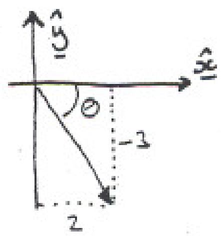
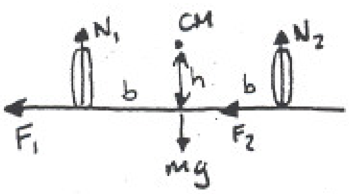
(5) $\underline{\tau} = aF \left[\begin{vmatrix} \hat{\underline{x}} & \hat{\underline{y}} & \hat{\underline{z}} \\ 1 & -1 & 0 \\ 1 & 2 & 1 \end{vmatrix} + \begin{vmatrix} \hat{\underline{x}} & \hat{\underline{y}} & \hat{\underline{z}} \\ 1 & 0 & 1 \\ 2 & -3 & 4 \end{vmatrix} \right]$

$= aF \left[\hat{\underline{x}}(-1+3) - \hat{\underline{y}}(1+4-2) + \hat{\underline{z}}(2+1-3) \right] = aF(2\hat{\underline{x}} - 3\hat{\underline{y}})$



$|\underline{\tau}| = \sqrt{13}\, aF$ making angle $\theta = \tan^{-1}\frac{3}{2} = 56.3°$ with $\hat{x}$ as shown.

(6)



Vertically: $N_1 + N_2 = mg \ldots$ (1)

Take torques around point on ground at centre of curve ($\underline{\tau} = \frac{dL}{dt}$)

$$N_1(r-b) + N_2(r+b) - mgr = h\frac{mv^2}{r} \quad \ldots \text{(2)}$$

↑ rate of change of ang. mom from centripetal accel.

Use (1) in (2) to give,

$$N_1 - N_2 = \frac{-h}{b} \cdot \frac{mv^2}{r} \quad \ldots \text{(3)}$$

Eliminate N_2 (assuming N_2 is normal force on outside wheel)
From (1) and (3)

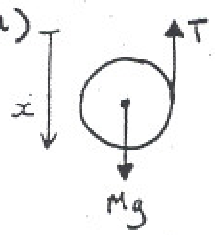
$$2N_1 = m\left(g - \frac{h}{b}\frac{v^2}{r}\right)$$

car will turn over if $N_1 < 0$, i.e. if $v^2 > \frac{gbr}{h}$, $\boxed{v > \sqrt{\frac{gbr}{h}}}$

For slipping: use radial eqn. of motion: $F_1 + F_2 = \frac{mv^2}{r}$
but: $F_1 + F_2 = \mu(N_1 + N_2) = \mu mg$, so slips when: $v^2 > \mu g r$

$\therefore$ slips before turning over if $\mu g r < grb/h \Rightarrow \boxed{\mu < \frac{b}{h}}$

(7) (a)



linear: $Mg - T = M\ddot{x}$
angular (torques w.r.t. CM): $Ta = Mk^2\dot{\omega}$
but: $a\dot{\omega} = \ddot{x}$
Eliminate T: $\boxed{\ddot{x} = \frac{g}{1 + k^2/a^2}}$

and $\boxed{T = \frac{Mgk^2}{k^2 + a^2}}$

Alternatively use energy conservation.

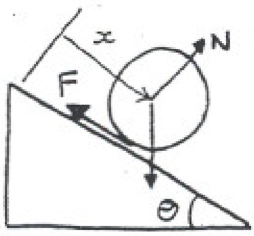
$$\frac{1}{2}mv^2 + \frac{1}{2}Mk^2\omega^2 = Mgx$$

$$\frac{1}{2}v^2\left(1+\frac{k^2}{a^2}\right) = gx$$

differentiate wrt time: $v\dot{v}\left(1+\frac{k^2}{a^2}\right) = gv \rightarrow \boxed{\dot{v} = \frac{g}{1+k^2/a^2}}$

Then use linear or angular equs to get T.

(b)



Friction force does no work: easiest to use energy conservation, so you don't have to eliminate $\underline{F}$ from equs of motion.

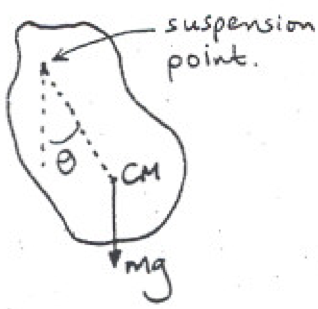
$$\frac{1}{2}Mv^2 + \frac{1}{2}\cdot\frac{1}{2}Ma^2.\omega^2 - Mgx\sin\theta = 0$$

where x is distance rolled down slope. But $v = a\omega$ for rolling, so:

$$\frac{3}{4}v^2 = g\sin\theta\, x$$

differentiate wrt time: $\frac{3}{2}v\dot{v} = g\sin\theta\, v \Rightarrow \boxed{\dot{v} = \frac{2}{3}g\sin\theta}$

8 (a)



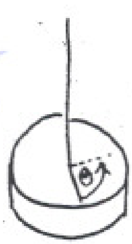
Use $\tau = \frac{dL}{dt}$ about suspension point

$$-mgl\sin\theta = I\ddot{\theta}$$

small $\theta \Rightarrow \ddot{\theta} = -\frac{mgl}{I}\theta$

$$\boxed{T = 2\pi\sqrt{\frac{I}{mgl}}}$$

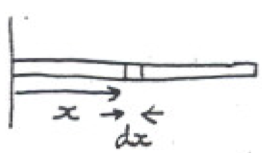
(b)



Torque $= -\tau\theta$

so: $-\tau\theta = I\ddot{\theta} \Rightarrow \boxed{T = 2\pi\sqrt{\frac{I}{\tau}}}$

9 (a)



Total length a; mass per unit length ρ

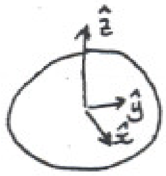
$$I = \int_0^a \rho\, dx . x^2 = \frac{1}{3}\rho a^3 = \frac{1}{3}ma^2$$

(b)

Radius a; mass per unit area ρ.

Consider thin ring at radius r and integrate:

$$I = \int_0^a \rho . 2\pi r\, dr . r^2 = \frac{2}{4}\pi \rho a^4 = \frac{1}{2} m a^2$$

(c) 

Use perpendicular axis theorem:

$$I_x + I_y = I_z = \frac{1}{2} m a^2$$

But $I_x = I_y$ by symmetry

$\therefore \quad I_x = \frac{1}{4} m a^2$ is MoI about a diameter.

(d) For thin spherical shell. Use xyz axes with origin at centre of shell.

$$I_x = \int \underset{\substack{\uparrow \\ \text{mass element}}}{dm} (y^2 + z^2) \quad \text{and similarly for } I_y, I_z$$

But $I_x = I_y = I_z \equiv I$ by symmetry

so:

$$3I = I_x + I_y + I_z = \int dm \; 2(x^2 + y^2 + z^2) = 2ma^2$$

$$I = \frac{2}{3} m a^2$$

(e) Use similar argument for sphere:

$$3I = \int dm \; 2(x^2 + y^2 + z^2)$$

but $dm = 4\pi r^2 dr\, \rho$ where ρ is density.

$$3I = 2\int_0^a 4\pi \rho\, r^2 . r^2\, dr = \frac{8\pi}{5} \rho a^5$$

$$I = \frac{8}{15}\pi \rho a^5 = \frac{2}{5} m a^2$$

(10)

Isolated system $\Rightarrow$ total ang mom is always zero.

$$I_1 \omega_1 + I_2 \omega_2 = 0$$

$$\Rightarrow \quad \theta_2 = -\frac{I_1}{I_2}\theta_1$$

if $\theta_{1,2}$ are angular displacements.

During operation (a): $\quad \phi = \theta_2 - \theta_1 = -\left(\frac{I_1 + I_2}{I_2}\right)\theta_1$

Similarly during (c): $\quad -\phi = \theta_2' - \theta_1' = -\left(\frac{I_1' + I_2'}{I_2'}\right)\theta_1'$

Total rotation is:

$$\theta_1 + \theta_1' = \phi\left[\frac{-I_2}{I_1 + I_2} + \frac{I_2'}{I_1' + I_2'}\right] = \boxed{\phi\left[\frac{I_2'/I_1' - I_2/I_1}{(1 + I_2/I_1)(1 + I_2'/I_1')}\right]}$$

(12) Kinetic energy: $\quad T = \frac{1}{2} m \dot{r}^2 + \frac{1}{2} m r^2 \dot{\theta}^2$

But $L = m r^2 \dot{\theta}$ (ang. mom.) so $\quad T = \frac{1}{2} m \dot{r}^2 + \frac{L^2}{2 m r^2}$

Potential energy: $V = -\frac{GMm}{r}$

$$\therefore \quad \boxed{E = \frac{1}{2}m\dot{r}^2 + \frac{L^2}{2mr^2} - \frac{GMm}{r}}$$

At r_{max} and r_{min}, $\dot{r} = 0$, so $E = \frac{L^2}{2mr_{max}^2} - \frac{GMm}{r_{max}} = \frac{L^2}{2mr_{min}^2} - \frac{GMm}{r_{min}}$

Eliminating L^2 gives: $\boxed{r_{max} + r_{min} = \frac{-GMm}{E}}$

For max and min speed: use $E = \frac{1}{2}mv^2 - \frac{GMm}{r}$

$\begin{Bmatrix} v_{max} \\ v_{min} \end{Bmatrix}$ occurs for $\begin{Bmatrix} r_{min} \\ r_{max} \end{Bmatrix}$

$$v_{max} = \left[\frac{2}{m}\left(E + \frac{GMm}{r_{min}}\right)\right]^{1/2} = \sqrt{2GM}\left(\frac{1}{r_{min}} - \frac{1}{r_{max}+r_{min}}\right)^{1/2}$$

$$= \sqrt{2GM}\sqrt{\frac{r_{max}}{r_{min}(r_{max}+r_{min})}}$$

Similarly: $v_{min} = \sqrt{2GM}\sqrt{\frac{r_{min}}{r_{max}(r_{max}+r_{min})}}$

Kepler's law is $T^2 = \frac{4\pi^2}{GM}a^3$ where $a = \frac{1}{2}(r_{max}+r_{min})$

Using $v_{max}v_{min} = \frac{2GM}{r_{max}+r_{min}}$ gives:

$$T^2 = 4\pi^2 \frac{2}{v_{max}v_{min}(r_{max}+r_{min})} \cdot \frac{(r_{max}+r_{min})^3}{8}$$

$$\boxed{T = \frac{\pi(r_{max}+r_{min})}{v_{max}v_{min}}}$$

13 (i) $\frac{d}{dt}(\underline{r}\cdot\underline{r}) = 2\underline{r}\cdot\underline{v} = \frac{d}{dt}(r^2) = 2r\frac{dr}{dt} \longrightarrow \frac{dr}{dt} = \frac{\underline{r}\cdot\underline{v}}{r}$

$$\frac{d\hat{\underline{r}}}{dt} = \frac{d}{dt}\left(\frac{\underline{r}}{r}\right) = \frac{\underline{v}}{r} - \frac{\underline{r}}{r^2}\frac{dr}{dt} = \boxed{\frac{\underline{v}}{r} - \frac{\underline{r}\cdot\underline{v}}{r^3}\underline{r}}$$

(ii) eqn motion: $\dot{\underline{p}} = \frac{-k}{r^3}\underline{r}$, so $\dot{\underline{p}}\times\underline{L} = \frac{-k}{r^3}\underline{r}\times(\underline{r}\times m\underline{v})$

$$= \boxed{-\frac{mk}{r^3}\underline{r}\times(\underline{r}\times\underline{v})}$$

(iii) $\underline{A} = \underline{p}\times\underline{L} - mk\hat{\underline{r}}$

$$\dot{\underline{A}} = \dot{\underline{p}}\times\underline{L} - mk\frac{d\hat{\underline{r}}}{dt} = -\frac{mk}{r^3}\underline{r}\times(\underline{r}\times\underline{v}) - \frac{mk}{r}\underline{v} + \frac{mk\,\underline{r}\cdot\underline{v}}{r^3}\underline{r}$$

$$\overset{\text{hint}}{=} \; -\frac{mk}{r^3}(\underline{r}\cdot\underline{v})\,\underline{r} + \frac{mk}{r^3}r^2\underline{v} - \frac{mk}{r}\underline{v} + \frac{mk\,(\underline{r}\cdot\underline{v})}{r^3}\underline{r} = 0$$

(iv) $$\underline{r}\cdot\underline{A} = \underline{r}\cdot(\underline{p}\times\underline{L}) - mkr \overset{\text{hint}}{=} (\underline{r}\times\underline{p})\cdot\underline{L} - mkr$$
$$= L^2 - mkr$$

so:
$$\boxed{rA\cos\theta = L^2 - mkr}$$

rearrange: $$\frac{1}{r} = \frac{mk}{L^2}\left(1 + \frac{A}{mk}\cos\theta\right)$$

comparing: $$\boxed{e = \frac{A}{mk}} \quad \text{and} \quad \ell = \frac{L^2}{mk}$$

Direction of A? $\underline{A}$ points towards the point of closest approach to the focus – e.g. $\underline{A}$ points towards the <u>perihelion</u> for an orbit around the Sun.

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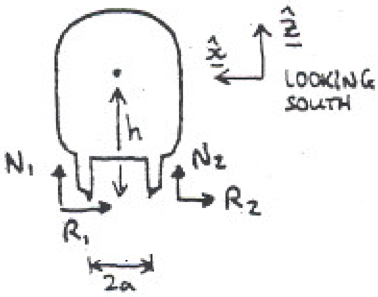


Coordinates: $\hat{\underline{x}}$ East, $\hat{\underline{y}}$ North
$\hat{\underline{z}}$ vertical

Eqn. motion:
$$\ddot{\underline{r}} = \frac{\underline{F}}{M} + \underline{g}^* - 2\underline{\omega}\times\dot{\underline{r}} - \underline{\omega}\times(\underline{\omega}\times\underline{r})$$

- Work to first order in ω; so drop $\underline{\omega}\times(\underline{\omega}\times\underline{r})$ term, and use $\underline{g}^* = -g^*\hat{\underline{z}} \simeq -g\hat{\underline{z}}$.
- Also use $\dot{\underline{r}} = v\hat{\underline{y}}$ and $\ddot{\underline{r}} = 0$
- Earth's angular velocity, $\underline{\omega} = \omega\cos\lambda\,\hat{\underline{y}} + \omega\sin\lambda\,\hat{\underline{z}}$
  $$\underline{\omega}\times\underline{v} = -\omega v\sin\lambda\,\hat{\underline{x}}$$
- Resolve horizontally: $\quad 0 = -(R_1+R_2)/M + 2\omega v\sin\lambda \quad \ldots (1)$
- Resolve vertically: $\quad 0 = (N_1+N_2)/M - g \quad \ldots (2)$
- Torques about CM : $\quad (R_1+R_2)h + N_2 a - N_1 a = 0 \quad \ldots (3)$
- Use (1) and (3) : $$N_1 - N_2 = \frac{2M\omega v h\sin\lambda}{a} \quad \ldots (4)$$
- Solve (2) and (4) for N_1 and N_2
  $$N_1 = \frac{Mg}{2}\left(1 + \frac{2\omega v h\sin\lambda}{ga}\right)$$
  $$N_2 = \frac{Mg}{2}\left(1 - \frac{2\omega v h\sin\lambda}{ga}\right)$$
- Magnitude of force on each rail is $(N_1^2+R_1^2)^{1/2}$ or $(N_2^2+R_2^2)^{1/2}$
  <u>But</u> : (1) says R_1+R_2 is order ω and we assume <u>both</u> of

R_1 and R_2 are $O(\omega)$. Therefore if $N_1 = \frac{Mg}{2}(1+\alpha\omega)$, we have,

$$(N_1^2 + R_1^2)^{1/2} = \frac{Mg}{2}\left(1 + 2\frac{\alpha}{2}\omega\right)$$ to order ω; likewise for $(N_2^2+R_2^2)^{1/2}$.

$\therefore$ Ratio of forces is, $\boxed{\frac{N_1}{N_2} = 1 + \frac{4\omega v h \sin\lambda}{ga}}$ to order ω.

N_1 is larger, so larger force is on <u>Eastward</u> rail.

For $v = 150\ \mathrm{km\,hr^{-1}}$ and $h = 2a$, we find:

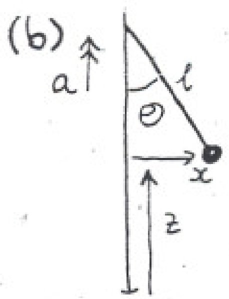
$$\frac{N_1}{N_2} = 1 + \frac{8\omega v h}{ga}\sin\lambda = 1 + \frac{8\times \frac{2\pi\ s^{-1}}{24\times 3600}\times\frac{150\times10^3\ ms^{-1}}{3600}}{9.8\ ms^{-2}}\cdot\frac{1}{\sqrt{2}}$$

$$= \boxed{1.00175}$$

(16) (a) $T = \frac{1}{2}m(\dot{x}^2+\dot{y}^2)$, $V = mgy$ $\Big\}$ $L = T - V = \frac{1}{2}m(\dot{x}^2+\dot{y}^2) - mgy$

(i) $\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{x}}\right) - \frac{\partial L}{\partial x} = 0$ gives $\frac{d}{dt}(m\dot{x}) - 0 = 0$ or $\boxed{\ddot{x} = 0}$

(ii) $\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{y}}\right) - \frac{\partial L}{\partial y} = 0$ gives $\frac{d}{dt}(m\dot{y}) - (-mg) = 0$ or $\boxed{\ddot{y} = -g}$

(b) 

Let θ be generalised coordinate. Actual position of pendulum bob has:

$$x = l\sin\theta$$
$$z = z_0 + u_0 t + \frac{1}{2}at^2 - l\cos\theta$$

where z_0, u_0 are constants.

$$T = \frac{1}{2}m(\dot{x}^2+\dot{z}^2) = \frac{1}{2}m\left(l^2\dot{\theta}^2 + (u_0+at)^2 + 2(u_0+at)\,l\sin\theta\,\dot{\theta}\right)$$

$$V = mgz = mg\left(z_0 + u_0 t + \frac{1}{2}at^2 - l\cos\theta\right)$$

so, $L = T - V$ and:

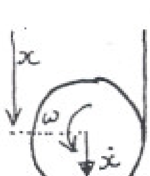
$$\frac{\partial L}{\partial \theta} = m(u_0+at)\,l\cos\theta\,\dot{\theta} - mgl\sin\theta$$
$$\frac{\partial L}{\partial \dot{\theta}} = ml^2\dot{\theta} + (u_0+at)\,ml\sin\theta$$

Euler-Lagrange: $\frac{d}{dt}\left(\frac{\partial L}{\partial\dot{\theta}}\right) - \frac{\partial L}{\partial\theta} = 0$ gives

$$ml^2\ddot{\theta} + (u_0+at)\,ml\cos\theta\,\dot{\theta} + aml\sin\theta - (u_0+at)\,ml\cos\theta\,\dot{\theta} + mgl\sin\theta = 0$$

$$ml^2\ddot{\theta} + m(g+a)\,l\sin\theta = 0$$

For small oscillations: $\ddot{\theta} + \frac{(g+a)}{l}\theta = 0 \Rightarrow \boxed{T = 2\pi\sqrt{\frac{l}{g+a}}}$

(17) 

$$T = \frac{1}{2}m\dot{x}^2 + \frac{1}{2}\cdot\frac{2}{5}ma^2\omega^2\ ;\ \text{but}\ \dot{x} = a\omega \Rightarrow T = \frac{7}{10}m\dot{x}^2$$

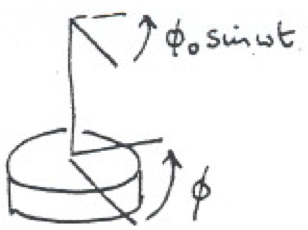
$$V = -mgx$$

$$L = T - V = \frac{7}{10}m\dot{x}^2 + mgx$$

$\frac{d}{dt}\left(\frac{\partial L}{\partial\dot{x}}\right) - \frac{\partial L}{\partial x} = 0$ gives:

$$\frac{d}{dt}\left(\frac{7}{10}m\dot{x}\right) - mg = 0 \Rightarrow \boxed{\ddot{x} = \frac{5}{7}g}$$

(18)



damping torque: $-k\dot{\phi}$

restoring torque: $-T(\underbrace{\phi - \phi_0 \sin\omega t}_{\text{twist in fibre}})$

angular equ. of motion:

$$I\ddot{\phi} + k\dot{\phi} + T(\phi - \phi_0 \sin\omega t) = 0$$

or: $$\ddot{\phi} + \frac{k}{I}\dot{\phi} + \frac{T}{I}\phi = \frac{T}{I}\phi_0 \sin\omega t$$

Look for solution $Ae^{i\omega t}$ (A complex) with driving term $\frac{T}{I}\phi_0 e^{i\omega t}$ and take imaginary part at end [since $\mathrm{Im}\left(\frac{T}{I}\phi_0 e^{i\omega t}\right) = \frac{T}{I}\phi_0 \sin\omega t$].

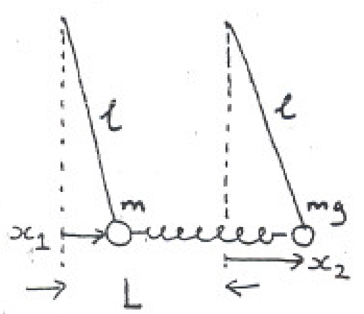
$$A\left[-\omega^2 + \frac{k}{I}i\omega + \frac{T}{I}\right] = \frac{T}{I}\phi_0 \quad \Rightarrow \quad A = \frac{T\phi_0}{I \, . \, i\omega \, k/I} = -i\sqrt{\frac{TI}{k^2}}\,\phi_0$$

$\therefore$ Twist in fibre is $$\phi - \phi_0 e^{i\omega t} = \phi_0\left(-i\sqrt{\frac{TI}{k^2}} - 1\right)e^{i\omega t}$$

Imaginary part: $$\phi_0\left[-\sqrt{\frac{TI}{k^2}}\cos\omega t - \sin\omega t\right]$$

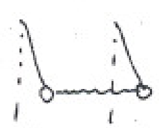
Max twist = amplitude = $\boxed{\phi_0\sqrt{1 + TI/k^2}}$

(19)



Expected form of normal modes:

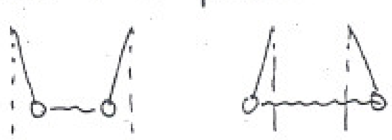
(i) both swing together, spring neither stretched nor compressed.



($x_1 = x_2$)

(ii) swing in antiphase - spring alternately stretched + compressed

($x_1 = -x_2$)



Eqns. motion for small x_1, x_2

$$m\ddot{x}_1 = -mg\frac{x_1}{\ell} + k(x_2 - x_1)$$

$$m\ddot{x}_2 = -mg\frac{x_2}{\ell} - k(x_2 - x_1)$$

$$\Rightarrow \begin{pmatrix}\ddot{x}_1 \\ \ddot{x}_2\end{pmatrix} = \begin{pmatrix} -[\frac{g}{\ell} + \bar{k}] & \bar{k} \\ \bar{k} & -[\frac{g}{\ell} + \bar{k}]\end{pmatrix}\begin{pmatrix}x_1 \\ x_2\end{pmatrix}$$

$\boxed{\bar{k} \equiv \frac{k}{m}}$

Look for NORMAL MODES: $\begin{pmatrix}x_1 \\ x_2\end{pmatrix} = \begin{pmatrix}A_1 \\ A_2\end{pmatrix}e^{i\omega t}$

$$\Rightarrow \quad -\omega^2\begin{pmatrix}A_1 \\ A_2\end{pmatrix} = \begin{pmatrix} -(\frac{g}{\ell} + \bar{k}) & \bar{k} \\ \bar{k} & -(\frac{g}{\ell} + \bar{k})\end{pmatrix}\begin{pmatrix}A_1 \\ A_2\end{pmatrix}$$

Allowed values of ω^2 fixed by: $\left[\omega^2 - \left(\frac{g}{l}+\bar{k}\right)\right]^2 - \bar{k}^2 = 0$

$$\omega^2 = \frac{2\left(\frac{g}{l}+\bar{k}\right) \pm \sqrt{4\left(\frac{g}{l}+\bar{k}\right)^2 - 4\left(\frac{g}{l}+\bar{k}\right)^2 + 4\bar{k}^2}}{2}$$

$$\boxed{\omega^2 = \left(\frac{g}{l}+\bar{k}\right) \pm \bar{k}}$$

(i) $\omega^2 = \frac{g}{l}$ $\qquad \begin{pmatrix} -\bar{k} & \bar{k} \\ \bar{k} & -\bar{k} \end{pmatrix}\begin{pmatrix} A_1 \\ A_2 \end{pmatrix} = 0 \Rightarrow A_1 = A_2$

This corresponds to expected mode (i) above.

(ii) $\omega^2 = \frac{g}{l} + 2\bar{k}$ $\qquad \begin{pmatrix} \bar{k} & \bar{k} \\ \bar{k} & \bar{k} \end{pmatrix}\begin{pmatrix} A_1 \\ A_2 \end{pmatrix} = 0 \Rightarrow A_1 = -A_2$

expected mode (ii) above.

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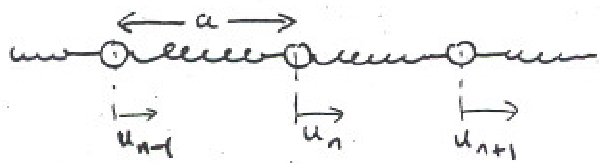

$$T = \sum_n \tfrac{1}{2} m \dot{u}_n^2$$

$$V = \sum_n \tfrac{1}{2}\mu (u_n - u_{n-1})^2$$

$$L = \sum_n \tfrac{1}{2} m \dot{u}_n^2 - \sum_n \tfrac{1}{2}\mu (u_n - u_{n-1})^2$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{u}_n}\right) = m\ddot{u}_n$$

$$\frac{\partial L}{\partial u_n} = -\mu(u_n - u_{n-1}) + \mu(u_{n+1} - u_n)$$

$$\Rightarrow \boxed{\ddot{u}_n = \frac{\mu}{m}\left(u_{n-1} - 2u_n + u_{n+1}\right)}$$

Eqn. motion for infinite system. Look for translation invariant normal modes:

$$u_n = A e^{i(kna - \omega t)}$$

Substituting in eqn. motion gives dispersion relation: $\quad \omega^2 = \frac{2\mu}{m}(1 - \cos(ka)) = \frac{4\mu}{m}\sin^2\left(\frac{ka}{2}\right)$

For semi-infinite system: have $u_0, u_1, u_2, \ldots$ with $u_0 = he^{-i\omega t}$ for some h. Try a combination:

$$u_n = \alpha e^{i(kna - \omega t)} + \beta e^{i(-kna - \omega t)}$$

Boundary condition on $u_0 \Rightarrow h = \alpha + \beta$. Physical requirement that only wave propagating out along the line says $\beta = 0$.

$$\therefore \boxed{u_n = h e^{i(kna - \omega t)}} \text{ with } \boxed{\omega = \omega_0 \sin(ka/2)}$$

Case when $\omega > \omega_0$: dispersion relation requires $\cos(ka) < -1$, so ka must be complex. Let $\lambda = e^{ika}$ and solve for λ

$$\frac{1}{\lambda} + \lambda = 2 - \frac{4\omega^2}{\omega_0^2} < -2 \qquad \text{Two solutions: } -1 < \lambda_1 < 0 \text{ and } \lambda_2 < -1$$

$|\lambda_2| > 1$ so this solution grows exponentially away from $n = 0 \Rightarrow$ unacceptable

$\therefore$ Use λ_1 with $-1 < \lambda < 0$ and write $u_n = h\lambda_1^n e^{-i\omega t}$

[Oscillation exponentially damped in n. No propagating wave]