$$ml^2\frac{d^2\theta}{dt^2} + mgl\sin\theta = 0$$

$$\sin\theta \approx \theta$$

$$l\frac{d^2\theta}{dt^2} + g\theta = 0$$

$$\alpha = \frac{-b \pm \sqrt{b^2 - 4mk}}{2m}$$

$$= -\frac{b}{2m} \pm \sqrt{\left(\frac{b}{2m}\right)^2 - \frac{k}{m}}$$

$$\frac{d^2y}{dx^2} + xy = 0$$

$$F = -kx - b\dot{x} + F\cos\omega_d t$$

$$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = F\cos\omega_d t$$

Simple harmonic Oscillation

$\vec{F} = -kx$

$m\frac{d^2x}{dt^2}$

$m(-\omega^2)\cos(\omega t) + k\cos(\omega t) = 0$

$\omega^2 = \frac{k}{m} \Rightarrow \omega = \left(\frac{k}{m}\right)^{1/2}$

$m\frac{d^2x}{dt^2} + kx = 0$

$x(t)$

$x(t) = A\cos(\omega t)$

$\omega^2 = \frac{g}{l} \Rightarrow \omega = \left(\frac{g}{l}\right)^{1/2}$

$l\frac{d^2\theta}{dt^2} + g\theta = 0$

$\theta(t) = \theta_0\cos(\omega t)$

$\omega T = 2\pi \Rightarrow T = 2\pi\sqrt{\frac{m}{k}}$

$T = 2\pi\sqrt{\frac{l}{}}$

Simple harmonic Oscillation

$F = -kx$

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Simple harmonic Oscillation

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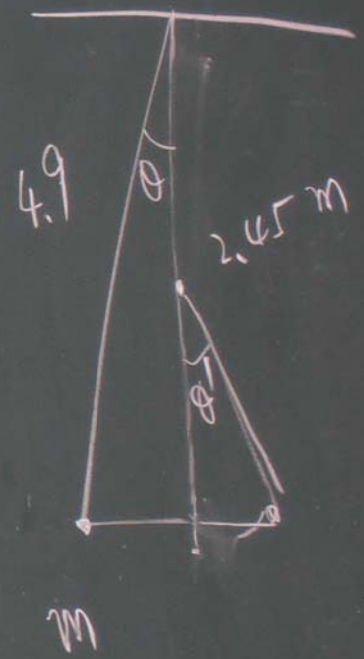
$l\frac{d^2\theta}{dt^2} + g\theta = 0$

$\omega T = 2\pi \Rightarrow T = 2\pi\sqrt{\frac{m}{k}}$

$T = 2\pi\sqrt{\frac{l}{g}}$

$\omega T = 2\pi \Rightarrow T = 2\pi\sqrt{\frac{m}{k}}$

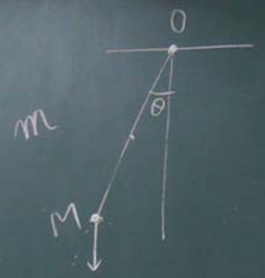
$T = 2\pi\sqrt{\frac{l}{g}}$



$$ml^2\frac{d^2\theta}{dt^2} + \cancel{l}\cancel{mg}\sin\theta = 0$$

$$\theta$$

$$l\frac{d^2\theta}{dt^2} + g\theta = 0$$



$$\vec{r}\times\vec{F} \qquad \tau = I\alpha = I\frac{d^2\theta}{dt^2}$$

$$lmg\sin\theta \qquad ml^2$$

Simple harmoni

$$m(-\omega^2)\cos(\omega t) + k$$

$$\omega^2 = \frac{k}{m} \Rightarrow \omega = \left(\frac{k}{m}\right.$$

$$\omega^2 = \frac{g}{l} \Rightarrow \omega = \left(\right.$$

$$\omega T = 2\pi$$

$$l(1-\cos\theta) = \frac{l}{2}(1-\cos\theta')$$

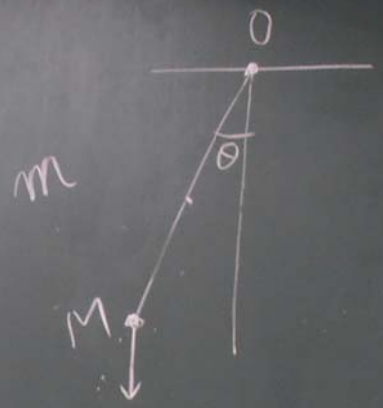
$$\frac{l}{2} - l\cos\theta = \frac{l}{2} - \frac{l}{2}\cos\theta'$$

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

$$l' = \frac{l}{2}m + lM \Big/ m+M$$

$$m\ell^2 \frac{d^2\theta}{dt^2} + \ell mg \sin\theta = 0$$

$$\ell \frac{d^2\theta}{dt^2} + g\theta = 0$$



$\vec{r} \times \vec{F}$

$\ell mg \sin\theta$

$\tau = I\alpha = I \frac{d^2\theta}{dt^2}$

$m\ell^2$

$$\ell(1-\cos\theta) = \frac{\ell}{2}(1-\cos\theta')$$

$$\frac{\ell}{2} - \ell\cos\theta = \frac{\ell}{2} - \frac{\ell}{2}\cos\theta'$$

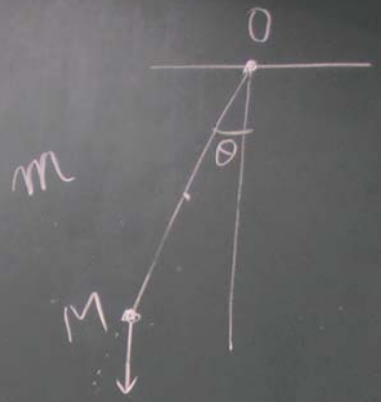
$$2\cos\theta - 1 = \cos\theta'$$

$$\ell' = \frac{\frac{\ell}{2}m + \ell M}{m+M}$$

$$m\ell^2\frac{d^2\theta}{dt^2} + \ell mg\sin\theta = 0$$

θ

$$\ell\frac{d^2\theta}{dt^2} + g\theta = 0$$



$\vec{r}\times\vec{F}$

$\ell mg\sin\theta$

$\tau = I\alpha = I\frac{d^2\theta}{dt^2}$

$m\ell^2$

$$\ell(1-\cos\theta) = \frac{\ell}{2}(1-\cos\theta')$$

$$\frac{\ell}{2} - \ell\cos\theta = \frac{\ell}{2} - \frac{\ell}{2}\cos\theta'$$

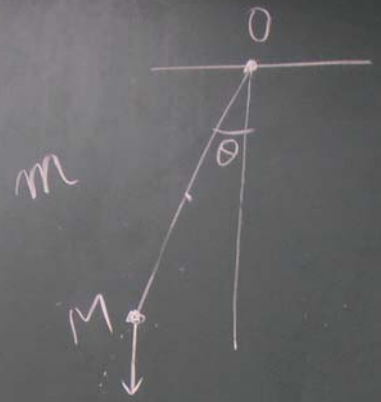
$$2\cos\theta - 1 = -\cos\theta'$$

$$\ell' = \frac{\ell}{2}m + \ell M \Big/ m+M$$

$$m\ell^2 \frac{d^2\theta}{dt^2} + \ell mg \sin\theta = 0$$

$$\theta$$

$$\ell \frac{d^2\theta}{dt^2} + g\theta = 0$$



$\vec{r} \times \vec{F}$

$\ell mg \sin\theta$

$\tau = I\alpha = I \frac{d^2\theta}{dt^2}$

$m\ell^2$

$$\ell(1-\cos\theta) = \frac{\ell}{2}(1-\cos\theta')$$

$$\frac{\ell}{2} - \ell\cos\theta = \frac{\ell}{2} - \frac{\ell}{2}\cos\theta'$$

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

$$\ell' = \frac{\ell}{2} m + \ell M \Big/ m+M$$

$\omega T = 2\pi \Rightarrow T = 2\pi\sqrt{\frac{m}{k}}$

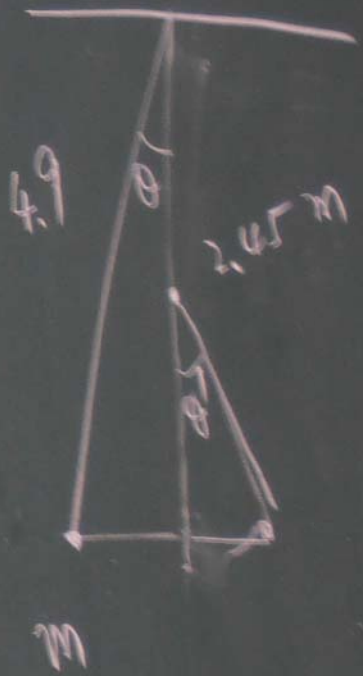
$T = 2\pi\sqrt{\frac{l}{g}}$

$T = \pi\sqrt{\frac{l}{g}} + \pi\sqrt{\frac{l}{2g}}$

$\omega T = 2\pi \Rightarrow T = 2\pi\sqrt{\frac{m}{k}}$

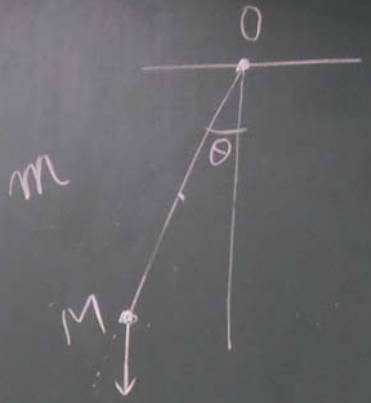
$T = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \pi\sqrt{\frac{\ell}{g}} + \pi\sqrt{\frac{\ell}{2g}}$



$$m\ell^2 \frac{d^2\theta}{dt^2} + \ell mg \sin\theta = 0$$

$$\ell \frac{d^2\theta}{dt^2} + g\theta = 0$$



$\vec{r} \times \vec{F}$

$\ell mg \sin\theta$

$\tau = I\alpha = I \frac{d^2\theta}{dt^2}$

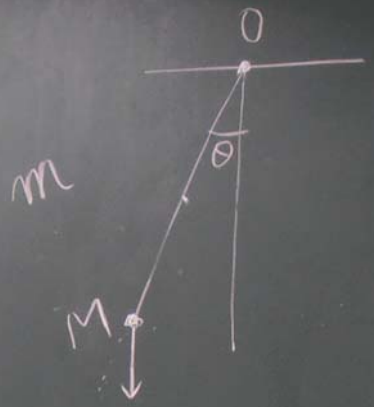
$I = m\ell^2$

M_m

$$-G \frac{M(m)}{r^2} \hat{r}$$

$$m\ell^2\frac{d^2\theta}{dt^2} + \ell mg\sin\theta = 0$$

$$\ell\frac{d^2\theta}{dt^2} + g\theta = 0$$



$\vec{r}\times\vec{F}$

$\ell mg\sin\theta$

$\tau = I\alpha = I\frac{d^2\theta}{dt^2}$

$I = m\ell^2$

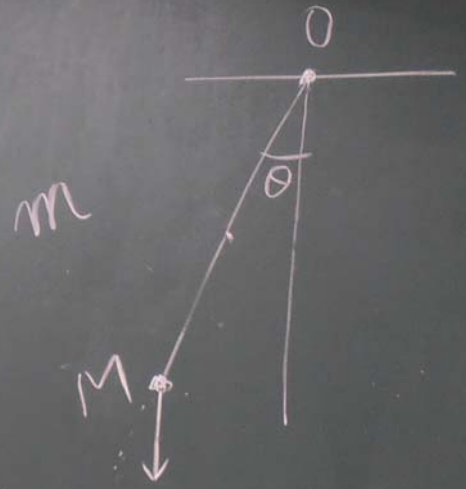
M_m

$$-G\frac{M(m)}{r^2}\hat{r}$$

$$ml^2\frac{d^2\theta}{dt^2} + lmg\sin\theta = 0$$

$$\theta$$

$$l\frac{d^2\theta}{dt^2} + g\theta = 0$$



$\vec{r} \times \vec{F}$

$lmg\sin\theta$

$\tau = I\alpha = I\frac{d^2\theta}{dt^2}$

ml^2

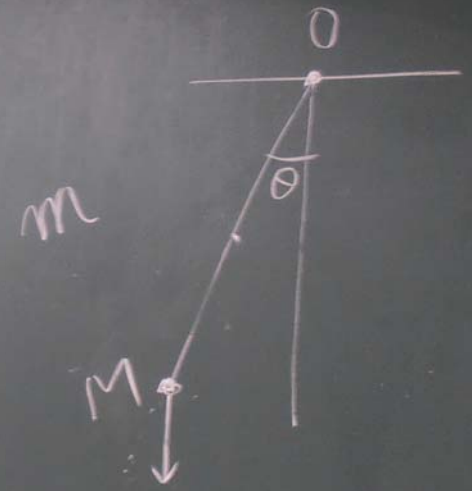
M_m

$$-G\frac{M(m)}{r^2}\hat{r}$$

$$m\ell^2 \frac{d^2\theta}{dt^2} + \ell mg \sin\theta = 0$$

$$\theta$$

$$\ell \frac{d^2\theta}{dt^2} + g\theta = 0$$



$$\vec{r} \times \vec{F}$$

$$\ell mg \sin\theta$$

$$\tau = I\alpha = I \frac{d^2}{d}$$

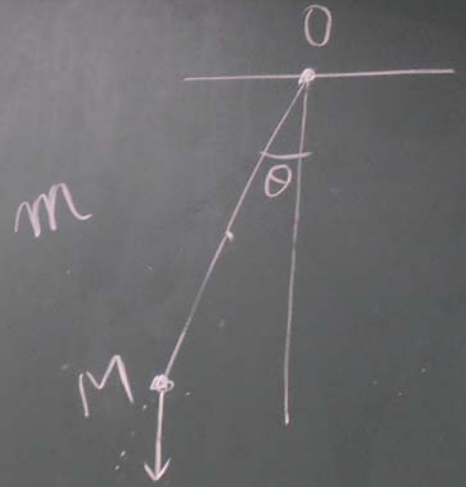
$$m\ell^2$$

$$M_m$$

$$-G \frac{M(m)}{r^2} \hat{r}$$

$$m\ell^2 \frac{d^2\theta}{dt^2} + \ell mg \sin\theta = 0$$

$$\ell \frac{d^2\theta}{dt^2} + g\theta = 0$$



$\vec{r} \times \vec{F}$

$\ell mg \sin\theta$

$\tau = I\alpha = I \frac{d^2\theta}{dt^2}$

I

$m\ell^2$

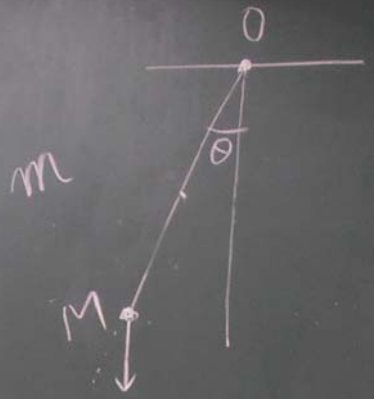
M_m

$$-G\frac{M(m)}{r^2}\hat{r}$$

$$ml^2\frac{d^2\theta}{dt^2} + lmg\sin\theta = 0$$

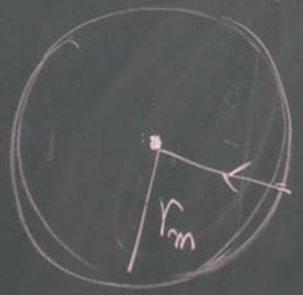
$\sin\theta \approx \theta$

$$l\frac{d^2\theta}{dt^2} + g\theta = 0$$



$\vec{r} \times \vec{F}$ $\quad \tau = I\alpha = I\frac{d^2\theta}{dt^2}$

$lmg\sin\theta$ $\quad mL^2$

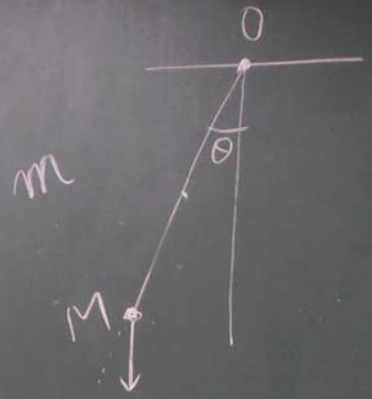


M_m

$$-G\frac{M(m)}{r^2}\hat{r}$$

$$m\ell^2 \frac{d^2\theta}{dt^2} + \ell mg \sin\theta = 0$$

$$\ell \frac{d^2\theta}{dt^2} + g\theta = 0$$



$\vec{r} \times \vec{F}$ $\quad \tau = I\alpha = I \frac{d^2\theta}{dt^2}$

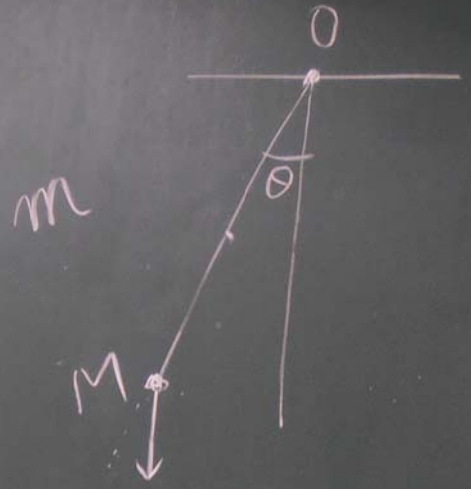
$\ell mg \sin\theta$ $\quad$ $m\ell^2$

$$-G \frac{M(m)}{r^2} \hat{r}$$

$$ml^2\frac{d^2\theta}{dt^2} + lmg\sin\theta = 0$$

$\sin\theta \approx \theta$

$$l\frac{d^2\theta}{dt^2} + g\theta = 0$$



$\vec{r} \times \vec{F}$

$lmg\sin\theta$

$\tau = I\alpha = I\frac{d^2\theta}{dt^2}$

$I = ml^2$

$$-G\frac{M(m)}{r^2}\hat{r}$$

$$m\ell^2\frac{d^2\theta}{dt^2} + \ell mg\sin\theta = 0$$

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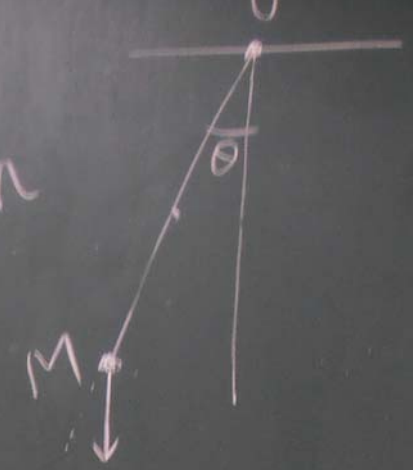


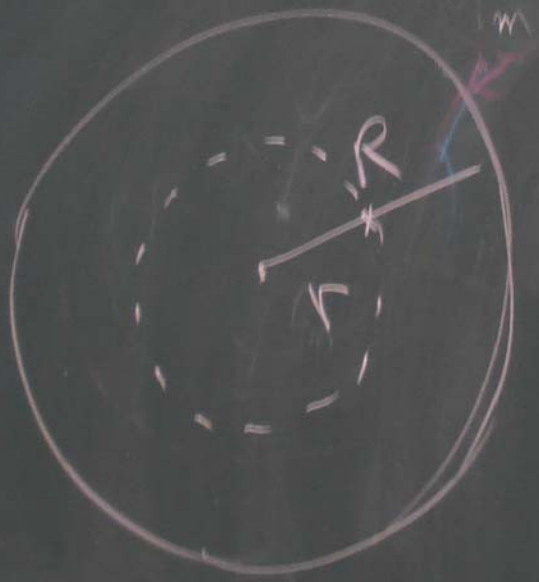
$\vec{r}\times\vec{F}$

$\ell mg\sin\theta$

$\tau = I\alpha = I$

$m\ell^2$

$$m\frac{d^2r}{dt^2} + m\frac{GM}{R^3}r = 0$$



$$\frac{m\left(-4\pi G\left(\frac{4}{3}\pi r^3\rho\right)\right)}{4\pi r^2}$$

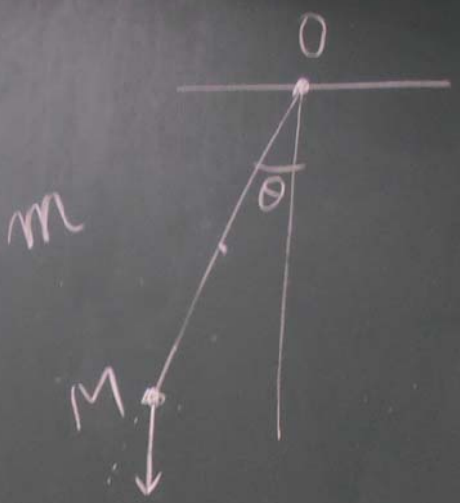
$\rho = \frac{M}{\frac{4}{3}\pi R^3}$

$$-m\frac{GM}{R^3}r$$

$$ml^2\frac{d^2\theta}{dt^2} + \cancel{l}mg\sin\theta = 0$$

$$\theta$$

$$l\frac{d^2\theta}{dt^2} + g\theta = 0$$



$\vec{r} \times \vec{F}$

$lmg\sin\theta$

$\tau = I\alpha = I\frac{d^2\theta}{dt^2}$

$I = ml^2$

$$m\frac{d^2r}{dt^2} + m\frac{GM}{R^3}r = 0$$

$$= \quad = -\frac{M}{\frac{4}{3}\pi R^3}$$

$$\frac{m\left(-4\pi G\left(\frac{4}{3}\pi r^3\rho\right)\right)}{4\pi r^2}$$

$$-m\frac{GM}{R^3}r$$

$$m\frac{d^2\vec{r}}{dt^2} + m\frac{GM}{R^3}\vec{r} = 0$$

$$= -G\frac{M}{\frac{4}{3}\pi R^3}$$

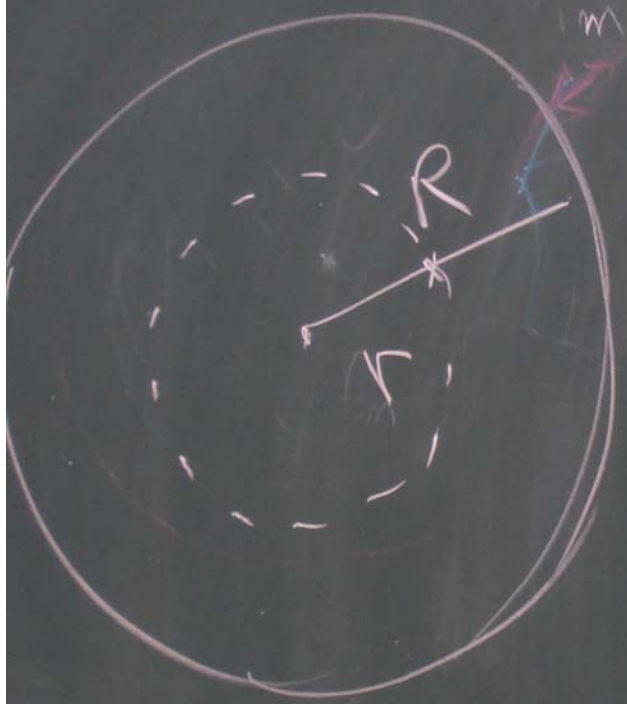
$$\frac{m\left(-4\pi G\left(\frac{4}{3}\pi r^3 \rho\right)\right)}{4\pi r^2}$$

$$-m\frac{GM}{R^3}r$$

$$m\frac{d^2\vec{r}}{dt^2} + m\frac{GM}{R^3}\vec{r} = 0$$

$$\vec{F} = -G\frac{Mm}{r^2}$$

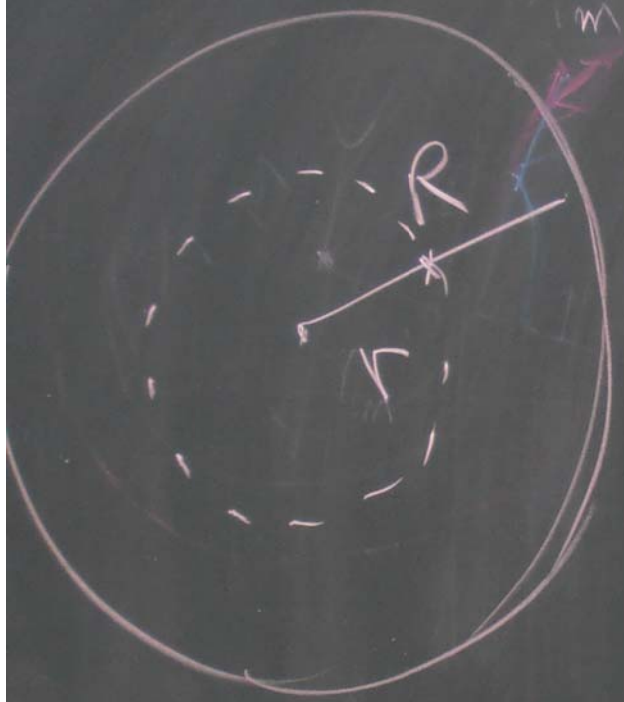
$$\frac{M}{\frac{4}{3}\pi R^3}$$



$$\frac{m\left(-4\pi G\left(\frac{4}{3}\pi r^3 \rho\right)\right)}{4\pi r^2}$$

$$-m\frac{GM}{R^3}r$$

$$\cancel{m}\frac{d^2 r}{dt^2} + \cancel{m}\frac{GM}{R^3} r = 0$$



$$\frac{M}{\frac{4}{3}\pi R^3}$$

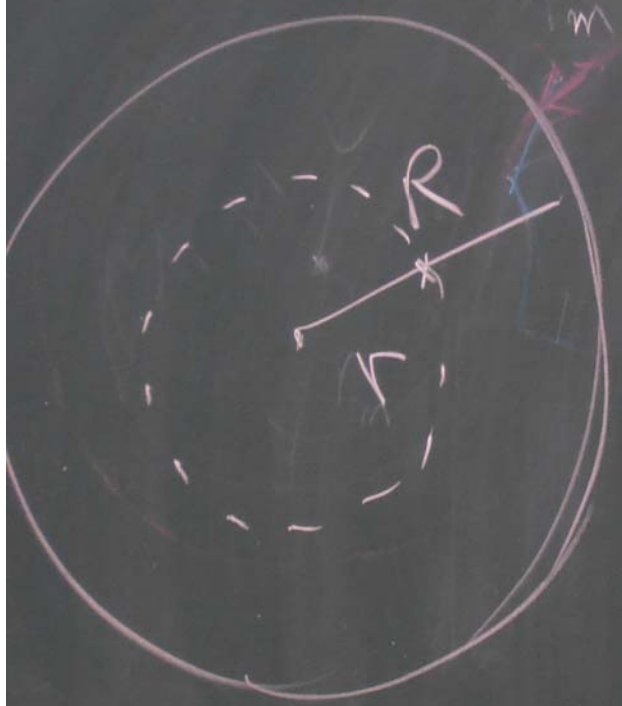
$$\frac{m\left(-\cancel{4\pi} G\left(\frac{4}{3}\pi r^{\cancel{3}} \rho\right)\right)}{\cancel{4\pi r^2}}$$

$$-m\frac{GM}{R^3} r$$

$$m\frac{d^2r}{dt^2} + m\frac{GM}{R^3}r = 0$$

$$= -\frac{GM}{R^2}$$

$$\frac{M}{\frac{4}{3}\pi R^3}$$



$$\frac{m\left(-4\pi G\left(\frac{4}{3}\pi r^3\rho\right)\right)}{4\pi r^2}$$

$$-m\frac{GM}{R^3}r$$

$$F = -kx - b\dot{x}$$

$$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = 0$$

$$\underline{\underline{x(t)}} \equiv Ae^{\alpha t}$$

$$mA(\alpha^2)e^{\alpha t} + bA(\alpha)e^{\alpha t} + kAe^{\alpha t} = 0$$

$$\underbrace{(m\alpha^2 + b\alpha + k)}_{0}\underset{\substack{\neq \\ \gamma}}{A}\underset{\substack{\neq \\ 0}}{\underline{\underline{e^{\alpha t}}}} = 0$$

$$F = -kx - b\dot{x}$$

$$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = 0$$

$$\underline{\underline{x(t)}} \equiv Ae^{\alpha t}$$

$$mA(\alpha^2)e^{\alpha t} + bA(\alpha)e^{\alpha t} + kAe^{\alpha t} = 0$$

$$\underbrace{(m\alpha^2 + b\alpha + k)}_{0}\underset{\substack{\neq \\ 0}}{A}\underset{\substack{\neq \\ 0}}{e^{\alpha t}} = 0$$

$$F = -kx - b\dot{x}$$

$$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = 0$$

$$x(t) \equiv Ae^{\alpha t}$$

$$mA(\alpha^2)e^{\alpha t} + bA(\alpha)e^{\alpha t} + kAe^{\alpha t} = 0$$

$$(m\alpha^2 + b\alpha + k)\,Ae^{\alpha t} = 0$$

$$\downarrow \qquad \uparrow \quad \neq \quad \neq$$

$$0 \qquad \gamma \quad 0$$

$$\frac{b}{2m}t$$

$$\alpha = \frac{-b \pm \sqrt{b^2 - 4mk}}{}$$

$$F = -kx - b\dot{x}$$

$$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = 0$$

$$x(t) \equiv Ae^{\alpha t}$$

$$mA(\alpha^2)e^{\alpha t} + bA(\alpha)e^{\alpha t} + kAe^{\alpha t} = 0$$

$$(m\alpha^2 + b\alpha + k)\,Ae^{\alpha t} = 0$$

$$\alpha = \frac{-b \pm \sqrt{b^2 - 4mk}}{2m}$$

$$x(t) = Ae^{-\frac{b}{2m}t}$$

$$+ \cancel{d}\cancel{m}g\sin\theta = 0$$

$$\alpha = \frac{-b \pm \sqrt{b^2 - 4mk}}{2m}$$

$$= -\frac{b}{2m} \pm \sqrt{\left(\frac{b}{2m}\right)^2 - \frac{k}{m}}$$

$$\alpha = \frac{-b \pm \sqrt{b^2 - 4mk}}{2m}$$

$$= -\frac{b}{2m} \pm \sqrt{\left(\frac{b}{2m}\right)^2 - \frac{k}{m}}$$

$$ml^2\frac{d^2\theta}{dt^2} + lmg\sin\theta = 0$$

$\sin\theta \approx \theta$

$$l\frac{d^2\theta}{dt^2} + g\theta = 0$$

$$\alpha = \frac{-b \pm \sqrt{b^2 - 4mk}}{2m}$$

$$= -\frac{b}{2m} \pm \sqrt{\left(\frac{b}{2m}\right)^2 - \frac{k}{m}}$$

$$\frac{d^2y}{dx^2} + xy = 0$$

$$F = -kx - b\dot{x}$$

$$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = 0$$

$$ml^2\frac{d^2\theta}{dt^2} + lmg\sin\theta = 0$$

$$\sin\theta \approx \theta$$

$$l\frac{d^2\theta}{dt^2} + g\theta = 0$$

$$\alpha = \frac{-b \pm \sqrt{b^2 - 4mk}}{2m}$$

$$= -\frac{b}{2m} \pm \sqrt{\left(\frac{b}{2m}\right)^2 - \frac{k}{m}}$$

$$\frac{d^2y}{dx^2} + xy = 0$$

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Simple harmonic Oscillation

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$\omega^2 = \frac{g}{l} \Rightarrow \omega = \left(\frac{g}{l}\right)^{1/2}$

$l\frac{d^2\theta}{dt^2} + g\theta = 0$

$e^{i\theta} = \cos\theta + i\sin\theta$

$\frac{b^2}{4m^2} << \left|\frac{-k}{m}\right|$

$b^2 << \frac{4km}{4m}$

$\sqrt{-\frac{k}{m} + \left(\frac{b}{2m}\right)^2}$

$-\left(\frac{k}{m} - \left(\frac{b}{2m}\right)^2\right)$

$$m\ell^2 \frac{d^2\theta}{dt^2} + \ell mg \sin\theta = 0$$

$$\theta$$

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$$\sin\theta \approx \theta$$

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$$\sqrt{-\frac{\varphi}{m} + \left(\frac{b}{2m}\right)^2}$$

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$$= 0$$

ω_d

$$-F\sin\omega_d t$$

$$-F(\omega_d)^2\cos\omega_d t$$

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$\omega T = 2\pi \Rightarrow T =$

$+ \left(\frac{}{2m}\right)$

Simple harmonic oscillation

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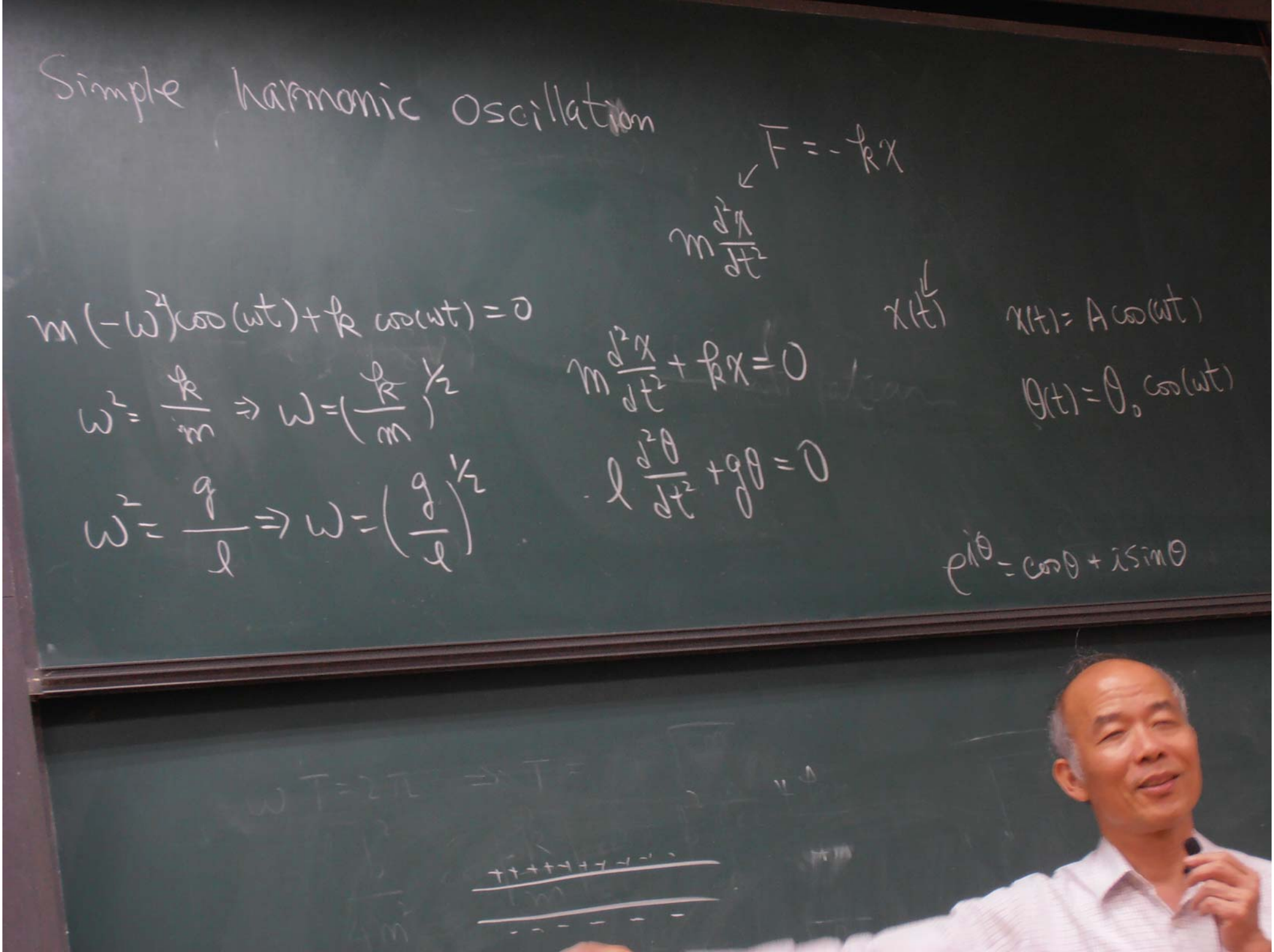
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