No.
Date :

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"Resume Materi"

2.4. Potensial Listrik

Sifat dari muatan listrik $\vec{B}$, yaitu :

$\nabla \times \vec{E} = 0$, ini berarti medan $\vec{E}$ merupakan gradien suatu skalar.

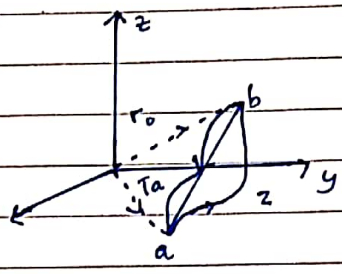
Gradien suatu skalar, jadi :

$\vec{E} \sim \nabla \phi$, maka $\nabla \times \vec{E} = 0$

Menurut teorema stokes

$\oint \vec{E} \, a\vec{p} = \int \nabla \times \vec{E} \, d\vec{r} = 0$

Artinya , $\oint_a^b \vec{E} \cdot a\vec{f}$



Hal ini berlaku untuk medan $\vec{E}$ dari suatu muatan listrik atau setiap konfigurasi muatan.

Bila lintasan a ke b tertutup melalui jalan I $\oint E \cdot a\vec{p} \neq 0$

Selanjutnya : $E = -\nabla V$

$\nabla \cdot \vec{E} = -\nabla \cdot \nabla V$

$\nabla \cdot \vec{E} = -\nabla^2 V$

$\rho / \varepsilon_0 = -\nabla^2 V$

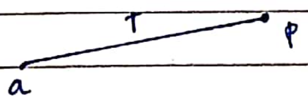
$\nabla V \cdot d\rho = dv$

$E = -\nabla V$

$\int \vec{E} \cdot d\vec{p} = -\int \nabla V \cdot d\vec{p} = -\int dv$

$V_b - V_a = \int_a^b \vec{E} \cdot a\vec{p} \rightarrow V(p) = -\int \vec{E} \cdot a\vec{p}$ (Rumus umum)

Misal :



$V(p) = -\int_{\infty}^{T} \vec{E} \cdot a\vec{p}$

$= -\int_{\infty}^{T} \frac{1}{4\pi\varepsilon_0} \frac{Q}{r^2} \, dr$

$\rightarrow V(p) = \frac{1}{4\pi\varepsilon_0} \frac{Q}{r}$

No.

Date :

Potensial oleh distribusi muatan

1). Untuk kawat

$$V(p) = \frac{1}{4\pi\varepsilon_0} \int \frac{\lambda\, dr}{r}$$

2). Untuk distribusi permukaan

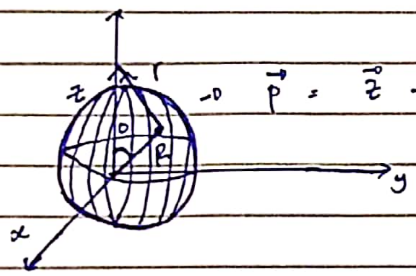
$$V(p) = \frac{1}{4\pi\varepsilon_0} \int \frac{\sigma\, \vec{a_s}}{r}$$

3). Distribusi oleh Volume

$$V(p) = \frac{1}{4\pi\varepsilon_0} \int \frac{\rho\, a_\sigma}{r}$$

Contoh.

1. Potensial oleh muatan permukaan bersambung



$\to \vec{P} = \vec{z} - \vec{R}$

bola konduktor bermuatan homogen dengan rapat muatan σ. Berapa potensial dititik P.

Solusi : distribusi muatan pada permukaan bola, maka :

$$V(p) = \int \frac{1}{4\pi\varepsilon_0} \frac{\sigma\, \vec{a_s}}{r}$$

$$= \frac{\sigma}{4\pi\varepsilon_0} \int \frac{R^2 \sin\theta\, d\theta\, d\phi}{(z^2 + R^2 - 2Rz\cos\theta)^{1/2}}$$

$$= \frac{\sigma . R^2}{4\pi\varepsilon_0} \int_0^{\pi} \int_0^{2\pi} \frac{d\phi\, \sin\theta\, d\theta}{(z^2 + R^2 - 2Rz\cos\theta)^{1/2}}$$

$$= \frac{\sigma R^2}{4\pi\varepsilon_0} \frac{1}{2} \int_0^{\pi} \frac{1}{Rz} \frac{d(-2Rz\cos\theta)}{(z^2 + R^2 - 2Rz\cos\theta)^{1/2}}$$

$$= \frac{\sigma R}{2\varepsilon_0 z} \left[(z^2 + R^2 + 2Rz)^{1/2} - (z^2 + R^2 - 2Rz)^{1/2} \right]$$

$$\therefore V(p) = \frac{\sigma R}{2\varepsilon_0 z} \left\{ [(R+z)^2]^{1/2} - [(R-z)^2]^{1/2} \right\}$$

Bila $z > R$, maka $[(R-z)^2]^{1/2} = z - R$, sehingga :

$$V(p) = \frac{\sigma R}{2\varepsilon_0 z} [(R+z) - (z-R)]$$

$$= \frac{\sigma R^2}{\varepsilon_0 z}$$

Bila $R > z$, maka $[(R-z)^2]^{1/2} = R - z$

$$V(p) = \sigma R / 2\varepsilon_0 z\, [(R+z) - R + z]$$

$$V(p) = \frac{\sigma R}{\varepsilon_0}$$

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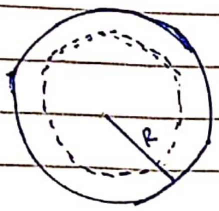
2). Potensial oleh muatan volume

a.



bola dengan rapat muatan ρ = konstan, dengan jari-jari R.
Hitung potensial pada
i $r < R$, ii $r > R$

Solusi : $r < R$, $E_1 \rightarrow \oint E_1 \, d\vec{s} = \dfrac{1}{\varepsilon_0} \rho V$.

$$E_1 (4\pi r^2) = \frac{1}{\varepsilon_0} \rho \left(\frac{4}{3} \pi r^3 \right)$$

$$\vec{E}_1 = \frac{1}{3\varepsilon_0} \rho r \, \hat{r}_0$$

$r > R$, $E_2 \rightarrow \oint E_2 \, d\vec{s} = \dfrac{1}{\varepsilon_0} \rho V$

$$E_2 (4\pi r^2) = \frac{1}{\varepsilon_0} \rho \left(\frac{4}{3} \pi R^3 \right)$$

$$\vec{E}_2 = \frac{1}{3\varepsilon_0 r^2} \rho R^3 \, \hat{r}_0$$

$$V_1 = - \int \vec{E} \cdot d\vec{l} = - \int_{\infty}^{R} E_2 \cdot d\vec{r} - \int_{R}^{r} \vec{E}_1 \cdot d\vec{r}$$

$$= - \int_{\infty}^{R} \frac{1}{3\varepsilon_0 r^2} \rho R^3 dr - \int_{R}^{r} \frac{1}{3\varepsilon_0} \rho r \, dr .$$

$$= - \frac{\rho R^3}{3\varepsilon_0} \int_{\infty}^{R} \frac{dr}{r^2} - \frac{\rho}{3\varepsilon_0} \int_{R}^{r} r \, dr$$

$$= \frac{\rho R^2}{3\varepsilon_0} + \frac{\rho R^2}{6\varepsilon_0} - \frac{\rho r^2}{6\varepsilon_0} = \frac{2\rho R^2}{6\varepsilon_0} + \frac{\rho R^2}{6\varepsilon_0} - \frac{\rho r^2}{6\varepsilon_0}$$

$$V_1 = \frac{\rho R^2}{\varepsilon_0} - \frac{\rho r^2}{6\varepsilon_0} . \qquad \frac{3}{6} \frac{\rho R^2}{\varepsilon_0} - \frac{\cancel{\rho}\, \rho r^2}{6\varepsilon_0}$$

$$\therefore \quad V_1 = \frac{\rho}{\varepsilon_0} \left(R^2 - \frac{r^2}{6} \right) \qquad = \frac{1}{6\varepsilon_0} \left(3\rho R^2 - \rho r^2 \right)$$

$$V_2 = \cancel{\rho R^3} - \int_{\infty}^{r} E_2 \cdot dr . \qquad = \frac{\rho}{6\varepsilon_0} \left(2R^2 - r^2 \right) .$$

$$= - \int_{\infty}^{r} \frac{1}{3\varepsilon_0} \int_{\infty}^{r} \frac{dr}{r^2}$$

$$= \frac{\rho R^3}{3\varepsilon_0 r}$$

No.

Date :

3). Potensial oleh muatan pada kawat

a) Kawat panjang sekali.

$$E_p = \frac{2\lambda}{4\pi \varepsilon_0 z}$$

$$V_p = -\int_{\infty}^{a} E \cdot a_p .$$

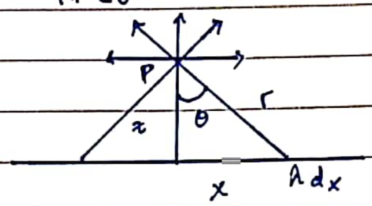
$$= \frac{-2\lambda}{4\pi\varepsilon_0} \int_{\infty}^{z} \frac{dz}{z}$$

$$= -\frac{2\lambda}{4\pi\varepsilon_0} \ln z$$

b). Kawat dengan panjang tertentu, misalnya $2l$

Dari perhitungan didepan

$$E_p = \frac{1}{4\pi\varepsilon_0} \frac{2\lambda l}{z\sqrt{z^2+l^2}}$$



$$V = \frac{2}{4\pi\varepsilon_0} \int_0^l \frac{\lambda\, dx}{r}$$

$$= \frac{2\lambda}{4\pi\varepsilon_0} \int_0^l \frac{dx}{(z^2+x^2)^{1/2}}$$

$$x = z \operatorname{tg} \theta$$

$$dx = z \sec^2 \theta \, d\theta$$

$$= \frac{2\lambda}{4\pi\varepsilon_0} \int_0^l z \frac{\sec^2\theta \, d\theta}{z(\operatorname{tg}^2\theta + 1)^{1/2}}$$

$$= \frac{2\lambda}{4\pi\varepsilon_0} \int_0^l \sec\theta \, d\theta$$

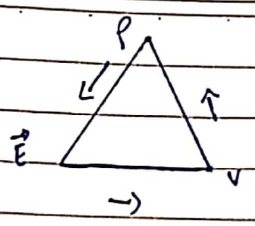
$$= \frac{2\lambda}{4\pi\varepsilon_0} \ln\left(\sec\theta + \operatorname{tg}\theta\right) + c$$

$$= \frac{2\lambda}{4\pi\varepsilon_0} \ln\left(\frac{\sqrt{x^2+z^2}}{z} + \frac{x}{z}\right)\Bigg|_0^l$$

$$\therefore V = \frac{\lambda}{2\pi\varepsilon_0} \ln\left(\frac{\sqrt{l^2+z^2}}{z} + \frac{l}{z}\right)$$

2.5. Hubungan antara $\vec{E}$, p dan V

Dalam elektronika hubungan antara kuat medan dengan rapat muatan volume dan V skalar.



$E = -\nabla V$

$\nabla^2 V = -\dfrac{\rho}{\varepsilon_0}$

$\left.\begin{aligned} \nabla \times \vec{E} &= 0 \\ \nabla \cdot \vec{E} &= \dfrac{1}{\varepsilon_0}\rho \end{aligned}\right\}$ Syarat elektrostatika

Bentuk Integralnya = $\vec{E} = \dfrac{1}{4\pi\varepsilon_0}\displaystyle\int \frac{dQ}{r^2}$; $dQ = \rho \, d\tau$

$= \dfrac{1}{4\pi\varepsilon_0}\displaystyle\int \frac{\rho \, d\tau}{r^2}$

$V = -\int \vec{E} \cdot d\vec{p}$ hubungan V dengan ρ =

$V = \dfrac{1}{4\pi\varepsilon_0}\displaystyle\int \frac{\rho \, d\tau}{r}$.

Solusi Segitiga diatas

1. Misal, E diketahui, V dan ρ dapat dihitung

$V = -\int E \cdot dp$

$\rho = \varepsilon_0 \nabla \cdot E$

2. Misal : V diketahui, E dan ρ dapat dicari

$E = -\nabla V$

$\rho = -\dfrac{1}{\varepsilon_0}\nabla^2 V$

3. Misal ρ diketahui, E dan V dapat dihitung

$E = \dfrac{1}{4\pi\varepsilon_0}\displaystyle\int \frac{\rho \, d\tau}{r^2}$

$V = \dfrac{1}{4\pi\varepsilon_0}\displaystyle\int \frac{\rho \, d\tau}{r}$

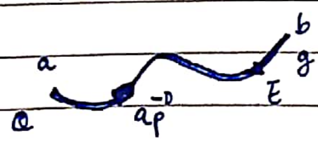
2.6. Usaha atau energi dalam Elektrostatika

$W = \int \vec{F} \cdot d\vec{s}$

Jika kerja yang dilakukan oleh gaya F melawan medan listrik yang ditimbulkan oleh muatan g, maka:

$W = \int (-F) \cdot ds$

misal, kita memindahkan muatan Q dari a ke b



$\vec{F} = \dfrac{Qg}{4\pi\varepsilon_0 r^2}\hat{r}_0$

$F = -QE$; $\vec{E} = \dfrac{-1}{4\pi\varepsilon_0}\dfrac{g}{r^2}\hat{r}_0$

No.

Date :

$$W = \int_a^b (-F) \cdot d\rho$$

$$= -\int_a^b Q\vec{E} \cdot d\vec{\rho}$$

$$= -Q \int_a^b E \cdot d\vec{\rho} \quad ; \quad -\int_a^b E \cdot a\vec{\rho} = V_b - V_a$$

$$\therefore \quad W = Q (V_b - V_a)$$

$$W = -Q \int_\infty^P E \cdot a\rho$$

$$W = Q V_\rho$$

2.6.2 Distribusi muatan

a). Distribusi muatan listrik .