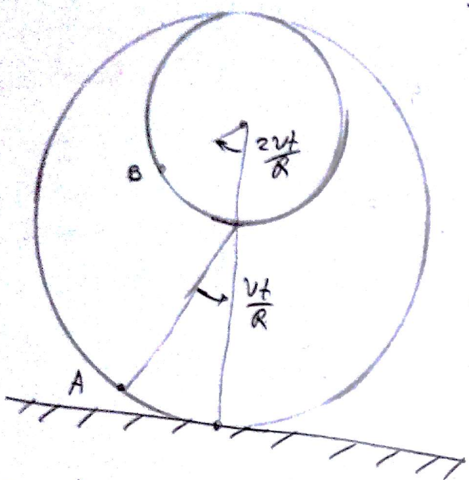
آزمون سال ۹۰

مسئله ۱ الف)



$$\vec{r}_A = \left[vt - R\sin\left(\frac{vt}{R}\right)\right]\hat{x} + R\left[1-\cos\left(\frac{vt}{R}\right)\right]\hat{y}$$

ب)

$$\vec{r}_B = \left[vt - R\sin\left(\frac{2vt}{R}\right)\right]\hat{x} + R\left[\left(1-\cos\left(\frac{2vt}{R}\right)\right)\times\frac{1}{2}+1\right]$$

$$= \left[vt - R\sin\left(\frac{2vt}{R}\right)\right]\hat{x} + R\left[\frac{3}{2}-\frac{1}{2}\cos\left(\frac{2vt}{R}\right)\right]\hat{y}$$

پ)

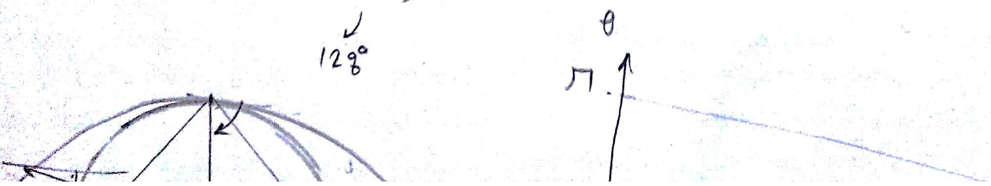
$$\theta = n\pi \to \tan\theta = 0 = \frac{y_B - y_A}{x_B - x_A} \to y_B = y_A$$

$$\frac{3}{2} - \frac{1}{2}\cos\left(\frac{2vt}{R}\right) = 1 - \cos\left(\frac{vt}{R}\right) \to 2\sin^2\left(\frac{vt}{R}\right) = -2\cos\left(\frac{vt}{R}\right)$$

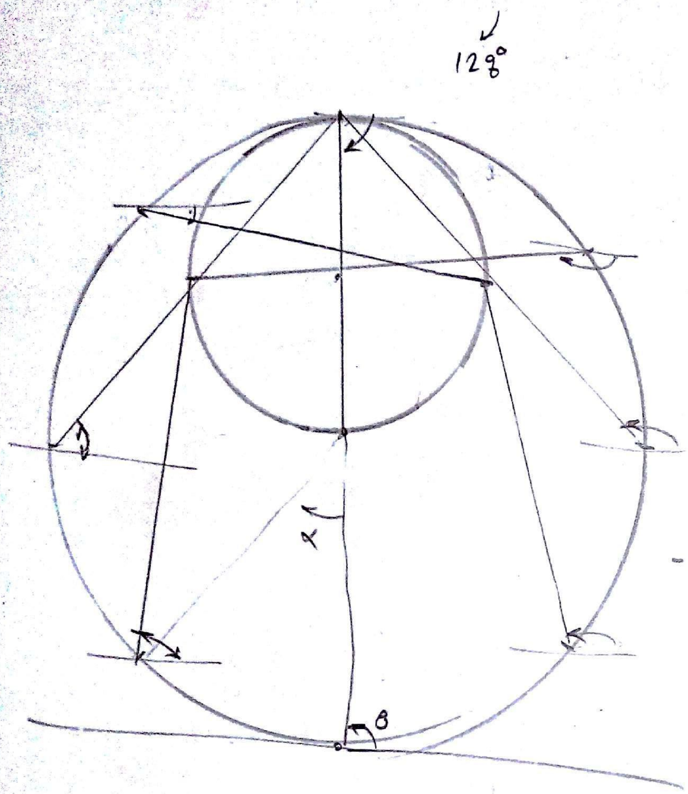
$$\to 2\left(1-\cos^2\left(\frac{vt}{R}\right)\right) + 2\cos\left(\frac{vt}{R}\right) = 0 \to \cos^2\left(\frac{vt}{R}\right) - \cos\left(\frac{vt}{R}\right) - 1 = 0 \to \cos\left(\frac{vt}{R}\right) = \frac{1\pm\sqrt{5}}{2} = \frac{1-\sqrt{5}}{2}$$

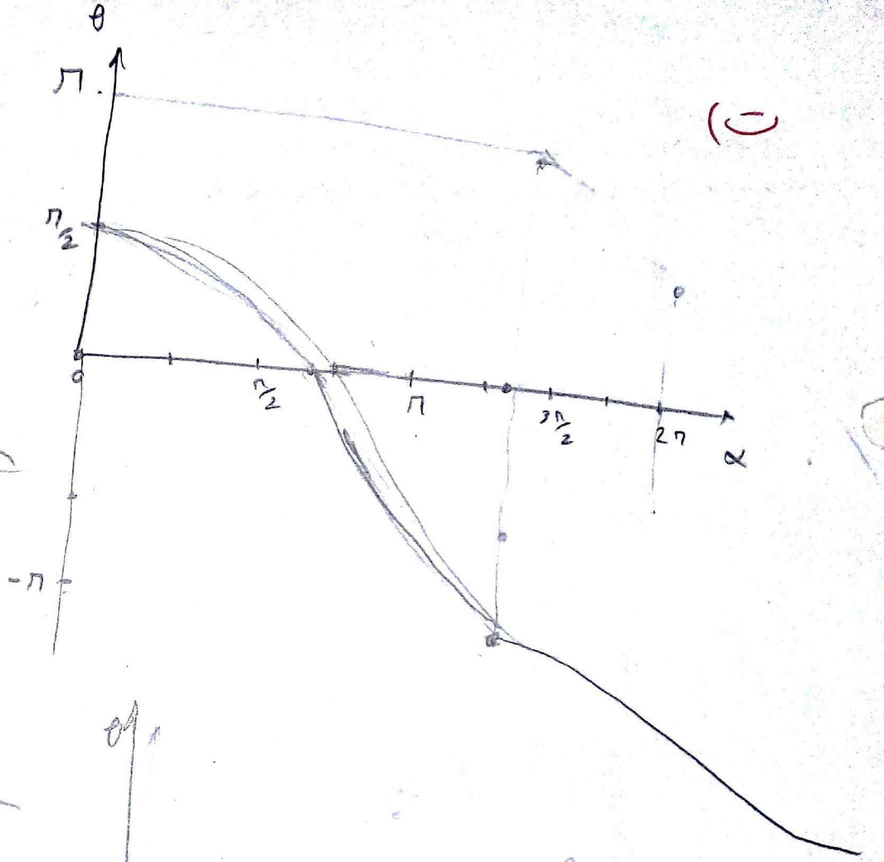
$$\to \frac{vt}{R} = 2n\pi \pm \cos^{-1}\left(\frac{1-\sqrt{5}}{2}\right) =$$

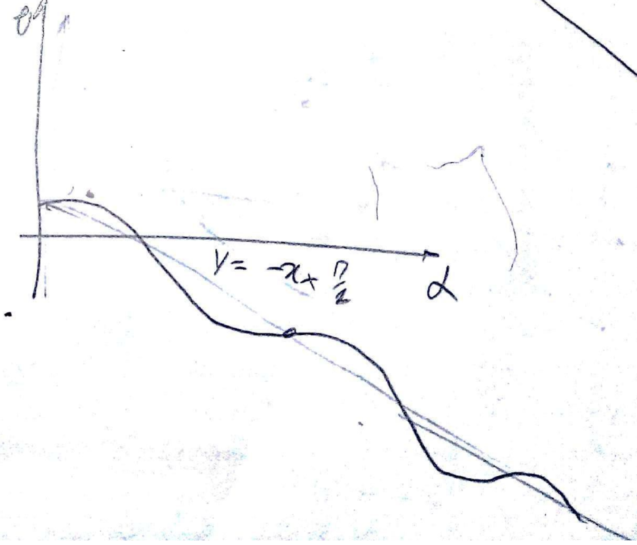
$129°$



$\cos\left(\frac{\quad}{2}\right) =$

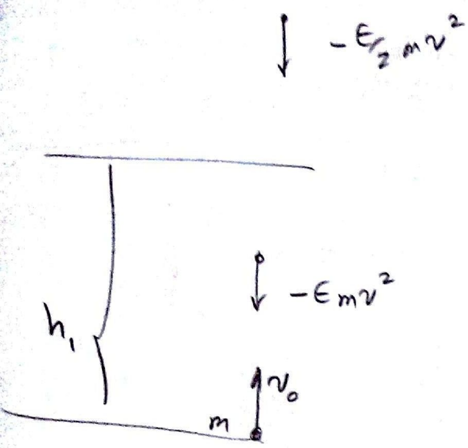






مسئله 2

الف)



$$v_0 t - \frac{gt^2}{2} = h_1 = \frac{3v_0^2}{8g}$$

$$\to \frac{gt^2}{2} - v_0 t + \frac{3v_0^2}{8g} = 0 \to t = \frac{v_0 \pm \sqrt{v_0^2 - \frac{3}{4}v_0^2}}{g}$$

$$t^{(0)} = \frac{v_0 - \frac{v_0}{2}}{g} = \frac{v_0}{2g}$$

$$m\ddot{x} = -mg - \epsilon m v^2 \to \ddot{x} = -g - \epsilon (v_0 - gt)^2 \to \dot{x} = -gt + v_0 - \epsilon$$

$$m\ddot{x} = -mg - \epsilon m v^2 \to \dot{x}^{(1)} = -\epsilon v^2 dt \qquad dv = -g\,dt \to \dot{x}^{(1)} = \epsilon \frac{v^2 dv}{g}$$

$$\dot{x}^{(1)} = \frac{\epsilon}{3g}\left(v^3 - v_0^3\right) \to x^{(1)} = \frac{\epsilon}{3g}\left(\frac{-v^3 dv}{g} - v_0^3 t\right) = \frac{\epsilon}{3g}\left(-\frac{v^4}{4g} - v_0^3 t\right)$$

$$v_0 t^{(1)} - \frac{g}{\cancel{2}} \times \cancel{2}\, \overset{\frac{v_0}{2g}}{t^{(0)}}\, t^{(1)} + \frac{\epsilon}{3g}\left(\frac{v_0^4 - \overset{\frac{v_0^4}{16}}{v^4}}{4g} - v_0^3 \times \frac{v_0}{2g}\right) = 0 \qquad v^2 - v_0^2 = -2g \times \frac{3v_0^2}{8g} \to v^2 = \frac{v_0^2}{4}$$

$$m\ddot{x} = -mg - \epsilon m v^2 \rightarrow \dot{x}^{(1)} = -\epsilon v^2 dt \qquad dv = -g dt \rightarrow \dot{x}^{(1)} = \frac{\epsilon v^2 dv}{g}$$

$$\dot{x}^{(1)} = \frac{\epsilon}{3g}\left(v^3 - v_0^3\right) \rightarrow x^{(1)} = \frac{\epsilon}{3g}\left(-\frac{v^3 dv}{g} - v_0^3 t\right) = \frac{\epsilon}{3g}\left(-\frac{v^4}{4g} - v_0^3 t\right)$$

$$v_0 t^{(1)} - \frac{g}{\cancel{2}} \times \cancel{2} \cancel{t^{(0)}}^{\frac{v_0}{2g}} t^{(1)} + \frac{\epsilon}{3g}\left(\frac{v_0^4 - \cancel{v^4}^{\frac{v_0^4}{16}}}{4g} - v_0^3 \times \frac{v_0}{2g}\right) = 0 \qquad v^2 - v_0^2 = -2g \times \frac{3v_0^2}{8g} \rightarrow v^2 = \frac{v_0^2}{4}$$

$$\rightarrow \frac{v_0 t^{(1)}}{2} = +\frac{\epsilon}{3g}\left(\frac{15 v_0^4}{64 g} + \frac{32 v_0^4}{64 \cdot 2g}\right) = \frac{\epsilon v_0^4}{3g^2} \frac{17}{64} \rightarrow \boxed{t^{(1)} = \frac{\epsilon v_0^3}{g^2} \times \frac{17}{96}}$$

$$v^{(0)} = v_0 - \frac{v_0}{2} = \frac{v_0}{2} \qquad v^{(1)} = -g t^{(1)} + \frac{\epsilon}{3g}\left(\cancel{v^3}^{\frac{v_0^3}{8}} - v_0^3\right) = -\cancel{g} \times \frac{\epsilon v_0^3}{g^{\cancel{2}}} \times \frac{17}{96} - \frac{7}{24}\frac{\epsilon v_0^3}{g}$$

$$-\frac{7}{8} v_0^3$$

ب)

$$= -\frac{\epsilon v_0^3}{g} \frac{-17 - 28}{96} = \boxed{-\frac{\epsilon v_0^3}{g} \frac{45}{96} = v^{(1)}}$$

$$t^{(0)} = \frac{v_0}{2g} \qquad \dot{x}^{(1)} = \frac{\epsilon}{2 \times 3g}\left(\cancel{v^3} - \frac{v_0^3}{8}\right) - g t^{(1)} - \frac{45}{96} \frac{\epsilon v_0^3}{g}$$

ب)

$$g t^{(1)} = \frac{-\epsilon v_0^3}{48 g} - \frac{45}{96} \frac{\epsilon v_0^3}{g} = \frac{-47}{96} \frac{\epsilon v_0^3}{g} \rightarrow \boxed{t^{(1)} = \frac{-47}{96} \frac{\epsilon v_0^3}{g^2}}$$

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(c)

$$x^{(1)} = v^{(1)} t^{(0)} + v^{(0)} t^{(1)} - g t^{(0)} t^{(1)} + \frac{\epsilon}{6g}\left(\frac{v_0^4}{\underset{64}{\cancel{4}g \times 2^4}} - v_0^3 \times \frac{v_0}{2g}\right)$$

$$= -\frac{\epsilon v_0^3}{g} \times \frac{45}{96} \times \underset{15}{\frac{v_0}{2g}} + \frac{v_0}{2} \times \frac{-47}{96}\frac{\epsilon v_0^3}{g^2} - \cancel{g} \times \frac{v_0}{2\cancel{g}} \times \frac{-47}{96}\frac{\epsilon v_0^3}{g^2} + \frac{\epsilon}{12g^2} v_0^4 \left(\frac{\overset{-31}{\cancel{1-32}}}{32}\right)$$

$$= \frac{\epsilon v_0^4}{g^2}\left(-\frac{\cancel{45}}{\underset{32}{2\times\cancel{96}}} - \frac{\cancel{47}}{\cancel{96\times 2}} + \frac{\cancel{47}}{\cancel{2\times 96}} - \frac{31}{32}\right) = \frac{-\epsilon v_0^4}{g^2}\,\frac{15+62}{64} = \boxed{\frac{-\epsilon v_0^4}{g^2}\,\frac{77}{64} = x^{(1)}}$$

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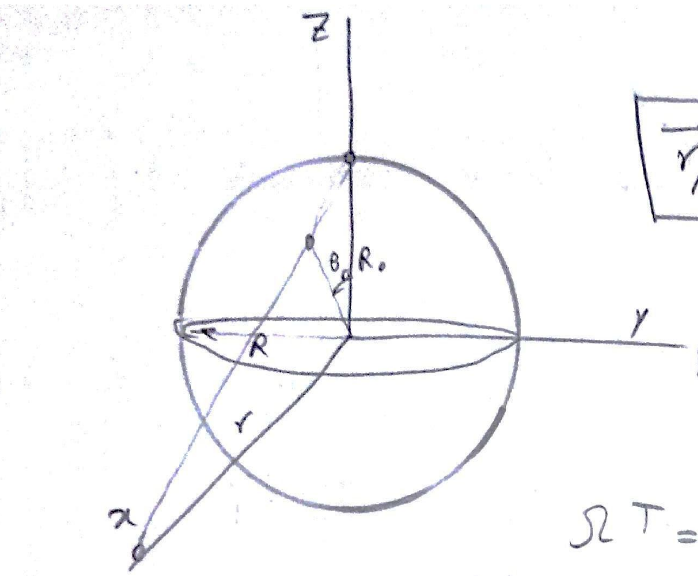
مسئله 3

الف)

$$\boxed{\vec{r}_A = R_0 \cot\left(\frac{\theta_0}{2}\right)\hat{x}}$$

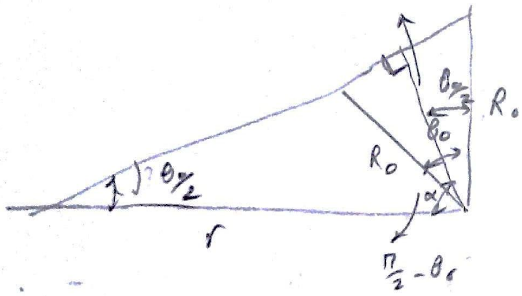


ب)

$$\boxed{r = (R_0 + vt)\cot\left(\frac{\theta_0 + \omega t}{2}\right)}$$

پ)

$$\Omega T = 2\pi \rightarrow T = \frac{2\pi}{\Omega}$$



$$R_0 \cot\left(\frac{\theta_0}{2}\right) = \left(R_0 + \frac{2\cancel{\pi} v x}{\cancel{\Omega}\,\omega}\right)\cot\left(\frac{\theta_0}{2} + \frac{\pi\omega}{\Omega}\right)$$

$$\frac{\pi}{\Omega} = \frac{x}{\omega} \rightarrow \tan\left(\frac{\theta_0}{2} + x\right) R_0 \cot\left(\frac{\theta_0}{2}\right) = R_0 + \frac{2vx}{\omega}$$

$$\frac{\tan\left(\frac{\theta_0}{2}\right) + \tan(x)}{1 - \tan\left(\frac{\theta_0}{2}\right)\tan(x)} \times R_0 \cot\left(\frac{\theta_0}{2}\right) = R_0 + \frac{2vx}{\omega}$$

$$\left(\tan\left(\frac{\theta_0}{2}\right) + \tan(x)\right) \times R_0 \cot\left(\frac{\theta_0}{2}\right) = \left(R_0 + \frac{2vx}{\omega}\right)\left(1 - \tan\left(\frac{\theta_0}{2}\right)\tan x\right)$$

$$\tan(x)\left(R_0 \cot\left(\frac{\theta_0}{2}\right) + \left(R_0 + \frac{2vx}{\ldots}\right)\tan(\theta_0 \ldots)\right)$$

$$\frac{\tan(\frac{\theta_0}{2})+\tan(x)}{1-\tan(\frac{\theta_0}{2})\tan(x)} \times R_0 \cot\left(\frac{\theta_0}{2}\right) = R_0 + \frac{2vx}{W}$$

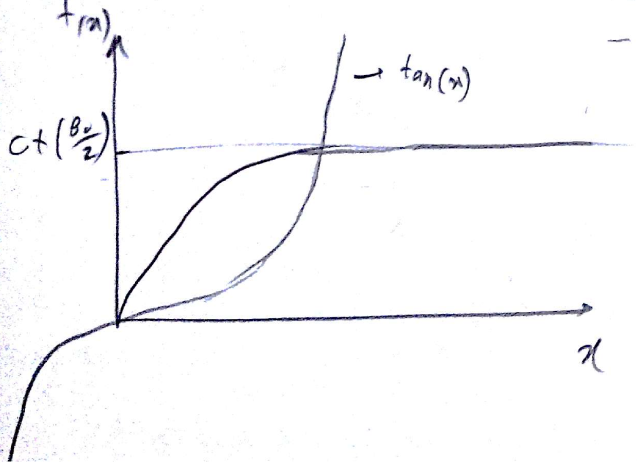
$$\left(\tan\left(\frac{\theta_0}{2}\right)+\tan(x)\right) \times R_0 ct\left(\frac{\theta_0}{2}\right) = \left(R_0+\frac{2vx}{W}\right)\left(1-\tan\left(\frac{\theta_0}{2}\right)\tan x\right)$$

$$\tan(x)\left(R_0 ct\left(\frac{\theta_0}{2}\right) + \left(R_0+\frac{2vx}{W}\right)\tan\left(\frac{\theta_0}{2}\right)\right) = \cancel{R_0} + \frac{2vx}{W} \cancel{- R_0}$$

$$\to \tan(x) = \frac{\frac{2vx}{W}}{\frac{R_0}{\sin(\frac{\theta_0}{2})\cos(\frac{\theta_0}{2})} + \frac{2vx}{W}\tan(\frac{\theta_0}{2})} = \frac{2vx}{WR_0} \times \frac{\sin\frac{\theta_0}{2}\cos\frac{\theta_0}{2}}{1+\sin^2\frac{\theta_0}{2}\times\frac{2vx}{RW}}$$

(ح

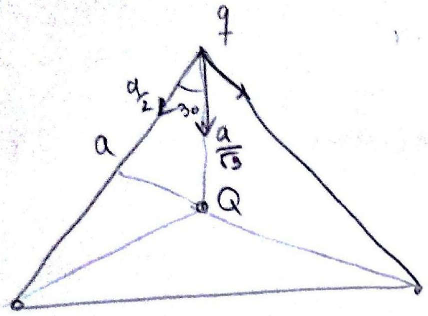
$$f(x) = \frac{vx}{R_0 W}\,\frac{\sin\theta_0}{1+\sin^2\frac{\theta_0}{2}\,\frac{2vx}{R_0 W}}$$



$$\boxed{\frac{v\sin\theta_0}{R_0 W} > 1}$$

(خ

مسئله 4



$$0 = \frac{+\cancel{k}q^2}{\cancel{a^2}} \times \sqrt{3} + \frac{3\cancel{k}\cancel{q}Q}{\cancel{a^2}}$$

(a

$$q\sqrt{3} + 3Q = 0 \rightarrow \frac{q}{Q} = \frac{-3}{\sqrt{3}} = \boxed{-\sqrt{3} = \frac{q}{Q}}$$

(b

$$-\frac{ma}{\sqrt{3}}\omega^2 = \frac{kq^2}{a^2} \times \sqrt{3} + \frac{3kqQ}{a^2} = \frac{kq}{a^2}\left(\sqrt{3}q + 3Q\right) = \frac{-ma\omega^2}{\sqrt{3}}$$

$$\rightarrow \omega^2 = \frac{-kq \times \sqrt{3}}{ma^3}\left(\sqrt{3}q + 3Q\right) = \frac{-kq}{ma^3}\left(3q + 3\sqrt{3}Q\right) = \boxed{\frac{-3kq}{ma^3}\left(q + \sqrt{3}Q\right) = \omega^2}$$

(c

$$r_i(t) = \frac{a}{\sqrt{3}} + \rho(t)$$

$$\cancel{m}\left(\ddot{\rho} - \rho\omega^2\right) = \frac{kq}{ma^3} \times -2\delta a\left(\sqrt{3}q + 3Q\right) \rightarrow \frac{\delta\ddot{a}}{\sqrt{3}} + \delta a\left(\frac{2kq}{ma^3}\left(\sqrt{3}q + 3Q\right) - \frac{\omega^2}{\sqrt{3}}\right) = 0$$

$$\frac{\frac{2kq}{ma^3}\left(\sqrt{3}q + 3Q\right) - \frac{\omega^2}{\sqrt{3}}}{1} = \frac{\frac{2\sqrt{3}\cancel{kq}}{\cancel{ma^3}}\left(q + \sqrt{3}Q\right) - \frac{\omega^2}{\sqrt{3}}}{\frac{1}{\sqrt{3}}} = \left(-\frac{2\sqrt{3}}{3} \times \sqrt{3} - 1\right)$$

$-\frac{\omega^2}{3}$

$$= (-2 \ldots 1)\omega^2 - \boxed{-3\omega^2 = \omega_r^2}$$

1b

$$-\frac{ma}{\sqrt{3}}\omega^2 = \frac{kq^2}{a^2}\times\sqrt{3} + \frac{3kqQ}{a^2} = \frac{kq}{a^2}\left(\sqrt{3}q + 3Q\right) = -\frac{ma\omega^2}{\sqrt{3}}$$

$$\rightarrow \omega^2 = \frac{-kq\times\sqrt{3}}{ma^3}\left(\sqrt{3}q+3Q\right) = \frac{-kq}{ma^3}\left(3q+3\sqrt{3}Q\right) = \boxed{-\frac{3kq}{ma^3}\left(q+\sqrt{3}Q\right) = \omega^2}$$

$$r_i(t) = \frac{q}{\sqrt{3}} + \rho(t)$$

(c

$$\cancel{m}\left(\ddot{\rho} - \rho\omega^2\right) = \frac{kq}{ma^3}\cancel{x} - 2\cancel{\delta}a\left(\sqrt{3}q+3Q\right) \rightarrow \frac{\ddot{\delta a}}{\sqrt{3}} + \delta a\left(\frac{2kq}{ma^3}\left(\sqrt{3}q+3Q\right) - \frac{\omega^2}{\sqrt{3}}\right) = 0$$

$$-\frac{\omega^2}{3}$$

$$\frac{\frac{2kq}{ma^3}\left(\sqrt{3}q+3Q\right) - \frac{\omega^2}{\sqrt{3}}}{\frac{1}{\sqrt{3}}} = \frac{\frac{2\sqrt{3}kq}{ma^3}\left(q+\sqrt{3}Q\right) - \frac{\omega^2}{\sqrt{3}}}{\frac{1}{\sqrt{3}}} = \left(-\frac{2\sqrt{3}}{3}\times\sqrt{3} - 1\right)$$

$$= \left(-2+1\right)\omega^2 = \boxed{-3\omega^2 = \omega_r^2}$$

مسئله 5

الف)

$$\vec F = \frac{q}{4\pi\varepsilon_0 |\vec r_2 - \vec r_1|^3}\left(\frac{3\vec p\cdot(\vec r_2-\vec r_1)(\vec r_2-\vec r_1)}{|\vec r_2-\vec r_1|^2} - \vec p\right)$$

ب)

$$\vec F = \vec F\left(q, \vec r + \frac{\vec p_2}{q}\right) + \vec F(-q, \vec r)$$

$$\left|\vec r + \frac{\vec p_2}{q}\right| = \left(\left(\vec r+\frac{\vec p_2}{q}\right)^2\right)^{1/2} = \left(r^2 + 2\vec r\cdot\frac{\vec p_2}{q}\right)^{1/2} = r\left(1+\frac{\vec r\cdot \frac{\vec p_2}{q}}{r^2}\right)$$

$$\vec F = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r^3}\left(1-\frac{3\vec r\cdot\frac{\vec p_2}{q}}{r^2}\right)\left[\frac{3\vec p_1\cdot\left(\vec r+\frac{\vec p_2}{q}\right)\left(\vec r+\frac{\vec p_2}{q}\right)}{r^2}\left(1-\frac{2\vec r\cdot\frac{\vec p_2}{q}}{r^2}\right) - \vec p_1\right]\right]$$

$$= \frac{q}{4\pi\varepsilon_0 r^3}\left(1-\frac{3\vec r\cdot\vec p_2}{q r^2}\right)\left[\frac{1}{r^2}\left(\frac{3\vec p_1\cdot\vec p_2}{q}\vec r + 3\vec p_1\cdot\vec r\,\frac{\vec p_2}{q} + 3\vec p_1\cdot\vec r\,\vec r\right)\left(1-\frac{2\vec r\cdot\vec p_2}{q r^2}\right) - \vec p_1\right]$$

$$= \frac{q}{4\pi\varepsilon_0 r^3}\left[\left(\frac{3\vec p_1\cdot\vec p_2}{q}\vec r + 3\vec p_1\cdot\vec r\,\frac{\vec p_2}{q}\right)\frac{1}{r^2} - 6\,\vec p_1\cdot\vec r\,\vec r\,\frac{\vec r\cdot\vec p_2}{q r^3} - \frac{3\vec r\cdot\vec p_2}{r^2}\left(\frac{3\vec p_1\cdot\vec r\,\vec r}{r^2} - \vec p_1\right)\right.$$

$$= \frac{\cdots}{4\pi\varepsilon_0} \cdots \frac{\cdots}{r^2}\Big)\Big[\frac{\cdots}{r^2}\left(1-\frac{\frac{2\vec{r}\cdot\vec{p}_2}{q}}{r^2}\right)-\vec{p}_1\Big)\Big]$$

$$= \frac{q}{4\pi\varepsilon_0 r^3}\left(1-\frac{3\vec{r}\cdot\vec{p}_2}{q r^2}\right)\left[\frac{1}{r^2}\left(\frac{3\vec{p}_1\cdot\vec{p}_2}{q}\vec{r}+3\vec{p}_1\cdot\vec{r}\,\frac{\vec{p}_2}{q}+3\vec{p}_1\cdot\vec{r}\,\vec{r}\right)\left(1-\frac{2\vec{r}\cdot\vec{p}_2}{q r^2}\right)-\vec{p}_1\right]$$

$$= \frac{q}{4\pi\varepsilon_0 r^3}\left[\left(\frac{3\vec{p}_1\cdot\vec{p}_2}{q}\vec{r}+3\vec{p}_1\cdot\vec{r}\,\frac{\vec{p}_2}{q}\right)\frac{1}{r^2}-6\,\vec{p}_1\cdot\vec{r}\,\vec{r}\,\frac{\vec{r}\cdot\vec{p}_2}{q r^3}-\frac{3\vec{r}\cdot\vec{p}_2}{r^2}\left(\frac{3\vec{p}_1\cdot\vec{r}\,\vec{r}}{r^2}-\vec{p}_1\right)\right]$$

$$\boxed{\vec{F} = \frac{1}{4\pi\varepsilon_0 r^3}\left[\frac{3\,\vec{p}_1\cdot\vec{p}_2}{r^2}\vec{r}+\frac{3\vec{p}_1\cdot\vec{r}\,\vec{p}_2}{r^2}+\frac{3\,\vec{p}_2\cdot\vec{r}}{r^2}\,\vec{p}_1-15\,\frac{\vec{p}_2\cdot\vec{r}\;\vec{p}_1\cdot\vec{r}}{r^4}\,\vec{r}\right]}$$

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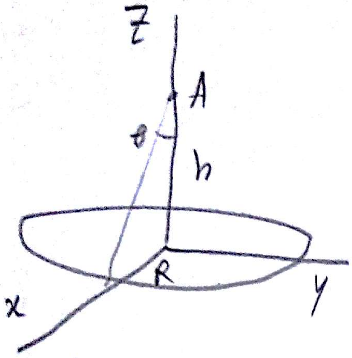
مسئله ۶



الف)

$$E = \frac{\sigma}{2\varepsilon_0}(1-\cos\theta)$$

$$dz \times \frac{\phi(z)-\phi(z+dz)}{dz} = \frac{-d\phi}{dz}\, dz = E\, dz$$

$$\phi = \frac{\sigma\, dz\,(1-\cos\theta)}{2\varepsilon_0} = \boxed{\frac{D}{2\varepsilon_0}\left(1-\frac{h}{\sqrt{R^2+h^2}}\right) = \phi}$$

ب)

$$F = -\frac{d\phi}{dh}q = \frac{Dq}{2\varepsilon_0}\,\frac{\sqrt{R^2+h^2}-\frac{2h^2}{2\sqrt{R^2+h^2}}}{R^2+h^2} = \boxed{\frac{Dq}{2\varepsilon_0}\,\frac{R^2\,\hat{z}}{(R^2+h^2)^{3/2}} = \vec{F}}$$

پ)

$$\frac{dF}{dh} = \frac{DqR^2}{2\varepsilon_0} \times -\frac{3}{2}\,\frac{2h}{(R^2+h^2)^{5/2}} = \frac{-3h\,DqR^2}{2\varepsilon(R^2+h^2)^{5/2}}$$

$$\rightarrow \boxed{\omega^2 = \frac{3h\,DqR^2}{m\varepsilon_0(R^2+h^2)^{5/2}}}$$

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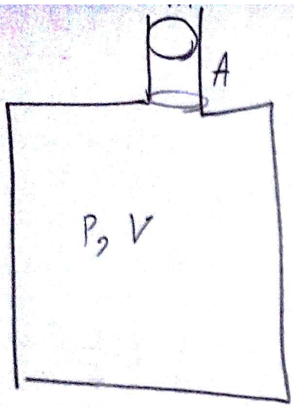
آزمون 2 سال ۹۰

مسئله ۱



الف)

$$T = m^{\alpha_1} v^{\alpha_2} p^{\alpha_3} A^{\alpha_4}$$

$$= M^{\alpha_1} (x^2 z)^{1/2} x^{2\alpha_4} \left(\frac{Mz}{T^2x^2}\right)^{\alpha_3}$$

$$= M^{1/2} (x^2 z)^{1/2} x^{-2} \left(\frac{Mz}{T^2x^2}\right)^{-1/2}$$

$$\rightarrow \boxed{T \propto \sqrt{\frac{mV}{A^2 P}}}$$

ب)

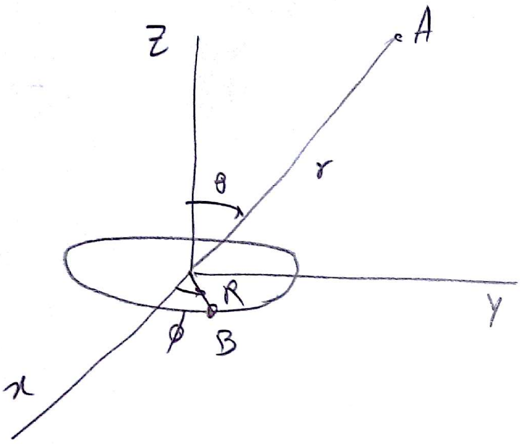
$$\frac{h}{T} = E \rightarrow [h] = \frac{ML^2}{T}$$

$$F \propto h^{\alpha_1} c^{\alpha_2} d^{\alpha_3}$$

$$\frac{ML}{T^2} = \left(\frac{ML^2}{T}\right)^{\cancel{\alpha_1}\,1} \left(\frac{L}{T}\right)^{\cancel{\alpha_2}\,1} L^{\cancel{\alpha_3}\,-2}$$

$$\rightarrow \boxed{F \propto \frac{hc}{d^2}}$$

$\rightarrow \boxed{F \propto \frac{hc}{d^2}}$



مسئله 2

$\vec{r}_B = R(\cos\phi\,\hat{x} + \sin\phi\,\hat{y})$, $\vec{r}_A = r(\sin\theta\,\hat{y} + \cos\theta\,\hat{z})$ (الف

$|\vec{r}_A - \vec{r}_B| = |R\cos\phi\,\hat{x} + (R\sin\phi - r\sin\theta)\,\hat{y} - r\cos\theta\,\hat{z}|$

$= \boxed{\left(R^2 + r^2 - 2Rr\sin\theta\sin\phi\right)^{\frac{1}{2}}}$

ب) $-\frac{1}{2}\times -\frac{3}{2}\times$

$$\phi^{(0)} = \frac{Q}{4\pi\varepsilon_0 r} \qquad \phi = \int \frac{Q\,d\phi}{2\pi \times 4\pi\varepsilon_0 \left(R^2 + r^2 - 2Rr\sin\theta\sin\phi\right)^{\frac{1}{2}}} = \frac{Q}{8\pi^2\varepsilon_0}\int \frac{d\phi}{r}\left(1 - \frac{2R}{r}\sin\theta\sin\phi + \frac{R^2}{r^2}\right)$$

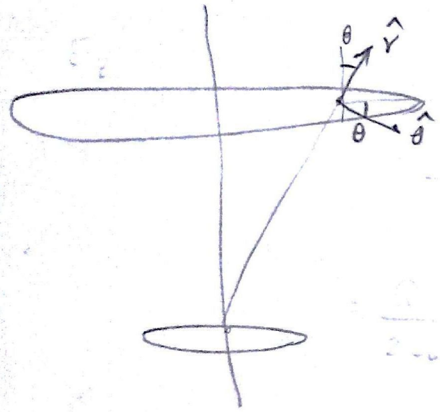
$$= \frac{Q}{8\pi^2\varepsilon_0 r}\int_0^{2\pi} d\phi\left(1 + \frac{R}{r}\sin\theta\sin\phi - \frac{R^2}{2r^2} + \frac{3}{\cancel{8}_{2}} \times \frac{\cancel{4}R^2}{r^2}\sin^2\theta\sin^2\phi\right)$$

$$= \frac{Q}{{}_{4}\cancel{8}\pi^{\cancel{2}}\varepsilon_0 r}\left(\cancel{2}\cancel{\pi}\left(1 - \frac{R^2}{2r^2}\right) + \frac{3}{\cancel{2}_{4}}\frac{R^2}{r^2}\sin^2\theta \times \cancel{\pi}\right) = \boxed{\frac{Q}{4\pi\varepsilon_0 r}\left(1 + \frac{R^2}{r^2}\left(\frac{3}{4}\sin^2\theta - \frac{1}{2}\right)\right) = \phi}$$

ب)

$$\vec{E} = -\frac{Q}{4\pi\varepsilon}\left[-\frac{\hat{r}}{r^2} + \frac{R^2}{r^4}\times\frac{3}{2}\sin\theta\cos\theta\,\hat{\theta} - \frac{3R^2}{r^4}\hat{r}\left(\frac{3}{4}\sin^2\theta-\frac{1}{2}\right)\right]$$

$$\boxed{\vec{E} = \frac{Q}{4\pi\varepsilon_0 r^2}\left[\hat{r}\left(1+\frac{3R^2}{r^2}\left(\frac{3}{4}\sin^2\theta-\frac{1}{2}\right)\right) - \frac{3}{2}\frac{R^2}{r^2}\sin\theta\cos\theta\,\hat{\theta}\right]}$$



$$E_z = \frac{Q}{4\pi\varepsilon_0 r^2}\left[\cos\theta\left(1+\frac{3R^2}{r^2}\left(\frac{3}{4}\sin^2\theta-\frac{1}{2}\right)\right)+\frac{3}{2}\frac{R^2}{r^2}\sin^2\theta\cos\theta\right]$$ ج)

$$\boxed{\Phi = \frac{Q}{2\varepsilon_0}\left[\frac{1-\cos^4\theta}{5} + \frac{R^2}{H^2}\left(-\frac{8}{21} - \frac{9}{28}\cos^7\theta + \frac{5}{12}\cos^9\theta\right)\right]}$$

$$\boxed{\Phi = \frac{Q}{2\varepsilon_0}\left[\frac{1-\cos^4\theta}{5} + \frac{R^2}{H^2}\left(-\frac{8}{21} - \frac{9}{28}\cos^7\theta + \frac{5}{12}\cos^9\theta\right)\right]}$$

$$\Phi = \frac{Q\cos^2\theta}{4\pi\varepsilon_0 H^2}\left[\cos\theta\left(1+\frac{3R^2\cos^2\theta}{H^2}\left(\frac{3}{4}\sin^2\theta - \frac{1}{2}\right)\right) + \frac{3}{2}\frac{R^2}{H^2}\sin^2\theta\cos^3\theta\right] 2\pi H^2 \frac{\sin\theta\, d\theta}{\cos^3\theta}$$

$$= \frac{Q}{2\varepsilon_0}\left[\sin\theta\left(1+\frac{3R^2\cos^2\theta}{H^2}\left(\frac{3}{4}\sin^2\theta - \frac{1}{2}\right)\right) + \frac{3}{2}\frac{R^2}{H^2}\sin^3\theta\cos^2\theta\right] d\theta$$

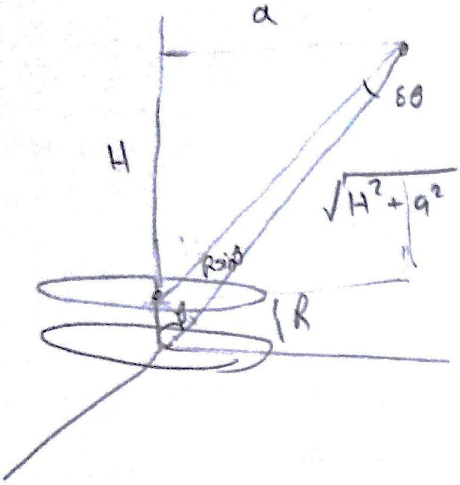
$$= \frac{Q}{2\varepsilon_0}\left[\sin\theta + \frac{R^2}{H^2}\left(\frac{\overset{15}{\cancel{9}}}{4}\cos^2\theta \cancel{\sin^3\theta} - \frac{3}{2}\cos^2\theta\sin\theta + \cancel{\frac{3}{2}\sin^3\theta\cos^2\theta}\right)\right] d\theta \qquad \sin\theta(1-\cos^2\theta)$$

$$= \frac{Q}{2\varepsilon_0}\left[\sin\theta + \frac{R^2}{H^2}\left(\frac{9}{4}\cos^2\theta\sin\theta - \frac{15}{4}\cos^4\theta\sin\theta\right)\right]$$

$$= \frac{Q}{2\varepsilon_0}\left[1-\cos\theta + \frac{R^2}{H^2}\left(\frac{-\overset{3}{\cancel{9}}}{\cancel{3}\times 4}\cos^3\theta + \frac{\overset{3}{\cancel{15}}\times\cos^5\theta}{\cancel{5}\times 4}\right)\right] = \frac{Q}{2\varepsilon_0}\left[1-\cos\theta - \frac{3R^2}{4H^2}\cos^3\theta\sin^2\theta\right] = \Phi$$

$$\to \quad \Phi = \frac{Q}{2\varepsilon_0}\left[1-\cos\theta - \frac{3R^2}{4H^2}\cos^3\theta\sin^2\theta\right]$$

ث)



$$\delta\theta = \frac{R\sin\theta}{\sqrt{H^2+a^2}}$$

$$\cos(\theta+\delta\theta) = \cos\theta - \frac{R\sin^2\theta}{\sqrt{H^2+a^2}}$$

$$\Phi = \frac{Q}{2\varepsilon_0}\left[2(1-\cos\theta)+\frac{R\sin^2\theta}{\sqrt{H^2+a^2}}\right] = \Phi_0$$

$$\rightarrow \Phi_0 = \frac{Q}{2\varepsilon_0}\left[2\left(1-\frac{H}{\sqrt{H^2+a^2}}\right)+\frac{Ra^2}{(H^2+a^2)^{3/2}}\right]$$

$$\boxed{\Phi_0 = \frac{Q}{2\varepsilon_0}\left[2\left(1-\frac{z}{\sqrt{z^2+\rho^2}}\right)+\frac{R\rho^2}{(z^2+\rho^2)^{3/2}}\right]}$$

مسئله 3

الف)

$$\frac{\dot{h}^2}{2}+gh = \frac{v^2}{2} \rightarrow v^2 = \dot{h}^2+2gh$$

$$vA = \frac{dV}{dt} = \frac{dV}{dh}\times\dot{h} = \pi x^2\dot{h} = \pi k h\dot{h} = vA$$

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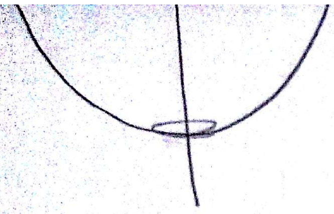

(الف

$$vA = \frac{dV}{dt} = \frac{dV}{dh} \times \dot{h} = \pi x^2 \dot{h} = \pi k h \dot{h} = vA$$

$$\left(\frac{\pi k h}{A}\right)^2 \dot{h}^2 = \dot{h}^2 + 2gh \rightarrow \dot{h}^2\left(\left(\frac{\pi k h}{A}\right)^2 - 1\right) = 2gh \rightarrow \boxed{\dot{h} = \left(\frac{2gh}{\left(\frac{\pi k h}{A}\right)^2 - 1}\right)^{\frac{1}{2}}}$$

(ب

$$\epsilon = \frac{A}{hk} \rightarrow \dot{h} = \left(\frac{2gh}{\left(\frac{\pi}{\epsilon}\right)^2 - 1}\right)^{\frac{1}{2}} = \left(\frac{2gh}{\left(\frac{\pi}{\epsilon}\right)^2\left(1 - \frac{\epsilon^2}{\pi^2}\right)}\right)^{\frac{1}{2}} = \frac{\epsilon\sqrt{2gh}}{\pi}\left(1 + \frac{\epsilon^2}{2\pi^2}\right) = \frac{dh}{dt}$$

$$\rightarrow \frac{t}{\pi} = \int \frac{dh}{\epsilon\sqrt{2gh}\left(1 + \frac{\epsilon^2}{2\pi^2}\right)} = \frac{dh}{\epsilon\sqrt{2gh}}\left(1 - \frac{A^2}{2\pi^2 h^2 k^2}\right) = \sqrt{\frac{h}{2g}} \times \frac{k}{A}\, dh \left(1 - \frac{A^2}{2\pi^2 k^2 h^2}\right)$$

$$= \frac{k}{A\sqrt{2g}}\left(\frac{2}{3}\left(h^{3/2} - h_0^{3/2}\right) + \frac{A^2}{\pi^2 k^2}\left(\frac{1}{\sqrt{h}} - \frac{1}{\sqrt{h_0}}\right)\right)$$

$$V = \pi x^2 dy = \pi x^2 \times \frac{2x\,dx}{k}$$

$$V \propto x^4 = h^2 \rightarrow \frac{V}{2} \rightarrow \frac{h_0}{\sqrt{2}} \rightarrow t = \frac{\pi k}{A\sqrt{2g}}\left(\frac{2}{3} h_0^{3/2}\left(\frac{1}{\cancel{(\sqrt{2})^{3/2}}} - 1\right) + \frac{A^2}{\pi^2 k^2 \sqrt{h_0}}\left(\sqrt[4]{2} - 1\right)\right)$$

$$2^{3/4}$$

$$t = \frac{\pi k}{A\sqrt{2g}}\left(\frac{h_0^{3/2}}{3}\left(2^{\frac{1}{4}} - 2\right) + \frac{A^2}{\pi^2 k^2 \sqrt{h_0}}\left(2^{\frac{1}{4}} - 1\right)\right)$$

مسئله 4

الف) $\frac{1}{2}$ ب)

$$v\,\frac{t_1+t_2}{2}=\ell \rightarrow v=\frac{2\ell}{t_1+t_2} \qquad P=\frac{v_2-\frac{2\ell}{t_1+t_2}}{v_2-v_1} \qquad v_1t_1=\ell\ ,\ v_2t_2=\ell$$

$$\frac{2\ell}{t_1+t_2}=\frac{2\ell}{\frac{\ell}{v_1}+\frac{\ell}{v_2}}=\frac{2v_1v_2}{v_1+v_2} \rightarrow P=\frac{v_2-\frac{2v_1v_2}{v_1+v_2}}{v_2-v_1}=\frac{v_2^2-v_1v_2}{v_2^2-v_1^2}=\frac{v_2\cancel{(v_2-v_1)}}{\cancel{(v_2-v_1)}(v_2+v_1)}=\boxed{\frac{v_2}{v_2+v_1}=P}$$

پ)

$$\int_{v_1}^{v_2}\alpha e^{-\lambda v}\,dv=1=-\frac{\alpha}{\lambda}e^{-\lambda v}\Big|_{v_1}^{v_2}=-\frac{\alpha}{\lambda}\left(e^{-\lambda v_2}-e^{-\lambda v_1}\right)=1$$

$$\boxed{\alpha=\frac{\lambda}{e^{-\lambda v_1}-e^{-\lambda v_2}}}$$

ت)

$$\alpha\int_{v_1}^{\frac{v_1+v_2}{2}}e^{-\lambda v}\,dv=-\frac{\alpha}{\lambda}\left(e^{-\frac{\lambda(v_1+v_2)}{2}}-e^{-\lambda v_1}\right)=\boxed{\frac{e^{-\lambda\frac{v_1+v_2}{2}}-e^{-\lambda v_1}}{e^{-\lambda v_1}-e^{-\lambda v_2}}=P}$$

$2v_1v_2$

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v_1+v_2

$$\boxed{P=\frac{e^{-\lambda v_2}-e^{-\lambda\frac{2v_1v_2}{v_1+v_2}}}{e^{-\lambda v_2}-e^{-\lambda v_1}}}$$

ن)

$$P=\frac{\cancel{1}-\cancel{\lambda} v_2+\frac{\lambda^2 v_2^2}{2}-\left(\cancel{1}-\cancel{\lambda}\frac{2v_1v_2}{v_1+v_2}+\lambda^2\frac{\cancel{4}\,2\, v_1^2v_2^2}{\cancel{2}(v_1+v_2)^2}\right)}{\cancel{1}-\cancel{\lambda} v_2+\frac{\lambda^2 v_2^2}{2}-\left(\cancel{1}-\cancel{\lambda} v_1+\frac{\lambda^2 v_1^2}{2}\right)}$$

ج)

$$=\frac{\frac{\overset{v_2(v_1-v_2)}{\cancel{v_1v_2-v_2^2}}}{v_1+v_2}+\frac{\lambda}{2}\,\frac{\cancel{v_2^2}(v_1+v_2)^2-4\cancel{v_1^2v_2^2}}{(v_1+v_2)^2}v_2^2}{v_1-v_2+\frac{\lambda}{2}(v_2^2-v_1^2)}=\frac{\frac{v_2(v_1-v_2)}{v_1+v_2}+\frac{\lambda}{2}v_2^2\frac{(v_1+v_2)^2-4v_1^2}{(v_1+v_2)^2}}{(v_1-v_2)}\times\frac{\left(1-\frac{\lambda}{2}(v_1+v_2)\right)}{\left(1+\frac{\lambda}{2}(v_1+v_2)\right)}$$

$$=\frac{v_2}{v_1+v_2}+\frac{\lambda}{2}\quad v_2^2\frac{(v_1+v_2)^2-4v_1^2}{(v_1+v_2)^2(v_1-v_2)}+\frac{\lambda}{2}v_2=P$$

$$P = \frac{v_2}{v_1+v_2} + \frac{\lambda}{2} v_2 \frac{\cancel{v_2(v_1+v_2)^2} - 4v_1^2 v_2 + (v_1+v_2)^2 (v_1 - v_2)}{(v_1+v_2)^2 (v_1-v_2)}$$

$$= \frac{v_2}{v_1+v_2} + \frac{\lambda}{2} v_2 v_1 \frac{(v_1-v_2)^{\cancel{3}}}{(v_1+v_2)^2 \cancel{(v_1-v_2)}} = \boxed{\frac{v_2}{v_1+v_2} + \frac{\lambda}{2} v_1 v_2 \frac{v_1-v_2}{(v_1+v_2)^2} = P}$$

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ج)

$$\int t\, p_{(t)}\, dt = \int t\, p_{(v)}\, dv = \int \frac{l}{v}\, \frac{dv}{v_2 - v_1} = \boxed{\frac{l}{v_2 - v_1} \ln\left(\frac{v_2}{v_1}\right) = \bar{t}}$$

$$\bar{t} = \int t\, p_{(t)}\, dt = \int \frac{l}{v}\, \frac{\lambda e^{-\lambda v}\, dv}{e^{-\lambda v_1} - e^{-\lambda v_2}} = \frac{\lambda l}{e^{-\lambda v_1} - e^{-\lambda v_2}} \int (1 - \lambda v)\, \frac{dv}{v}$$

$$= \frac{\cancel{\lambda} l}{\cancel{1} - \cancel{\lambda} v_1 + \frac{\lambda^{\cancel{2}} v_1^2}{2} - \left(\cancel{1} - \cancel{\lambda} v_2 + \frac{\lambda^{\cancel{2}} v_2^2}{2}\right)} \left(\ln\left(\frac{v_2}{v_1}\right) - \lambda (v_2 - v_1)\right)$$

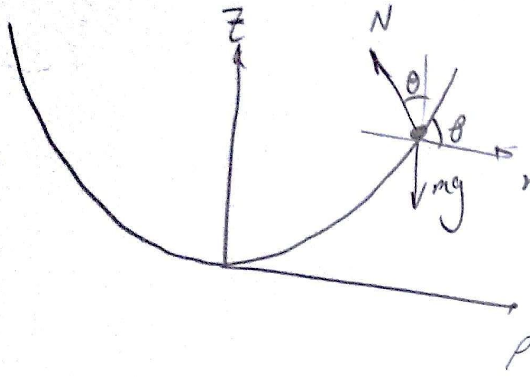
$$= \frac{l \left(\ln\left(\frac{v_2}{v_1}\right) - \lambda (v_2 - v_1)\right)}{v_2 - v_1 + \frac{\lambda}{2} (v_1^2 - v_2^2)} = \boxed{\frac{l}{v_2 - v_1} \left(\ln\left(\frac{v_2}{v_1}\right) - \lambda (v_2 - v_1) + \frac{\lambda}{2} (v_1 + v_2) \ln\left(\frac{v_2}{v_1}\right)\right) = \bar{t}}$$

د)

$$\boxed{\lambda \; \frac{\frac{v_1 + v_2}{2} \ln\left(\frac{v_2}{v_1}\right) - (v_2 - v_1)}{\ln\left(\frac{v_2}{v_1}\right)} = \eta \longrightarrow \text{خطای نسبی}}$$

مسئله 5

الف)



$N\cos\theta = mg$

$m\rho\dot\phi^2 \quad N\sin\theta = m\rho\dot\phi^2 = \cancel{m}g\tan\theta = \cancel{m}\rho\dot\phi^2$

$\to \dot\phi^2 = \frac{g}{R_0}\times 4K\cancel{\rho^3}R_0^3 = 4KgR_0^2 = \dot\phi^2$

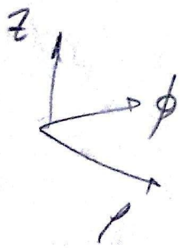
$\to \boxed{\dot\phi = \sqrt{Kg}\times 2R_0}$

ب)

$R_0^2\times 2R_0\sqrt{Kg} = \rho^2\dot\phi \to \boxed{\dot\phi = \frac{2R_0^3\sqrt{Kg}}{\rho^2}}$

پ)

$\vec v = \dot\rho\hat\rho + \rho\dot\phi\hat\phi + \dot z\hat z \qquad \vec B = B\hat\phi \to \vec F = qB(\dot\rho\hat z - \dot z\hat\rho)$



$$\begin{cases} m(\ddot\rho - \rho\dot\phi^2) = -N\sin\theta - qB\dot z \\ m\ddot z = N\cos\theta - mg + qB\dot\rho \end{cases}$$

$m\left(\ddot\rho - \rho\times\frac{4R_0^6 Kg}{\rho^{\cancel{4}3}}\right) = -N\times 4K\rho^3$

$$\rho \qquad m\ddot z = N\cos\theta - mg + qB\dot\rho$$

$$m\left(\ddot\rho - \rho\times\frac{4R_0^6\,kg}{\rho^{\cancel{4}3}}\right) = -\frac{N\times 4K\rho^3}{\sqrt{1+16K^2\rho^6}} - qB\cancel{\dot z}\times 4K\rho^3\dot\rho$$

$$z = K\rho^4 \to \dot z = 4K\rho^3\dot\rho \to \ddot z = 4K\left(3\rho^2\dot\rho^2 + \rho^3\ddot\rho\right)$$

$$4Km\left(3\rho^2\dot\rho^2 + \rho^3\ddot\rho\right) = \frac{N}{\sqrt{1+16K^2\rho^6}} - mg + qB\dot\rho$$

$$m\left(\ddot\rho - \frac{4R_0^6\,kg}{\rho^3}\right) = -4K\rho^3\times\left(4Km(3\rho^2\dot\rho^2 + \rho^3\ddot\rho) + mg - \cancel{qB\dot\rho}\right) - \cancel{4K\rho^3\dot\rho\, qB}$$

$$\ddot\rho\left(\cancel{m} + 16K^2\cancel{m}\rho^6\right) = -16K^2m\rho^3\times 3\rho^2\dot\rho^2 - 4K\rho^3 mg + \frac{4mR_0^6\,kg}{\rho^3}$$

$$= -48K^2\cancel{m}\rho^5\dot\rho^2 - 4K\rho^3\cancel{m}g + \frac{4\cancel{m}R_0^6\,kg}{\rho^3}$$

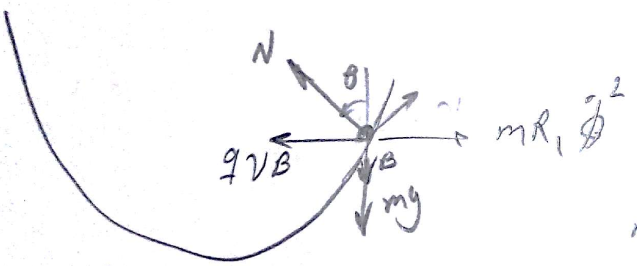
$$\boxed{\ddot\rho\left(1 + 16K^2\rho^6\right) = -48K^2\rho^5\dot\rho^2 - 4K\rho^3 g + \frac{4R_0^6\,kg}{\rho^3}}$$

$$\delta\ddot{\rho}\,(1+16K^2R_0^6) = \left(-12K\cancel{\rho^2}R_0^2\, g - \frac{12R_0^{\cancel{6}\,2}Kg}{\cancel{R_0^4}}\right)\delta\rho$$ (ب

$$= -24KR_0^2\, g$$

$$\to \boxed{\omega^2 = \frac{24KR_0^2\, g}{1+16K^2R_0^6}}$$

$$mR_1\dot{\phi}^2 = N\sin\theta + qR_1\dot{\phi}B$$ (ج



$$N\cos\theta = mg$$

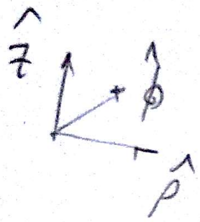
$$mR_1\dot{\phi}^2 = mg\times 4K\cancel{\rho^3}R_1^3 + qR_1\dot{\phi}B$$

$$mR_1\dot{\phi}^2 - 4KmgR_1^3 - qR_1\dot{\phi}B = 0 \to \dot{\phi} = \frac{q\cancel{R_1}B \pm \sqrt{(qR_1B)^2 + 16Km^2gR_1^{\cancel{4}\,2}}}{2m\cancel{R_1}}$$

$$\boxed{= \frac{qB}{2m} + \frac{\sqrt{(qB)^2 + 16Km^2gR_1^2}}{2m} = \dot{\phi}}$$

$$= \boxed{\frac{qB}{2m} + \frac{\sqrt{(qB)^2 + 16Km^2 g R_1^2}}{2m} = \dot{\phi}} \qquad 2m R_1$$

$$\vec{v} = \dot{\rho}\hat{\rho} + \rho\dot{\phi}\hat{\phi} + \dot{z}\hat{z} \qquad \vec{B} = -B_0\hat{z} \rightarrow \vec{F} = -qB_0(-\dot{\rho}\hat{\phi} + \rho\dot{\phi}\hat{\rho})$$



$$m(\rho\ddot{\phi} + 2\dot{\rho}\dot{\phi}) = qB_0\dot{\rho} \rightarrow \frac{m}{\rho}\frac{d}{dt}(\rho^2\dot{\phi}) = qB_0\dot{\rho}$$

$$\frac{qB_0}{m}\rho\, d\rho = \rho^2\dot{\phi} - R_1^2\dot{\phi}_0$$

$$\dot{\phi}_0 = \frac{qB}{2m} + \left(\frac{1}{\cancel{4}_{16}}\left(\frac{qB}{m}\right)^2 + \cancel{4Kg}R_1 \times \frac{3}{\cancel{64}_{16}} \times \left(\frac{qB}{m}\right)^2\right)^{1/2}$$

$$= \frac{qB}{2m} + \left(\frac{7}{16} \times \left(\frac{qB}{m}\right)^2\right)^{1/2} = \frac{qB}{2m}\left(1 + \frac{\sqrt{7}}{2}\right) = \dot{\phi}_0$$

$$\frac{qB_0}{2m}(\rho^2 - R_1^2) = \rho^2\dot{\phi} - \frac{qB}{2m}R_1^2\left(\cancel{1} + \frac{\sqrt{7}}{2}\right)$$

$$\rightarrow \dot{\phi} = \frac{qB}{2m\rho^2}\left(\rho^2 + \frac{\sqrt{7}}{2}R_1^2\right) = \boxed{\frac{qB}{2m}\left(1 + \frac{\sqrt{7}}{2}\frac{R_1^2}{\rho^2}\right) = \dot{\phi}}$$

$$m(\ddot{\rho}-\rho\dot{\phi}^2) = -N\sin\theta - qB_0\rho\dot{\phi}$$

$$m\ddot{z} = N\cos\theta - mg \qquad z = k\rho^4 \to \dot{z} = 4k\rho^3\dot{\rho} \quad \ddot{z} = 4k(3\rho^2\dot{\rho}^2+\rho^3\ddot{\rho})$$

$$m\left(\ddot{\rho}-\rho\times\left(\frac{qB}{2m}\right)^2\left(1+\frac{7}{4}\frac{R_1^4}{\rho^4}+\sqrt{7}\frac{R_1^2}{\rho^2}\right)\right) = \frac{-N\times 4k\rho^3}{\sqrt{1+(4k\rho^3)^2}} - qB_0\rho\dot{\phi}$$

$$\frac{N\alpha}{\sqrt{1+(4k\rho^3)^2}} = m\times 4k(3\rho^2\dot{\rho}^2+\rho^3\ddot{\rho})+mg$$

$$m\left(\underline{\ddot{\rho}}-\rho\times\frac{q^2B^2}{4m^2}\left(1+\frac{7}{4}\frac{R_1^4}{\rho^4}+\sqrt{7}\frac{R_1^2}{\rho^2}\right)\right) = -4k\rho^3\left(4km\,(\underline{3\rho^2\dot{\rho}^2}+\underline{\rho^3\ddot{\rho}})+mg\right)$$

$$-\frac{q^2B_0^2\rho}{2m}\left(1+\frac{\sqrt{7}}{2}\frac{R_1^2}{\rho^2}\right)$$

$$\ddot{\rho}(m+16k^2m\rho^6) = -48k^2m\times\rho^5\dot{\rho}^2-4kmg\rho^3-\frac{q^2B_0^2\rho}{2m}\left(1+\frac{\sqrt{7}}{2}\frac{R_1^2}{\rho^2}\right)$$

$$+\rho\frac{q^2B^2}{2m}\left(1+\frac{7}{4}\frac{R_1^4}{\rho^4}+\sqrt{7}\frac{R_1^2}{\rho^2}\right)$$

$$\frac{\ldots\rho}{2m}\left(1+\frac{\sqrt{7}}{2}\frac{R_1}{\rho^2}\right)$$

$$\ddot{\rho}\left(m+16K^2 m\rho^6\right) = -\cancel{16}^{48}K^2 m \times \cancel{3}\rho^{\cancel{5}}\dot{\rho}^2 - 4Kmg\rho^3 - \frac{q^2B_0^2\rho}{2m}\left(1+\frac{\sqrt{7}}{2}\frac{R_1^2}{\rho^2}\right)$$
$$+\ \rho\frac{q^2B^2}{2m}\left(1+\frac{7}{4}\frac{R_1^4}{\rho^4}+\sqrt{7}\frac{R_1^2}{\rho^2}\right)$$

$$m\delta\ddot{\rho}\left(1+16K^2R_0^6\right) = -12KmgR_0^2\delta\rho - \frac{q^2B_0^2}{2m}\left(\cancel{\delta\rho}+\cancel{\frac{\sqrt{7}}{2}\frac{R_1^2}{\rho^2}}\delta\rho\right)$$ (2
$$+\ \frac{q^2B^2}{2m}\left(\cancel{\delta\rho}+\frac{7}{4}\frac{\cancel{R_1^4}}{\cancel{R_1^4}}\times -3\delta\rho + \cancel{\sqrt{7}}^{-\frac{\sqrt{7}}{2}}\frac{\cancel{R_1^2}}{\cancel{R_1^2}}\delta\rho\right)$$

$$m\delta\ddot{\rho}\left(1+16K^2R_0^6\right) + 12KmgR_0^2\delta\rho - \frac{q^2B_0^2}{2m}\left(-\frac{21}{4}-\frac{\sqrt{7}}{2}\right)\delta\rho = 0$$

$$\boxed{\omega^2 = \frac{\frac{q^2B_0^2}{2m}\left(\frac{21}{4}+\frac{\sqrt{7}}{2}\right)+12KmgR_0^2}{1+16K^2R_0^6}}$$

$$\boxed{m\ddot{\rho}\left(1+16K^2\rho^6\right) = -48K^2m\rho^5\dot{\rho}^2 - 4Kmg\rho^3 + \frac{\rho q^2B^2}{2m}\left(\frac{\sqrt{7}}{2}\frac{R_1^2}{\rho^2}+\frac{7}{4}\frac{R_1^4}{\rho^4}\right)}$$

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