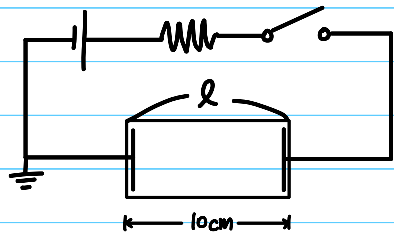
29강

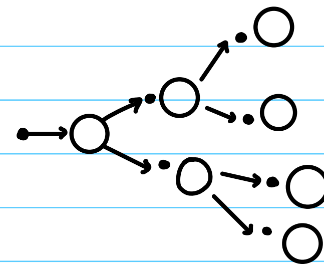
Plasma Breakdown



breakdown (방전, 절연파괴)

$V = V_s$: 방전 개시 전압

Seed electron
- cosmic ray
- radiation
- 자외선



J.S. Townsend (1858 ~ 1947)
$$\left[\begin{array}{l} I = I_0 e^{\alpha l} \\ \dfrac{\alpha}{P} = A\exp\left(-\dfrac{B}{E/P}\right) \end{array}\right]$$

① α - 작용 (e)

α : 단위 길이 당 이온화 수

$n \alpha \, dl = dn \qquad \dfrac{dn}{n} = \alpha \, dl \qquad \therefore \underline{n = n_0 e^{\alpha l}}$

$\vec{J} = \sum n q \vec{u} \propto n \quad \Rightarrow \quad \underline{I = I_0 e^{\alpha l}}$

δ : 전자가 이온화 에너지를 얻을만큼 이동한 거리

$\underline{U_I = E\delta}$, $(\lambda > \delta)$

$\underline{\dfrac{n}{N} = \exp\left(-\dfrac{\delta}{\lambda}\right)}$, $\underline{n = N\lambda\alpha}$

$\hookrightarrow \cancel{N}\exp\left(-\dfrac{\delta}{\lambda}\right) = \cancel{N}\lambda\alpha \Rightarrow \dfrac{\lambda\alpha}{P} = \dfrac{1}{P}\exp\left(-\dfrac{\overset{\delta}{U_I/\lambda P}}{E/P}\right)$

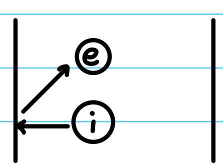
$\therefore \underline{\dfrac{\alpha}{P} = \dfrac{1}{P\lambda}\exp\left(-\dfrac{V_I/\lambda P}{E/P}\right)}$, $\left(A = \dfrac{1}{P\lambda}, \; B = \dfrac{V_I}{P\lambda}\right)$

seed 전자가 mean free path 가기 전에,

충분한 이온화에너지를 가지고 때려주면 α가 exponential 하게 증가.

③ γ - 작용 (Secondary e)

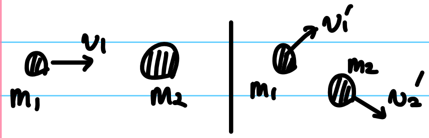
벽



② β - 작용 (i)

$$X^+ + Y \rightarrow X^+ + Y^+ + e$$

Head on collision



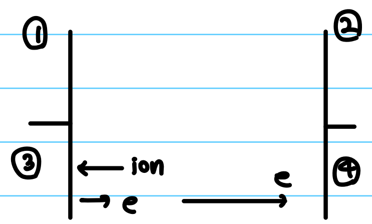
$$\left.\begin{aligned} m_1 v_1 &= m_1 v_1' + m_2 v_2' \\ \tfrac{1}{2} m_1 v_1^2 &= \tfrac{1}{2} m_1 v_1'^2 + \tfrac{1}{2} m_2 v_2'^2 \end{aligned}\right) \rightarrow v_2' = \frac{2 m_1 v_1}{m_1 + m_2}$$

$$K = \frac{\frac{1}{2} m_2 v_2'^2}{\frac{1}{2} m_1 v_1^2} = \frac{m_2}{m_1 v_1^2} \frac{4 m_1^2 v_1^2}{(m_1+m_2)^2} = \frac{4 m_1 m_2}{(m_1+m_2)^2} \quad , \quad \bar{K} = \frac{2 m_1 m_2}{(m_1+m_2)^2} \approx \frac{2 m_2}{m_1} \sim 10^{-4}$$

(energy loss factor)

이온이 전자와 충돌하여 이온화를 시키는 것은
거의 영향을 주지 못한다.

[α, β, γ 작용 모두 고려]



①~②

$$I_0 \longrightarrow I_0 e^{\alpha l}$$

②~③   ③

ion : $I_0 e^{\alpha l} - I_0$,   e : $\gamma (I_0 e^{\alpha l} - I_0)$

③~④

$$\gamma (I_0 e^{\alpha l} - I_0) e^{\alpha l} = \eta I_0 e^{\alpha l}$$

$$\therefore \eta = \gamma (e^{\alpha l} - 1)$$

$$\Rightarrow I = I_0 e^{\alpha l} + \eta I_0 e^{\alpha l} + \eta^2 I_0 e^{\alpha l} + \cdots$$

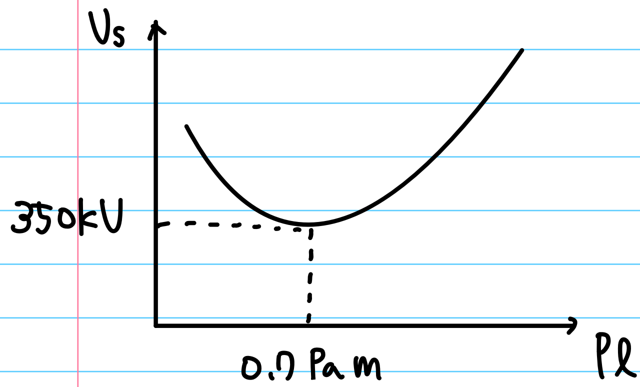
$$= (1 + \eta + \eta^2 + \cdots) I_0 e^{\alpha l}$$

$$= \frac{I_0}{1 - \eta} e^{\alpha l}$$

$\eta = 1$ 이면, $I_0 = 0$ 이더라도 I가 존재할수 있다.

↳ Breakdown condition $\quad \eta = \gamma (e^{\alpha l} - 1) = 1$ //

F. Paschen (1848~1945)



$\gamma=1$ 인 상황

$$e^{\alpha l}-1=\frac{1}{\gamma}, \quad e^{\alpha l}=1+\frac{1}{\gamma}$$

$$\left.\begin{aligned} &\alpha l=\Phi=\ln\left(1+\frac{1}{\gamma}\right) \\ &\frac{\alpha}{P}=A\exp\left(-\frac{B}{E/P}\right)\end{aligned}\right\} \Rightarrow \alpha l = AP\exp\left(-\frac{B}{E/P}\right)=\Phi$$

$$(E=V_s/l) \Rightarrow \exp\left(-\frac{B}{V_s/Pl}\right)=\frac{\Phi}{APl}$$

$$-\frac{B}{V_s/Pl}=\ln\frac{\Phi}{APl}, \quad -\frac{BPl}{V_s}=\ln\frac{\Phi}{APl}$$

$$V_s=-\frac{BPl}{\ln\frac{\Phi}{APl}} \qquad \therefore V_s=\frac{BPl}{\ln\frac{APl}{\Phi}}$$