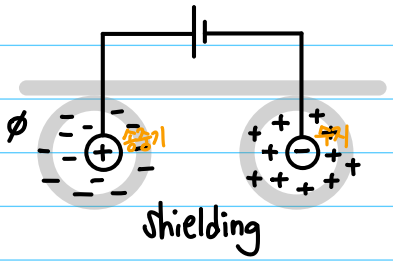
* What is a plasma?

A plasma is a quasineutral gas of charged and neutral particles which exhibits collective behavior.

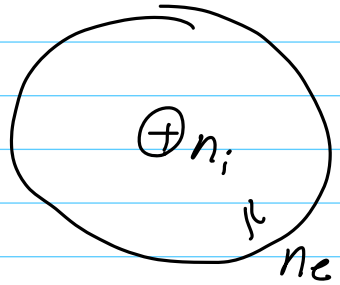
전하의 균형 (+,-) / 이온과 전자 / 중성

Gedank experiment (사고실험)

(V) 매력도,
(n) 군중의 밀도,
(E) 군중들의 바쁜 정도



〈가정〉
- 1-D (x)
- hydrogen plasma (Z=1)
- steady state
- $n_i \gg n_e$ (이온은 고정되있다고 가정)



(전자기학 식 정리한 사람)
Maxwell → J.J Thompson → Oliver Heaviside

$$\left.\begin{aligned} \nabla\cdot\vec{D}&=\sigma \\ \varepsilon_0\nabla\cdot\vec{E}&=\sigma \\ \vec{E}&=-\nabla\phi \\ -\varepsilon_0\nabla^2\phi&=\sigma \end{aligned}\right\} \rightarrow \frac{d^2\phi}{dx^2}=-\frac{\sigma}{\varepsilon_0}=-\frac{1}{\varepsilon_0}(en_i-en_e)$$

$$\left(\text{put } n_i=n,\ n_e=n\cdot\exp\left(\frac{e\phi}{kT_e}\right)=n\left(1+\frac{e\phi}{kT_e}+\cancel{\cdots}\right)\ \text{단, } \left|\frac{e\phi}{kT_e}\right|\ll 1\right)$$

($e^x=1+x+\frac{x^2}{2!}+\cdots$) ($|x|\ll 1$)

$e\phi$: 중심에서 끌어당기는 힘
kT_e : 군중이 바쁜 정도

무한대에 있는 이온의 밀도 := n
& 이온은 움직이지 X

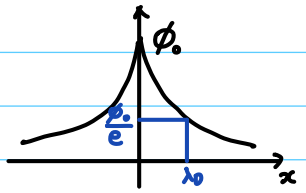
불손만의 가정

$$\frac{d^2\phi}{dx^2}=-\frac{\sigma}{\varepsilon_0}=-\frac{1}{\varepsilon_0}(en_i-en_e)=\frac{e}{\varepsilon_0}(n_e-n_i)=\frac{e}{\varepsilon_0}\left[\cancel{n}+\frac{ne\phi}{kT_e}-\cancel{n}\right]=\frac{ne^2}{\varepsilon_0 kT_e}\phi$$

Q. λ_D 밖에서도 $\frac{1}{e}$만큼의 퍼텐셜은 느끼지 않나?
∴ Quasi-neutral

$$\frac{d^2\phi}{dx^2}=\frac{1}{\lambda_D^2}\phi\ ,\qquad \boxed{\lambda_D=\sqrt{\frac{\varepsilon_0 kT_e}{ne^2}}}\ \text{: Debye length ; } \phi\text{가 } \tfrac{1}{e}\text{만큼 줄어드는 길이}$$

$$\rightarrow \phi=C_1e^{-\frac{|x|}{\lambda_D}}+C_2e^{\frac{|x|}{\lambda_D}}\quad (\text{초기조건 } \phi(x=0)=\phi_0,\ \phi(x\to\infty)=0)\quad \therefore \phi=\phi_0e^{-\frac{|x|}{\lambda_D}}$$



Q. 전하 구름의 가장자리, 즉 $x=\lambda_D$에서도
$kT_e=\frac{ne^2\lambda_D^2}{\varepsilon_0}=\frac{2}{3}\times\left(\frac{1}{2}mv^2\right)$ ..?
이면 물리적 의미..?
열E = n·전기퍼텐셜E ..?
$\frac{1}{2}mv^2=\frac{3}{2}kT_e=\frac{3ne^2\lambda_D^2}{2\varepsilon_0}$
맞는 것인가?
맞다면 n은 몇 일까?

Q. quasi-neutrality의 의미.

플라즈마 정의

① $\lambda_D \ll L$; quasi neutrality ($n_e\simeq n_i\simeq n$)

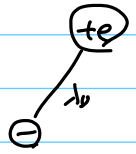
② $N_D=\frac{4}{3}\pi\lambda_D^3 n \gg 1$: Debye sphere 내부 입자수 $\gg 1$; Collective behavior

③ $\omega\tau\gg 1$: ω : plasma frequency, τ : neutral과의 collision time
($\omega\gg\frac{1}{\tau}$) : plasma frequency ≫ collision frequency

* 입자의 평균 운동에너지

$$\overline{\frac{1}{2}mv_{TH}^2}=\frac{3}{2}kT$$

$$kT=eV\rightarrow T=\frac{1eV}{k}=\frac{1.6\times10^{-19}\ J}{1.38\times10^{-23}\ J/K}=11600\ K\rightarrow \underline{10keV\sim10^8K=1억^\circ C}$$



TMI: Debye는 Arnold Sommerfeld의 제자
자기는 노벨상 X
제자 4명 노벨상

$(n_i \approx n_e \approx n)$

$$\frac{d^2\phi}{dx^2} = \frac{ne^2}{\varepsilon_0 kT}\phi$$

$$\frac{d^2\phi}{dx^2} = \frac{e}{\varepsilon_0}(n_e - n_i) \quad \left(\lambda_D^2 = \frac{\varepsilon_0 kT}{ne^2} \rightarrow \frac{e}{\varepsilon_0} = \frac{kT}{ne\lambda_D^2}\right)$$

$$\sim \frac{\phi}{L^2} = \frac{e}{\varepsilon_0}(n_e - n_i) = \frac{kT}{\lambda_D^2 ne}(n_e - n_i)$$

끌려가는 경우보다 ↙ 내가 너무 바쁜 경우

$$e\phi \ll kT_e$$

$$\frac{e^2L^2}{\varepsilon_0}(n_e - n_i) \ll kT$$

$$\frac{L^2}{\lambda_D^2}\frac{(n_e - n_i)kT}{n} \ll kT$$

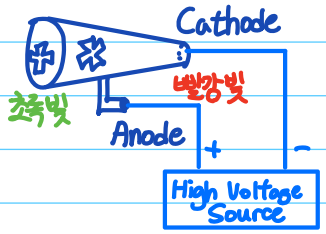
$$\frac{n_e - n_i}{n} \ll \frac{\lambda_D^2}{L^2} \longrightarrow 0 \quad (\lambda_D \ll L)$$

$$\therefore n_e = n_i$$

(quasi-neutrality)

〈1강〉

* Crookes Tube



- First Identified in a Crookes tube : William Crookes
  plasma → radiant matter → The fourth state of matter
- Cathode ray = electron : JJ Thomson
- The term "plasma" : Irving Langmuir

plasma의 그리스어 : πλάσμα ; "to mold" or "anything formed"
(plasma)

질문

Q. 지구 상에는 왜 플라즈마가 적은가?

- 온도가 낮고, 이온화에너지가 더 크기 때문.