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Prodi/kelas : Pendidikan Fisika / B

Mekanika

Latihan chapter 4 (4.1 - 4.9 ; 4.12 - 4.13 ; 4.17 dan 4.20)

4.1) (a) $\vec{F} = -\vec{\nabla} V$

$= \hat{i}\frac{\partial V}{\partial x} - \hat{j}\frac{\partial V}{\partial y} - \hat{k}\frac{\partial V}{\partial z}$

$= -c(\hat{i}yz + \hat{j}xz + \hat{k}xy$

(b) $\vec{F} = -\vec{\nabla} V$

$= -\hat{i}2\alpha x - \hat{j}2\beta y - \hat{k}2\gamma z$

(c) $\vec{F} = -\vec{\nabla} V$

$= ce^{-(\alpha x + \beta y + \gamma z)}(\hat{i}\alpha + \hat{j}\beta + \hat{k}\gamma)$

(d) $\vec{F} = -\vec{\nabla} V$

$= \hat{e}_r \frac{\partial V}{\partial r} - \hat{e}_\theta \frac{1}{r}\frac{\partial V}{\partial \theta} - \hat{e}_\phi \frac{1}{r\sin\theta}\frac{\partial V}{\partial \phi}$

$= -\hat{e}_r C n r^{n-1}$

4.2) (a)
$$\vec{\nabla}\times\vec{F} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ x & y & z \end{vmatrix} = 0$$
(konservatif.)

(b)
$$\vec{\nabla}\times\vec{F} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ y & -x & z^2 \end{vmatrix} = \hat{k}(-1-1) \neq 0$$
(konservatif)

(c)
$$\vec{\nabla}\times\vec{F} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ y & x & z^3 \end{vmatrix} = \hat{k}(1-0) = 0$$
(konservatif)

(d)
$$\vec{\nabla}\times\vec{F} = \frac{1}{r^2\sin\theta}\begin{vmatrix} \hat{e}_r & e_\theta r & e_\phi r\sin\theta \\ \frac{\partial}{\partial r} & \frac{\partial}{\partial \theta} & \frac{\partial}{\partial \phi} \\ -kr^{-n} & 0 & 0 \end{vmatrix} = 0$$
(konservatif).

4.3) (a)
$$\vec{\nabla}\times\vec{F} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ xy & cx^2 & z^3 \end{vmatrix} = k(2cx - x)$$

- $2cx - x = 0$

$c = \frac{1}{2}$

(b)
$$\vec{\nabla}\times\vec{F} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ \frac{z}{y} & \frac{cxy}{y^2} & \frac{x}{y} \end{vmatrix}$$

$= \hat{i}\left(-\frac{x}{y^2} - \frac{cx}{y^2}\right) + \hat{j}\left(\frac{1}{y} - \frac{1}{y}\right) + \hat{k}\left(\frac{cz}{y^2} + \frac{z}{y^2}\right)$

$-\frac{x}{y^2} - \frac{cx}{y^2} = 0 \Rightarrow c = -1$

- $\frac{cz}{y^2} + \frac{z}{y^2} = 0 \Rightarrow c = -1$

4.4) (a) E = konstan : $V(x,y,z) + \frac{1}{2}mv^2$

$E = 0 + \frac{1}{2}mv^2$

pada (1,1,1) $E = \alpha + \beta + \gamma + \frac{1}{2}mv^2 = \frac{1}{2}mv_0^2$

$v^2 = v_0^2 - \frac{2}{m}(\alpha + \beta + \gamma)$

$v = \left[v_0^2 - \frac{2}{m}(\alpha + \beta + \gamma\right]^{\frac{1}{2}}$

(b) $v_0^2 = -\frac{2}{m}(\alpha + \beta + \gamma) = 0$

$v_0 = \left[\frac{2}{m}(\alpha + \beta + \gamma)\right]^{\frac{1}{2}}$

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(c) $m\ddot{x} = F_x = -\frac{\partial V}{\partial x}$

$m\ddot{x} = -\alpha$

$m\ddot{y} = -\frac{\partial V}{\partial y} = -2\beta y$

$m\ddot{z} = -\frac{\partial V}{\partial z} = -3\gamma z$

4.5) (a) $\vec{F} = \hat{i}x + \hat{j}y$

$x = y$; $d\vec{r} = \hat{i}dx + \hat{j}dy$

$\int_{(0,0)}^{(1,1)} \vec{F}\cdot d\vec{r} = \int_0^1 F_x\,dx + \int_0^1 F_y\,dy$

$= \int_0^1 x\,dx + \int_0^1 y\,dy$

$= 1$

- $x \Rightarrow d\vec{r} = \hat{i}dx$

$x = 1 \Rightarrow d\vec{r} = \hat{j}dy$

$\int_{(0,0)}^{(1,1)} \vec{F}\cdot d\vec{r} = \int_0^1 F_x\,dx + \int_0^1 F_y\,dy = 1$

$\vec{F}$ merupakan konservatif.

(b) $\vec{F} = \hat{i}y - \hat{j}x$, $x = y$

$\int_{(0,0)}^{(1,1)} \vec{F}\cdot d\vec{r} = \int_0^1 F_x\,dx + \int_0^1 F_y\,dy$

$= \int_0^1 y\,dx - \int_0^1 x\,dy$

- $x = y \Rightarrow \int_{(0,0)}^{(1,1)} \vec{F}\cdot d\vec{r} = \int_0^1 x\,dx - \int_0^1 y\,dy = 0$

- $x \Rightarrow \int_{(0,0)}^{(1,0)} \vec{F}\cdot d\vec{r} = \int_0^1 F_x\,dx = \int_0^1 y\,dx$

- $y = 0$ pada sumbu x $\Rightarrow \int_{(0,0)}^{(1,0)} \vec{F}\cdot d\vec{r} = 0$

- $x = 1 \Rightarrow \int_{(1,0)}^{(1,1)} \vec{F}\cdot d\vec{r} = \int_0^1 F_y\,dy = \int_0^1 x\,dy$

- $x = 1 \Rightarrow \int_{(1,0)}^{(1,1)} \vec{F}\cdot d\vec{r} = \int_0^1 dy = 1$

$\int_{(0,0)}^{(1,1)} \vec{F}\cdot d\vec{r} = 0 + 1 = 1$

$\vec{F}$ merupakan bukan konservatif

4.6) $V(z) = -mg\frac{r_e^2}{(r_e + z)}$

$V(z) = -mgr_e\left(1 + \frac{z}{r_e}\right)^{-1}$

Dari Apendiks D $(1+x)^{-1} = 1 - x + x^2 + \ldots$

$V(z) = -mgr_e\left(1 - \frac{z}{r_e} + \frac{z^2}{r_e^2} + \ldots\right)$

$V(z) = -mgr_e + mgz - \frac{mgz^2}{r_e} + \ldots$

Dengan $-mgr_e$ konstan

$V(z) \approx mgz\left(1 - \frac{z}{r_e}\right)$

$\vec{F} = -\nabla V = -\hat{k}\frac{\partial}{\partial z}V(z)$

$= -\hat{k}mg\left[1 - \frac{z}{r_e} + z\left(-\frac{1}{r_e}\right)\right]$

$\vec{F} = -\hat{k}mg\left(1 - \frac{2z}{r_e}\right)$

* $m\ddot{x} = F_x = 0$ $\quad m\ddot{y} = F_y = 0$ $\quad m\ddot{z} = -mg\left(1 - \frac{2z}{r_e}\right)$

$m\dot{z}\frac{d\dot{z}}{dz} = -mg\left(1 - \frac{2z}{r_e}\right)$

$\int_V^0 \dot{z}\,d\dot{z} = -g\int_0^h \left(1 - \frac{2z}{r_e}\right)dz$

$-\frac{1}{2}V_{0z}^2 = -g\left(h - \frac{h^2}{r_e}\right)$

$h^2 - r_e h + \frac{r_e V_{0z}^2}{2g} = 0$

$h = \frac{r_e}{2} - \frac{1}{2}\sqrt{r_e^2 - \frac{2r_e V_{0z}^2}{g}}$ $\quad (h, z < r_e)$

$h = \frac{r_e}{2} - \frac{r_e}{2}\sqrt{1 - \frac{2V_{0z}^2}{gr_e}}$

Dari Apendix D $(1+x)^{\frac{1}{2}} = 1 + \frac{x}{2} - \frac{x^2}{8} + \ldots$

$h = \frac{r_e}{2} - \frac{r_e}{2} + \frac{V_{0z}^2}{2g} + \frac{V_{0z}^4}{4gr_e} + \ldots$

$h \approx \frac{V_{0z}^2}{2g}\left(1 + \frac{V_{0z}^2}{2gr_e}\right)$

* $h = \frac{V_0^2}{2g}\left(1 - \frac{V_0^2}{2gr_e}\right)^{-1}$

* $(1-x)^{-1} \approx 1 + x$, $\quad h \approx \frac{V_0^2}{2g}\left(1 + \frac{V_0^2}{2gr_e}\right)$

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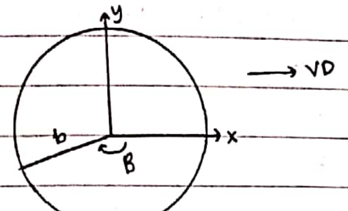
4.7)



• $\vec r = \hat i b\cos\theta - \hat j b\sin\theta$

$\theta = \omega t = \frac{v_0 t}{b} \Rightarrow \vec r = -\hat i v_0\sin\theta - \hat j v_0\cos\theta$

$\vec v = \hat i v_0(1-\sin\theta) - \hat j v_0\cos\theta$

• $y_0 = -b\sin\theta$ dan $v_{oy} = -v_0\sin\theta$

$v_y = v_{oy} - gt = -v_0\cos\theta - gt$

$y = -b\sin\theta - v_0 t\cos\theta - \frac{1}{2}gt^2$

• Ketinggian maksimum, $v_y = 0$

$t = -\frac{v_0\cos\theta}{g}$

$h = -b\sin\theta - v_0\left(-\frac{v_0\cos\theta}{g}\right)\cos - \frac{1}{2}g\left(-\frac{v_0\cos\theta}{g}\right)^2$

$h = -b\sin\theta + \frac{v_0^2\cos^2\theta}{2g}$

h maksimum

$\frac{dh}{d\theta} = 0 = -b\cos\theta - \frac{2v_0^2\cos\theta\sin\theta}{2g}$

$\sin\theta = -\frac{gb}{v_0^2}$

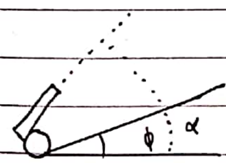
$\cos^2\theta = 1-\sin^2\theta = \frac{v_0^4 - g^2 b^2}{v_0^4}$

$h_{max} = \frac{gb^2}{v_0^2} + \frac{v_0^4 - g^2b^2}{2gv_0^2} = \frac{gb^2}{2v} + \frac{v_0^2}{2g}$

$h'_{max} = b + \frac{gb^2}{2v_0^2} + \frac{v_0^2}{2g}$

$\theta = \sin^{-1}\left(-\frac{gb}{v_0^2}\right)$

4.8)



• $x = R\cos\phi$ dan $x = v_{ox}t = (v_0\cos\alpha)t$

$t = \frac{R\cos\phi}{v\cos\alpha}$

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• $y = R\sin\phi$ dan $y = v_{oy}t - \frac{1}{2}gt^2 = (v_0\sin\alpha)t - \frac{1}{2}gt^2$

$R\sin\phi = (v_0\sin\alpha)\frac{R\cos\phi}{v_0\cos\alpha} - \frac{1}{2}g\left(\frac{R\cos\phi}{v_0\cos\alpha}\right)^2$

$\sin\phi = \tan\alpha\cos\phi - \frac{gR\cos^2\phi}{2v_0^2\cos^2\alpha}$

$R = \frac{2v_0^2\cos^2\alpha}{g\cos^2\phi}(\tan\alpha\cos\phi - \sin\phi)$

$= \frac{2v_0^2\cos\alpha}{g\cos\phi}(\sin\alpha\cos\phi - \cos\alpha\sin\phi)$

Dari lampiran B, $\sin(\theta+\phi) = \sin\theta\cos\phi + \cos\theta\sin\phi$

$R = \frac{2v_0^2\cos\alpha}{g\cos^2\phi}\sin(\alpha-\phi)$

R maksimum untuk

$\frac{dR}{d\alpha} = 0 = \frac{2v_0^2}{g\cos\phi}[-\sin\alpha\sin(\alpha-\phi) + \cos\alpha\cos(\alpha-\phi)]$

sehingga $\cos\alpha\cos(\alpha-\phi) - \sin\alpha\sin(\alpha-\phi) = 0$

Dari lampiran B, $\cos(\theta+\phi) = \cos\theta\cos\phi - \sin\theta\sin\phi$

Jadi $\cos(2\alpha-\phi) = 0$

$2\alpha - \phi = \frac{\pi}{2}$, $\alpha = \frac{\pi}{4} + \frac{\phi}{2}$

$R_{max} = \frac{2v^2}{g\cos\phi}\cos\left(\frac{\pi}{4}+\frac{\phi}{2}\right)\sin\left(\frac{\pi}{4}-\frac{\phi}{2}\right)$

$\sin\left(\frac{\pi}{4}-\frac{\phi}{2}\right) = \cos\left[\frac{\pi}{2}-\left(\frac{\pi}{4}-\frac{\phi}{2}\right)\right] = \cos\left(\frac{\pi}{4}+\frac{\phi}{2}\right)$

$R_{max} = \frac{2v_0^2}{g\cos^2\phi}\cos^2\left(\frac{\pi}{4}+\frac{\phi}{2}\right)$

Gunakan lagi lampiran B, $\cos 2\theta = \cos^2\theta - \sin^2\theta$

$= 2\cos^2\theta - 1$

$R_{max} = \frac{2v_0^2}{g\cos\phi}\left[\frac{1}{2}\cos\left(\frac{\pi}{2}+\phi\right) + \frac{1}{2}\right]$

$= \frac{v_0^2}{g\cos\phi}\left[\cos\left(\frac{\pi}{2}+\phi\right)+1\right]$

Gunakan $\cos\left(\frac{\pi}{2}+\theta\right) = -\sin\theta$

$R_{max} = \frac{v_0^2}{g(1-\sin^2\phi)}(1-\sin\phi)$

$R_{max} = \frac{v_0^2}{g(1+\sin\phi)}$

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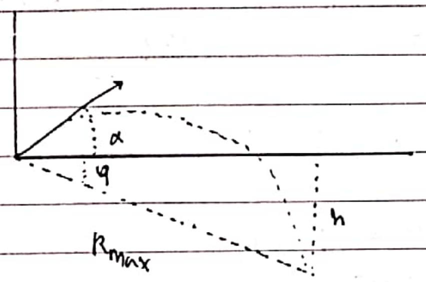
4g)



a). $R = \frac{2v_0^2 \cos\alpha \sin(\alpha+\varphi)}{g \cos^2\varphi}$

Jangkauan Maksimum dan sudut α diperoleh dengan mengganti φ dengan −φ

$R_{max} = \frac{V_0^2}{g} \cdot \frac{(1+\sin\varphi)}{\cos^2\varphi}$ dan $2\alpha = \frac{\pi}{2} - \varphi$

$R_{max} = \frac{h}{\sin\varphi} = \frac{V_0^2}{g} \frac{(1+\sin\varphi)}{\cos^2\varphi} = \frac{V_0^2}{g(1-\sin\varphi)}$

$\sin\varphi = \frac{gh}{V_0^2} \Big/ \left(1 + \frac{gh}{V_0^2}\right)$

$\sin\varphi = \sin\left(\frac{\pi}{2} - 2\alpha\right) = \cos 2\alpha = 1 - 2\sin^2\alpha$

$1 - 2\sin^2\alpha = \frac{gh}{V_0^2} \Big/ \left(1 + \frac{gh}{V_0^2}\right)$

$2\sin^2\alpha = \frac{2}{\csc^2\alpha} = 1 - \frac{gh}{V_0^2} \Big/ \left(1 + \frac{gh}{V_0^2}\right)$

$= \frac{1}{1 + \frac{gh}{V_0^2}}$

$\csc^2\alpha = 2\left(1 + \frac{gh}{V_0^2}\right)$

(b) $R_{max} = \frac{h}{\sin\varphi} = \frac{h}{1 - 2\sin^2\alpha} = \frac{h}{1 - 2/\csc^2\alpha}$

$R_{max} = \frac{V_0^2}{g}\left(1 + \frac{gh}{V_0^2}\right)$

4.12) posisi x dan z terhadap waktu

$x = v_0 t \frac{1}{2} \cos\theta_0$

$z = v_0 t \cos\frac{1}{2}\theta_0 \sin\theta_0 - \frac{1}{2} g t^2$

$v_x = v_0 \cos\frac{1}{2}\theta_0$

Horizontal : $R = \frac{V_0^2 \cos\frac{1}{2}\theta_0 \sin 2\theta_0}{g}$

Maksimum: $\frac{dR}{d\theta_0} = 0$

$\frac{dR}{d\theta_0} = \frac{V_0^2}{g}\left(2\cos^2\frac{1}{2}\theta_0 \cos 2\theta_0 - \cos\frac{1}{2}\theta_0 \sin 2\theta_0\right) =$

Lalu, $2\cos^2\frac{1}{2}\theta_0 \cos 2\theta_0 = \cos\frac{1}{2}\theta_0 \sin\frac{1}{2}\theta_0 \sin 2\theta_0$

Gunakan identitas $2\cos\theta_0 = 1 + \cos 2\theta_0$

$\sin 2\theta = 2\sin\theta_0 \cos\theta_0$

Kita dapatkan:

$(1+\cos\theta_0)(2\cos^2\theta_0 - 1) = \sin\theta_0 \sin\theta_0 \cos\theta_0$

$= (1 - \cos^2\theta_0)\cos\theta$

atau $(1+\cos\theta_0)(3\cos^2\theta_0 - \cos\theta_0 - 1) = 0$

$\cos\theta_0 = -1$, $\cos\theta_0 = \frac{1}{6}(1 \pm \sqrt{13})$

hanya berlaku untu positif untuk rentang θ_0 , $0 \leq \theta_0 \leq \frac{\pi}{2}$

$\cos\theta_0 = \frac{1}{6}(1+\sqrt{13}) = 0{,}7676$

$\theta_0 = 39°$

⇒ untuk $V_0 = 25$ m/s $R_{max} = 55{,}4$ m $\theta_0 = 39°$

Ketinggian maksimum $\frac{dH}{d\alpha} = 0$

$\frac{dH}{d\alpha} = \frac{V_0^2}{2g}\left(2\cos^2\frac{1}{2}\theta_0 \sin\theta_0 \cos\theta_0 - \cos\theta_0 \sin\frac{1}{2}\theta \sin^2\theta\right) = 0$

Lalu, kita dapatkan:

$(1+\cos\theta_0)\sin\theta_0\cos\theta_0 = \frac{1}{2}\sin\theta_0 \sin^2\theta$

$= \frac{1}{2}\sin\theta_0(1 - \cos^2\theta_0)$

atau $\sin\theta(1+\cos\theta_0)(3\cos\theta_0 - 1) = 0$

dengan $\sin\theta_0 = 0$, $\cos\theta_0 = -1$, $\cos\theta_0 = \frac{1}{3}$

Maka, $H_{max} = 18{,}9$ m

$\theta_0 = \cos^{-1}\frac{1}{3} = 70°$

4.13) Diketahui:

$$z = \frac{\dot z_0}{\dot r_0} r - \frac{g}{2\dot r_0^2} r^2 \quad \text{dimana} \quad \dot r_0 = V_0 \cos\theta_0, \quad \dot z_0 = V_0 \sin\theta_0$$

• $z = r\tan\theta_0 - \frac{g r^2}{2V_0^2}\sec^2\theta_0$

$\sec^2\theta_0 = 1 + \tan^2\theta_0$

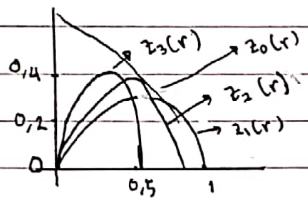
Kita punya:

$$\frac{g r^2}{2v_0^2}\tan^2\theta - r\tan\theta_0 + z + \frac{g r^2}{2v_0^2} = 0$$

$$\tan\theta_0 = \frac{1}{gr}\left[v_0^2 \pm \left(v_0^4 - 2gz v_0^2 - g^2 r^2\right)^{\frac{1}{2}}\right]$$

• $v_0^4 - 2gzv_0^2 - g^2r^2 \geq 0$

• $v_0^4 - 2gzv_0^2 - g^2r^2 = 0$



4.17) • $m\ddot x = F_x = -\frac{\partial V}{\partial x} = -kx = -\pi^2 m x$

$x = A\cos\left(\sqrt{\frac{k}{m}}\,t + \alpha\right) = A\cos(\pi t + \alpha)$

• $m\ddot y = -\frac{\partial V}{\partial y} = -4\pi^2 m y$

$y = B\cos(2\pi t + \beta)$

• $m\ddot z = -\frac{\partial V}{\partial z} = -9\pi^2 m z$

$z = C\cos(3\pi t + \gamma)$

* $x = y = z = 0$ at $t = 0$ $\quad \alpha = \beta = \gamma = -\frac{\pi}{2}$

$x = A\cos\left(\pi t - \frac{\pi}{2}\right) = A\sin\pi t$

$\dot x = A\pi\cos\pi t$

* $V_0^2 = \dot x_0^2 + \dot y_0^2 + \dot z_0^2$ dan $\dot x_0 = \dot y_0 = \dot z_0$

• $\dot x_0 = \frac{V_0}{\sqrt3} = A\pi$

$A = \frac{V_0}{\pi\sqrt3}$

• $x = \frac{V_0}{\pi\sqrt3}\sin\pi t$

• $y = B\sin 2\pi t, \quad \dot y = 2B\pi\cos 2\pi t$

$\dot y_0 = \frac{V_0}{\sqrt3} = 2\pi B$

$B = \frac{V_0}{2\pi\sqrt3}$

$y = \frac{V_0}{2\pi\sqrt3}\sin 2\pi t$

• $z = C\sin 3\pi t, \quad \dot z = 3C\pi\cos 3\pi t$

$\dot z_0 = \frac{V_0}{\sqrt3} = 3C\pi$

$C = \frac{V_0}{3\pi\sqrt3}$

$z = \frac{V_0}{3\pi\sqrt3}\sin 3\pi t$

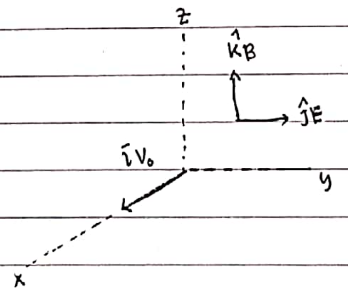
* $\omega_x = \pi$, $\omega_y = 2\pi$ dan $\omega_z = 3\pi$

$t_{min} = \frac{2\pi n_1}{\omega_x} = \frac{2\pi n_2}{\omega_y} = \frac{2\pi n_3}{\omega_z}$

Waktu minimal pada $n_1 = 1$, $n_2 = 2$, $n_3 = 3$

$t_{min} = \frac{2\pi}{\pi} = 2$

4.20)



* $\vec F = q(\vec E + \vec v \times \vec B)$

$\vec v \times \vec B = (\hat i\dot x + \hat j\dot y + \hat k\dot z) \times \hat k B = \hat i\dot y B - \hat j\dot x B$

$\vec F = \hat i q\dot y B + \hat j q(E - \dot x B)$

$m\ddot x = F_x = q\dot y B$

$\dot x - \dot x_0 = \frac{qB}{m} y$

* $m\ddot y = F_y = qE - q\dot x B = qE - qB\left(\dot x_0 + \frac{qB}{m} y\right)$

$\ddot y = \frac{qE}{m} - \frac{qB\dot x_0}{m} - \left(\frac{qB}{m}\right)^2 y$

$= \frac{-eE}{m} + \frac{eB\dot x_0}{m} - \left(\frac{eB}{m}\right)^2 y$

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$$\ddot{y} + \omega^2 y = -\frac{eE}{m} + \omega \dot{x}_0 \qquad \omega = \frac{eB}{m}$$

$$y = \frac{1}{\omega^2}\left(-\frac{eE}{m} + \omega \dot{x}_0\right) + A\cos\left(\omega t + \theta_0\right)$$

$$\dot{y} = -A\omega \sin(\omega t + \theta_0)$$

$\dot{y}_0 = 0$ Jadi $\theta_0 = 0$

$y_0 = 0$ Jadi $A = -\frac{1}{\omega^2}\left(-\frac{eE}{m} + \omega \dot{x}_0\right)$

$$y = a(1-\cos\omega t), \quad a = \frac{1}{\omega^2}\left(-\frac{eE}{m} + \omega \dot{x}_0\right)$$

$$\dot{x} = \dot{x}_0 + \frac{qB}{m} y = \dot{x}_0 - \omega y = \dot{x}_0 - \omega a(1-\cos\omega t)$$

$$\dot{x} = (\dot{x}_0 - \omega a) + \omega a \cos\omega t$$

$$x = (\dot{x}_0 - \omega a)t + a\sin\omega t$$

$$x = a\sin\omega t + bt, \quad b = \dot{x}_0 - \omega a$$

$$m\ddot{z} = F_z = 0$$

$$z = \dot{z}_0 t + z_0 = 0$$

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