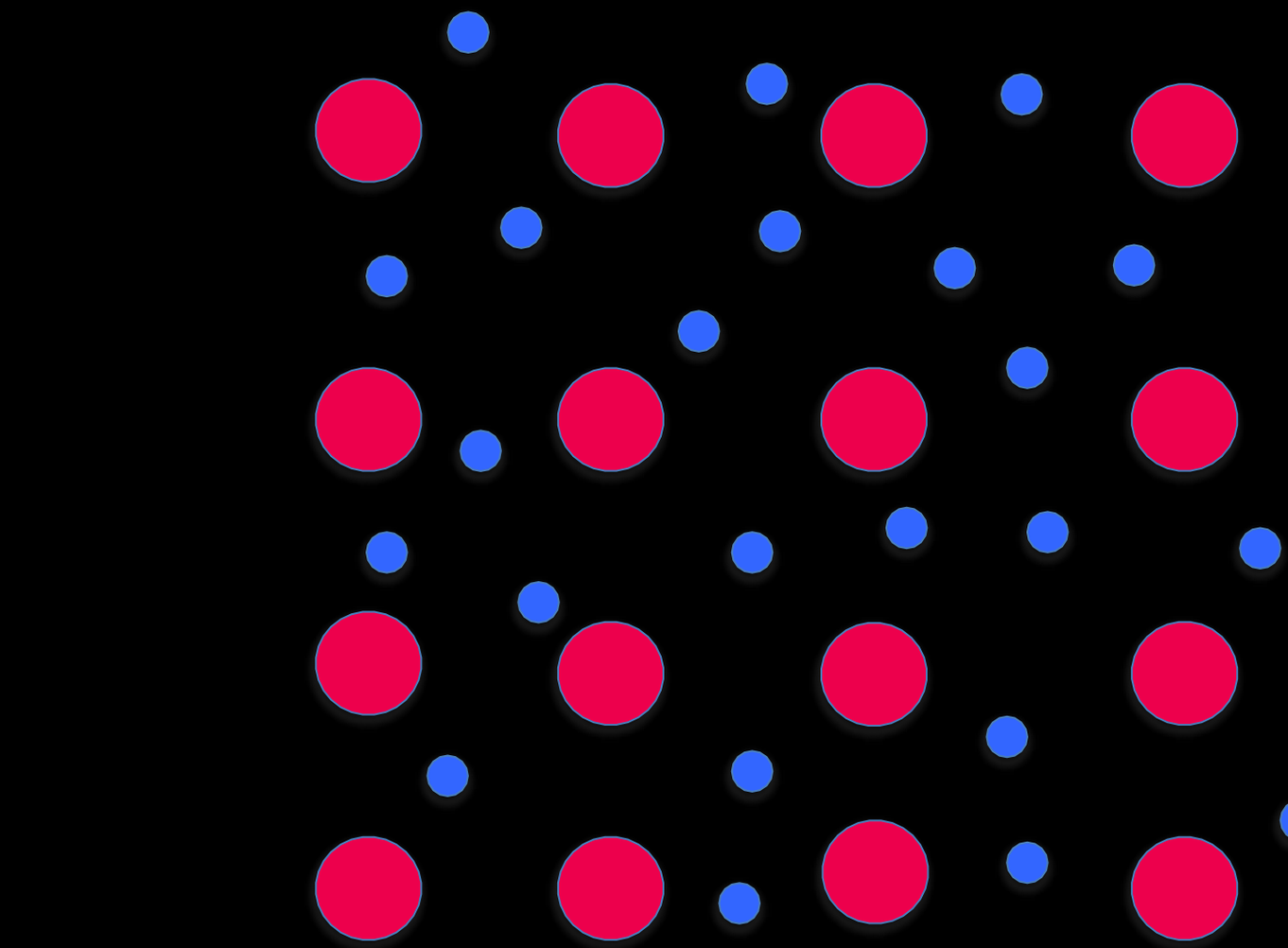

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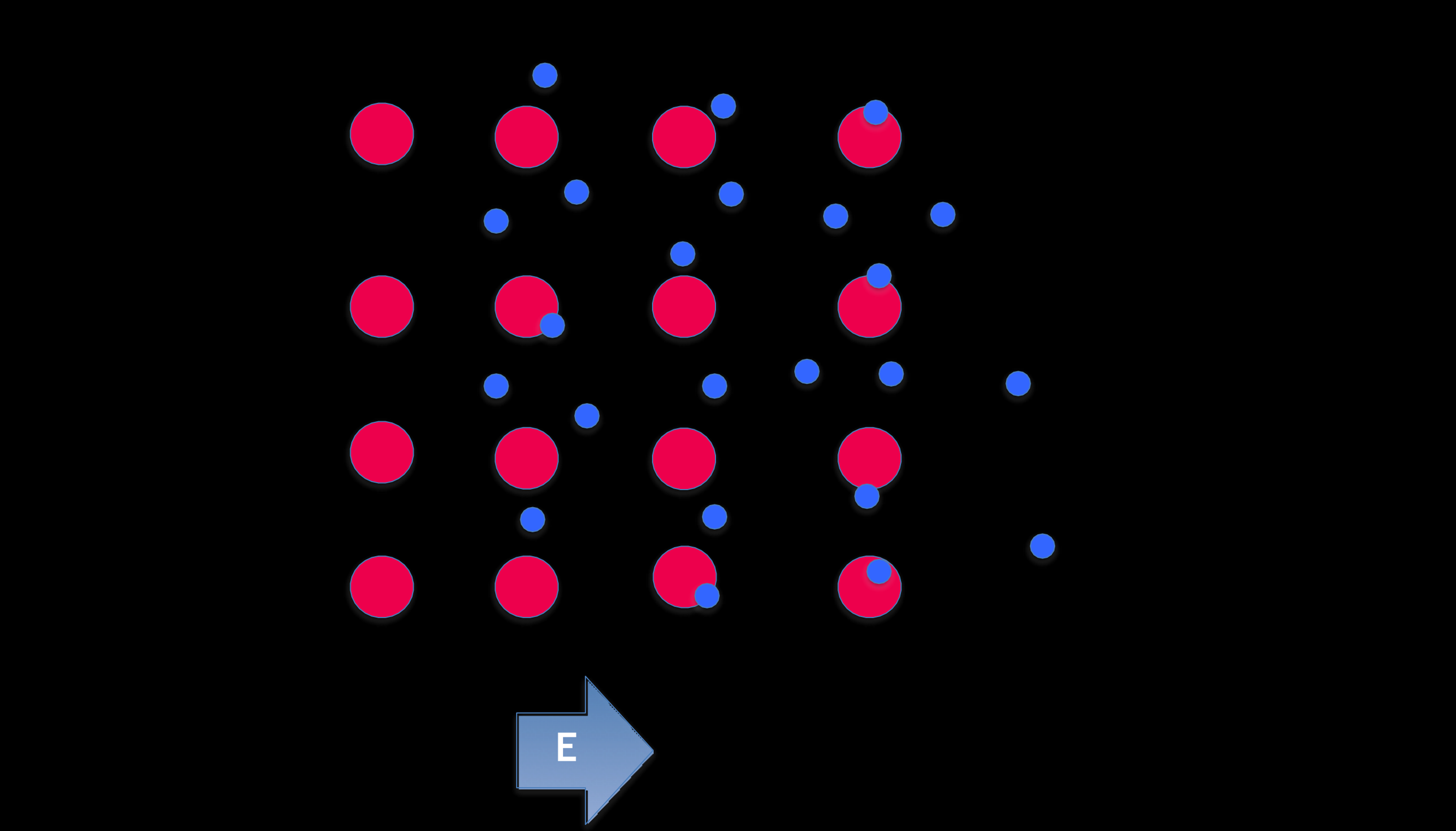
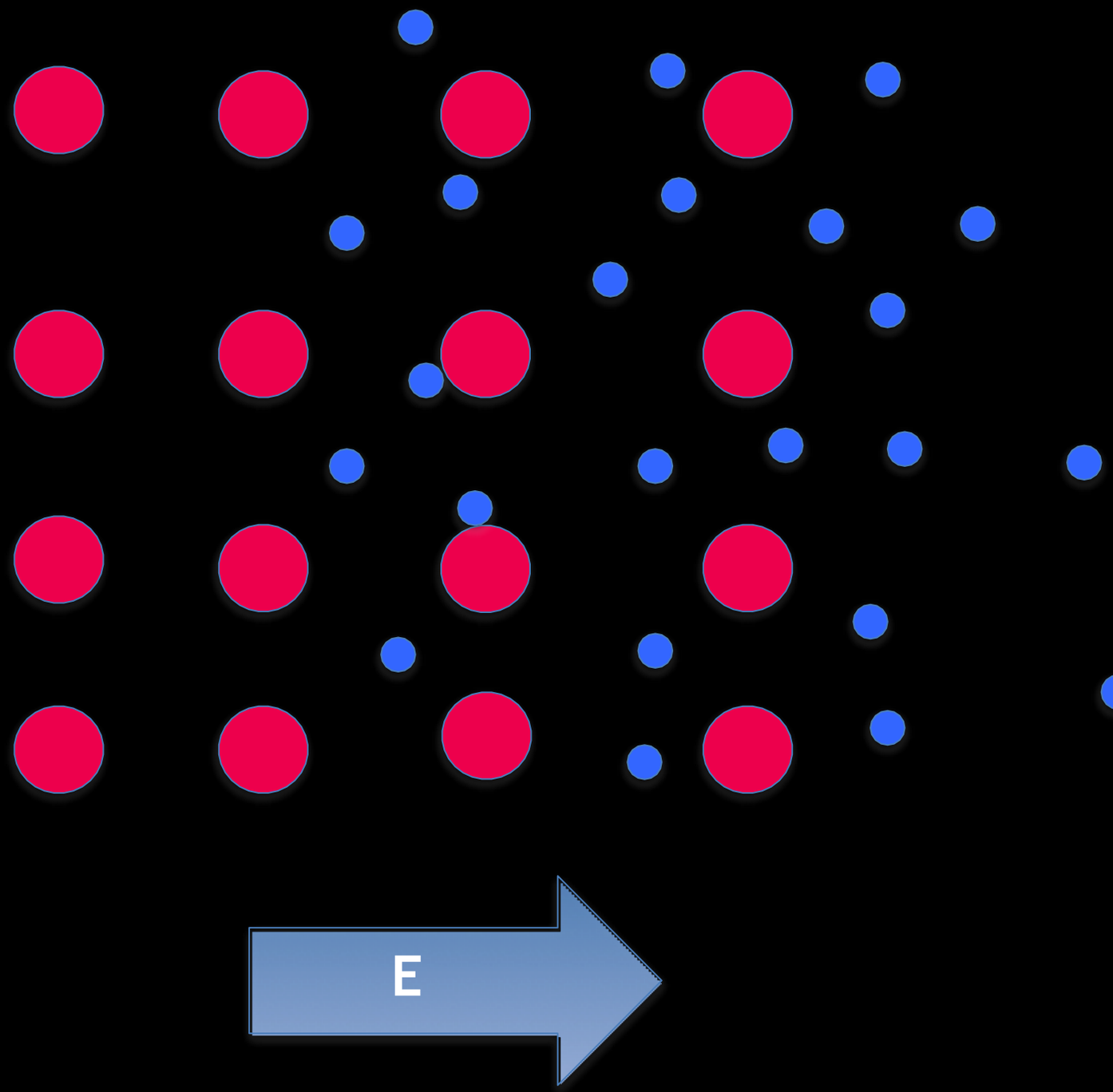

E
Positive Ions
Electrons



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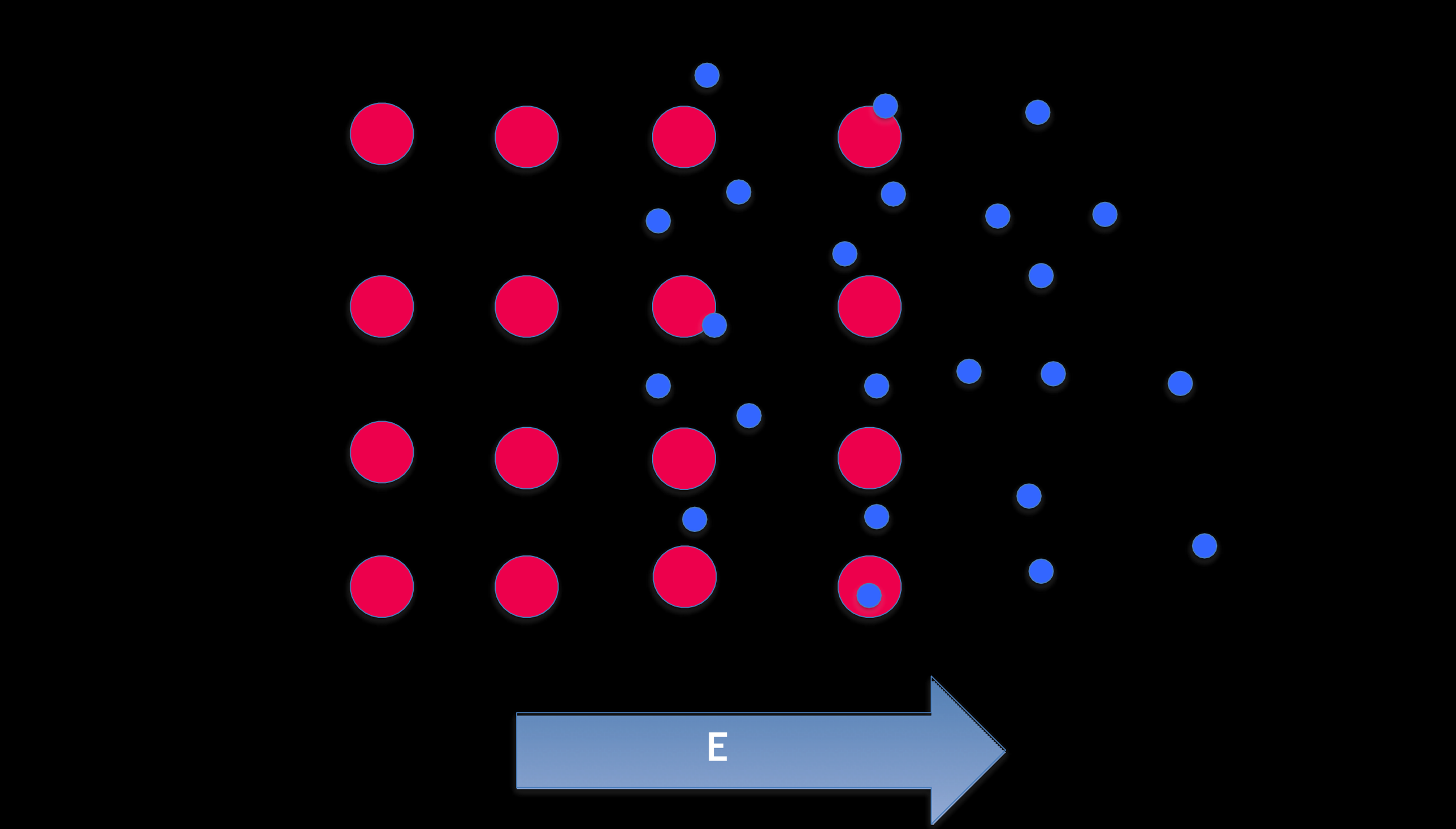

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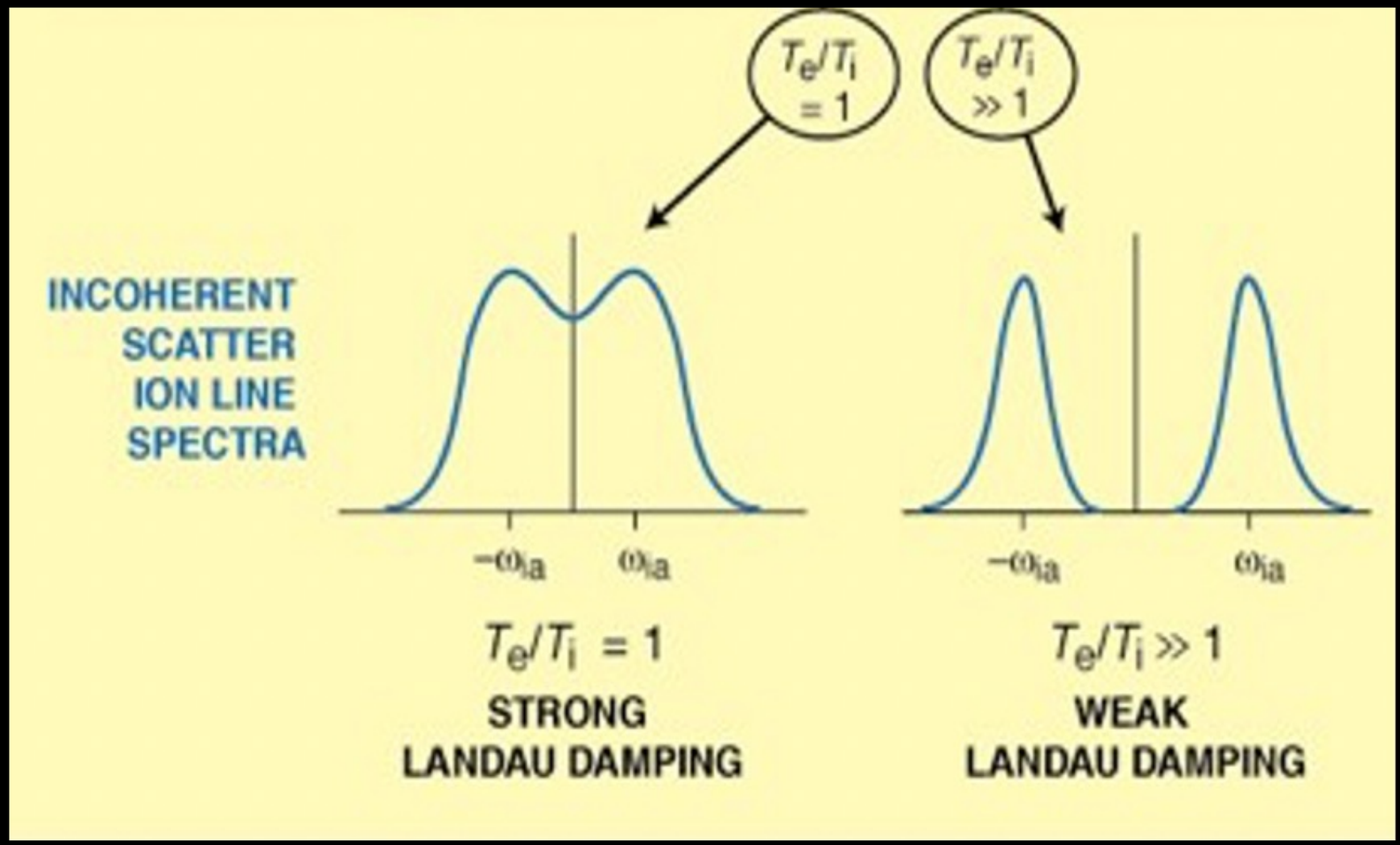
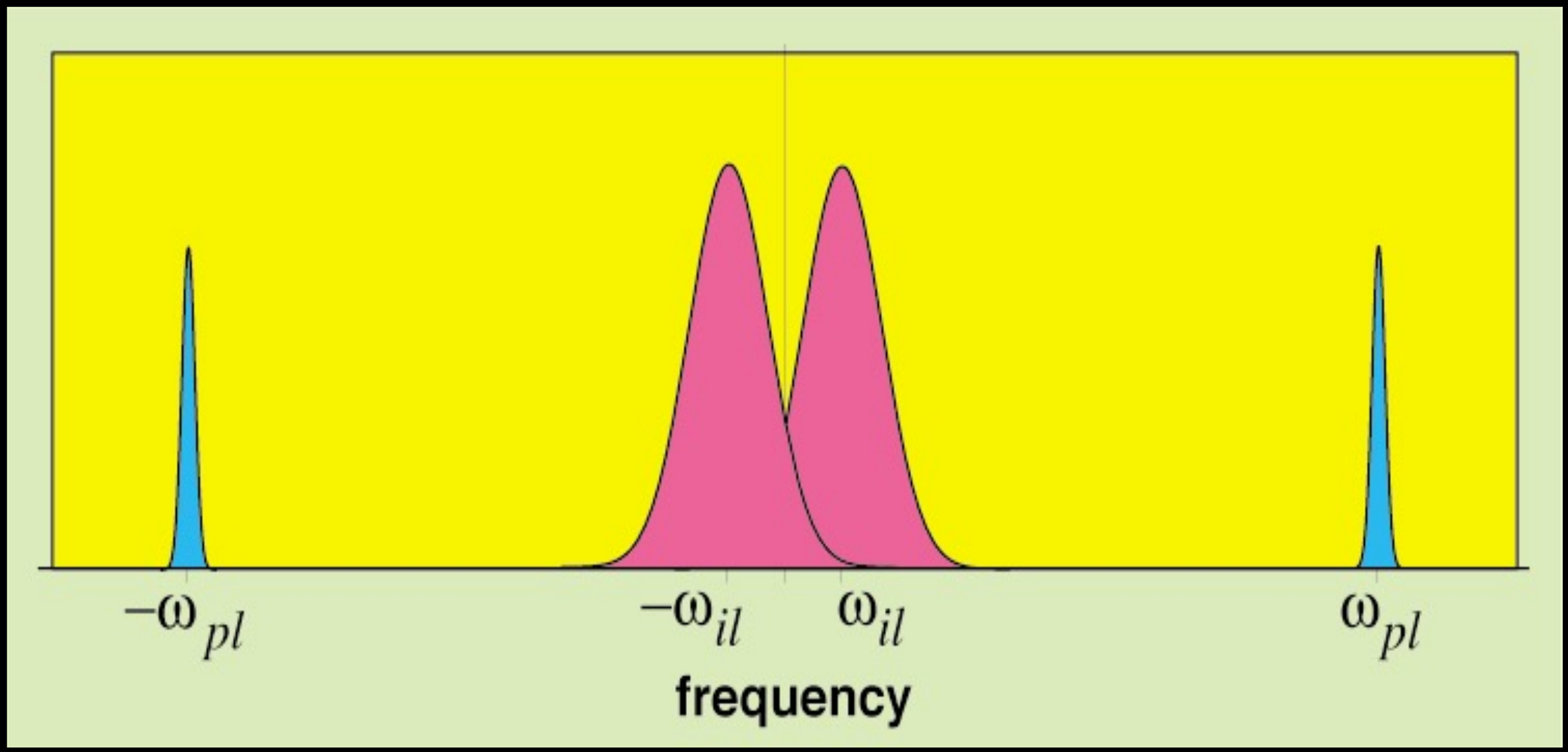

INCOHERENT
SCATTER
ION LINE
SPECTRA
T_e/T_i = 1
$T_e/T_i \gg 1$
$-\omega_{ia}$
ω_{ia}
$-\omega_{ia}$
ω_{ia}
T_e/T_i = 1
STRONG
LANDAU DAMPING
$T_e/T_i \gg 1$
WEAK
LANDAU DAMPING

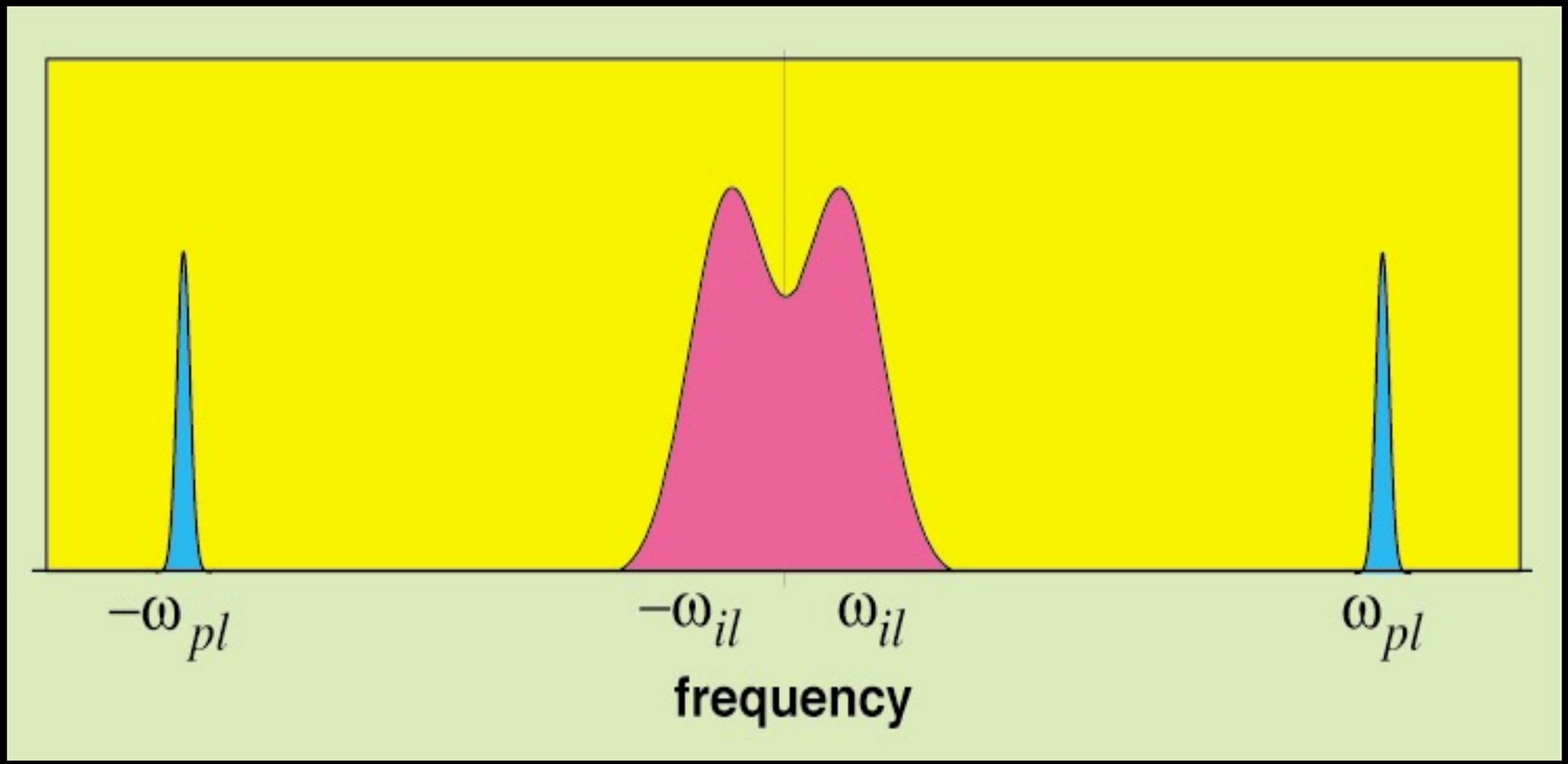
Landau wave-particle interactions

wave

particle gains energy

wave gains energy


$-\omega_{pl}$
$-\omega_{il}$
ω_{il}
ω_{pl}
frequency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$-\omega_{il}$
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ω_{pl}
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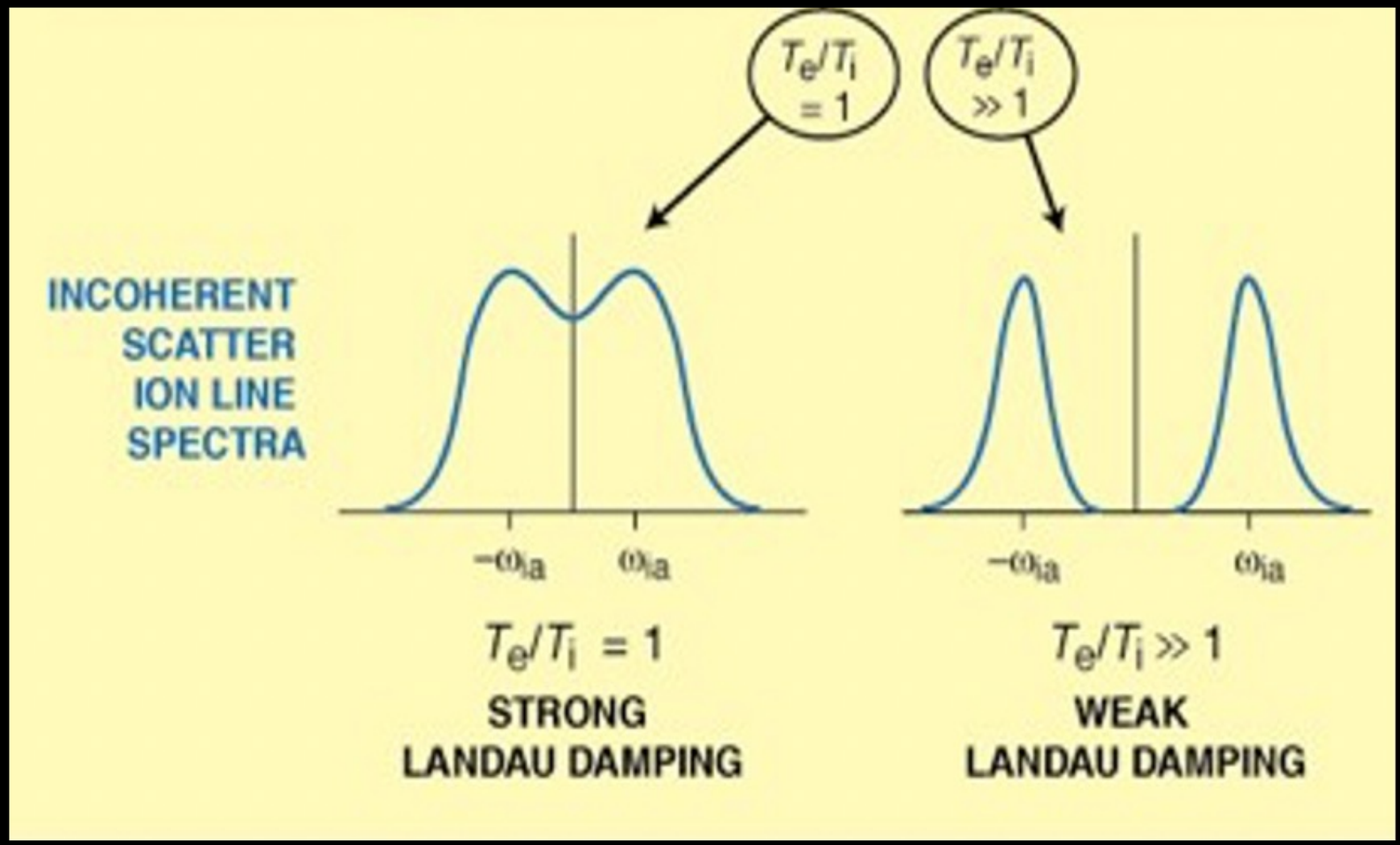
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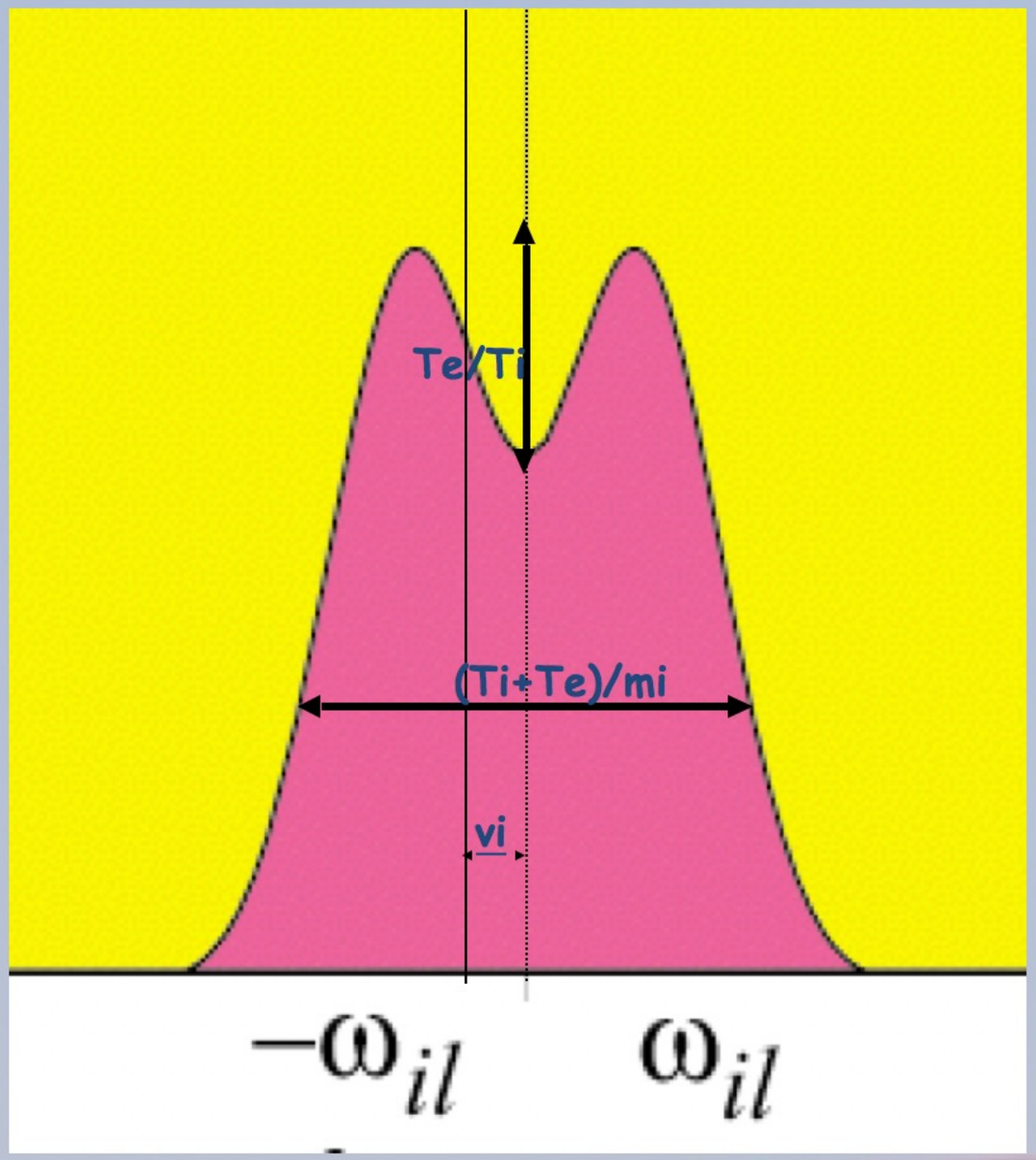
STRONG
LANDAU DAMPING
$T_e/T_i \gg 1$
WEAK
LANDAU DAMPING

Ion Acoustic Wave

$$\omega_r = k\sqrt{\frac{k_B}{m_i}\left(T_e + \gamma_i T_i\right)} \qquad \gamma_i \approx 3$$

$$\omega_i = \text{Strong function of } \frac{T_e}{T_i}$$

…or to sum up…



- Ion (and electron) temperature (Ti and Te) to ion mass (mi) ratio from the width of the spectra
- Electron to ion temperature ratio (Te/Ti) from "peak_to_valley" ratio
- Electron (= ion) density from total area (corrected for temperatures)
- Ion velocity (vi) from the Doppler shift