

MDIA3007

 $A YX]U'UbX'5fhg' + bhYfbg \]d$

HYfa 'H\fYY''##'&\$&\$

7ci fgY'Cj Yfj]Yk

GHJZZ7cbHJWh8YHJ]`g

7cbj Ybcfg

B Ua Y	9a U]`	5j U]`UV]`] m	@cWUh]cb	D\cbY
9a a U'5"'>UbY	Ya a U"^UbY4 i bgk "YXi "Ui	•	‰)ž@YjY``%ž FcVYfh KYVghYf	

GWkcc~7cbhJWh~abZcfa Uh]cb

GWXcc``cZhXY`5fhg`UbX`AYX]U

Fcca ' %&ž@Yj Y`' žFcVYfhK YVghYf6i]X]b[fl %(Ł

D\cbY. f\$&L'-',) '(,) *

9a U]` gUa 4 i bgk "YXi "Ui

K YVg]hY. k k k "Ufhg"i bgk "YXi "Ui #gUa

 $\label{eq:hamiltonian} $$HY'GWCC``cZhY'5ftg'UbX'AYX]U'kci`X``]_Y'tc'FYgdYWM\cong \cong m5W_bck`YX[Y'thY'HfUX]tjcbU``7i gtcX]Ubgž thY'6YXY[U'`fPYbg]b[tcb'WJadigŁZ'; UX][U'`fP]tmUbX'5fth/'8Yg][b'7UadigYgŁ'UbX'thY'B[ibbUkU`dYcd'Y'fbigtfU]Ub'8YZYbW': cfW'5WJXYam]b'7UbVYffUŁ'cZthY'`UbXg'k\YfY'YUW\cong WJadig'cZIBGK']g`cWJtYX''$

7ci fgY 8YHJ] g

7 fYX]hDc]bhg *

Gi a a UfmcZh\Y'7ci fgY

H\]g`Wci fgY`cZYfYX`Vmh\Y`GW\cc``cZh\Y`5fhg`UbX`A YX]U`dfcj]XYg`mci `k]h\`Ub`cddcfhi b]hmhc i bXYfhU_Y`]bXi ghfm\Yb[U[YX``YUfb]b[`h\fci [\`]bhYfbg\]d`cddcfhi b]h]Yg`k]h\`fY`Yj Ubh]bXi ghfm\cghg" ⇒XYU``mž`mci `k]```i bXYfhU_Y`Ub`]bhYfbg\]d`UZhYf`mci `\Uj Y`Wca d`YhYX`U`mYUf`cZZ\``!h]a Y`ghi Xmffcf Yei]j U`Ybht"5hh\Y`YbX`cZh\Y`]bhYfbg\]d`mci `k]```dfcj]XY`U`gi a a Uh]j Y`fYdcfhicZmci f`YI dYf]YbWYg`UbX k cf_YI Ua d`Yg`Wca d`YhYX`Xi f]b[`h\Y`]bhYfbg\]d"

 $H\Y'] bhYfbg\] d`fYei]fYg`U`hchU``Wcaa]haYbhcZ\$$!\%) $`\cifg`cZkcf_'k]h\`U`\cghcf[Ub]gUh]cb`UbX`WUb`VYhU_Yb`]b`Z]fghz`gYWcbX`cf`h\]fX`hYfaz`cf`cjYf`h\Y`giaaYf`dYf]cX"`\bhYfbg\]d`cddcfhib]h]Yg`UfY`UXjYfh]gYX`j]Uh\Y: 5GGSK \&SG5A\\bhYfbg\]d`dU[Y.`$

\htdg.##a ccX`Y"HY`h'i bgk "YXi "Ui #\ti fgY#]Yk "d\d3]X1'') \(\lambda \) "5`h\fbUh] Y`m\timci 'a Umi]bXYdYbXYbh\m UddfcUW\ 'U`fY`Yj Ubhcf[Ub]gUh]cb`hc`Udd`m\ticfUb`]bh\fbg\]d"`Df]cf`hc`gYY_]b['Ub`]bh\fbg\]d\timci 'a Umik]g\hc`WcbhU\hii BGK '7 UfYYfg`UbX`9a d`cma Ybh! \\htdg.##k k k "\\ubfYYfg"i bgk "YXi "Ui # '\ticf\\Y`d`UggYa V`]b[mci f`7 J \tildo \tildo \forall Yf\'Yf\'d`UbX'ch\\Yf\\cappa dcbYbhg`cZmci f`Udd`\\\ubfYhfcb"

: cf`a cfY`]bZcfa Uh]cbžj]g]h\hdg.#k k k "Ufhg"i bgk "YXi "Ui #gUa #ghi Xmli g#bhYfbg\]dg": cf`UbmYbei]f]Ygž d`YUgY`Ya U]``h\Y`K =@I b]hUh<u>: 5GG!K =@4 i bgk "YXi "Ui</u>

Hc VY Y`][]V`Y Zef'h\]g Wei fgYžmci 'a i gh\Uj Y 'U'a]b†a i a 'K \$†A 'cZ*) "† † † † †

7ci fqY @YUfb]b[Ci hWca Yq

5ggYgga Ybh

H\]c	j gi	V Y Whi]	g"i b[fUXYX	gc 'U	J ⁻ dUgg]g XY	YXdYb	'bh'cb	`GUh]gZl	JWtcfmi	ifGMŁ'(cfil I	bgUh	gZUW∱	cfmfl	@L`]b`;	а ҮҮ	h]b[
H\ Y	₩ti	fgY fY	ei]fYa	a Ybhg"	.2p.	GM[fl	JXY 'k]```bch	iUZZY W	himci fik	(Y][\r	YX'Uj'	YfU[Y a l	Jf_'fK	5Ał	·Vi h'U	·: @·	fUXY
k]``"																			

7 ci fgY fYei]fYa Ybhg JbWl XY.

• 7 ca d`Yhjcb'cZU'a]b]a i a 'cZ%\$\$'\ci fg'cZd`UWYa Ybh'Gi Va]gg]cbg'cZUggYgga Ybh'HUg_g'%/ '&

k YfY'd`UWX']b`f]b`[YbYfU`HYfa g`cb`mžk]h\ci hibua]b[Ł'UbX'h\Y]f`fc`Y'k]h\jb']b'f]b'[YbfJZYg`UʻfY`Yj Ubhfc`Y]b`f\Y'cf[Ub]nUh]cb`Uhcf`WcgY'hc`'Ybhfm``Yj Y``UbX'h\Y'g_]``g`UbX'Uhff]Vi hYg`bYYXYX'hc`Wca d`YhY'gi WX'U'fc`Y/f]]L`UXXfYggYg`\ck 'h\Y'hmdY'cZk cf_'h\Ym\Uj Y'i bXYfhU_Yb#dfcXi WX'Xi f]b['h\Y]f`d`UWa YbhiWcbhf]Vi hYg hc'h\Y]f'\cghcf[Ub]nUh]cb`UbX#cf`fY`Yj Ubha YX]U']bXi ghfm' \(\delta\) h\]g``UghWca dcbYbhghi XYbhg`g\ci `X'YI d`]W]hm fYZYWhcb gi WX'ZJWcfg`Ug'h\Y'\cgh#bXi ghfmU[YbXUž'WXU``Yb[Yg`UbX']bbcj Uh]cbg`Zcf'h\Y'\cgh#bXi ghfmž ei Ygh]cbg`cZYh\]Wg`k\]W`a UmUf]gY`]b`fY`Uh]cb'hc'h\]g'k cf_žei Ygh]cbg`cZ]bXi ghfmghUbXUfXgž]bXi ghfm dfcWyggYg`cf`a YX]U'Zcfa g"'5WJXYa]WfYZYfYbWY'g\ci `X'VY'a UXYži g]b['h\Y'<Uf] UfX'gmghYa ž'UbX'U a]b]a i a 'cZZ]j Y`gYdUfUhY'UWJXYa]Wgci fWyg'i gYXž'hc'gi ddcfh#Yl d`U]b#XYZ]bY'h\Y'fY`Yj UbhWcbWYdhg"'H\Y fYZYWhj Y'UbU`mg]g'Ug'U'k\c`Y'g\ci `X'VY'Ua]b]a i a 'cZ) \$\$'k cfXg'Vi ha Uma U_Y'i d'a cfY'cZh\Y Wca V]bYX'hchU`cZ%) \$\$!&) \$\$'k cfX`]a]hZcf'Vch\`UggYgga YbhWca dcbYbhg"

; fUX]b['k]``VY`GUhjqZJWcfm# bgUhjqZJWcfmcb`mUbX'bc'Z fh\Yf'ZYYXVUW_k]``VY'dfcj]XYX"

Hi fb]hb gYhb[. H\]g]g bchU Hi fb]hb Ugg][ba Ybh

Fygci fWyg

DfYgWf]VYX F Ygci fWYg

FYWca a YbXYX FYgci fWYg

7 ci fgY '9j U'i Uh]cb 'UbX '8 Yj Y`cda Ybh

K Y fYgdcbX hc ZYYXVUW_fYWY]j YX j]U X]fYWhYa U] hc h Y 7 ci fgY 7 cbj Ybcf UbX h Y K ≠0 b]hž UbX]bZcfa Uh]cb dfcj]XYX jb h Y gh XYbh UbX \cgh ZYYXVUW_Zcfa g"

KY\cdYmciYb&mmcif]bhYfbg\]d°

Gi Va]gg]cb cZ5ggYgga YbhHUg_g

Hi fb]h]b Gi Va]gg]cb

Image: Ybwei bhyfu'dfcv'ya k \yb'uhhya dhjb['hc'gi va]hmci f'Ugg][ba Ybhh\fci [\ 'Hi fb]h]bž'd'YUgY

Hy'Yd\cby'9| hy'fbu''Gi ddcfhcb'-',) '' ' ' %cf'Ya U]''h\Ya 'cb'Y! hy'fbu'hy'hgi ddcfh4 i bgk "YXi "Ui "''Gi ddcfh
\ci fg'UfY', .\$\$Ua '-'%\$.\$\$da 'cb'k YY_XUmg'UbX'-.\$\$Ua '-').\$\$da 'cb'k YY_YbXg'fl *) 'XUmg'U'mYUft"'=Z'mci
UfY'i bUV'Y'hc'gi va]hmci f'Ugg][ba YbhXi Y'hc'U'ZJi 'hk]h\ 'Hi fb]h]b'mci 'a UmUdd'mZcf'Ub'Y! hy'bg]cbž'Vi hmci
a i ghfYhJ]b'mci f'h]W_Yhbi a VYf'Zfca '9! hy'fbU''Gi ddcfhfU'cb['k]h\ 'Ubmch\Yf'fy'Yj UbhXcW a Ybhgt'hc
]bWi XY'Ug'Yj]XYbW' hc'gi ddcfhmci f'Y! hy'bg]cb'Udd']WUh]cb"'=Zmci 'Ya U]''9! hy'fbU''Gi ddcfhmci 'k]'`
Ui hca Uh]WJ'`mfYW']j Y'U'h]W_Yhbi a VYfZ'Vi h]Zmci 'hy'Yd\cby'mci 'k]``bYYX'hc'gdYW]Z]WJ'`mUg_'Zcf'cby''
Hi fb]h]b'U'gc'dfcj]XYg'i dXUhy'g'cb'h\Y]f'gmghYa 'ghUh' g'cb'Hk]hyf''

; YbYfU`mž'UggYgga YbhiHug_g'a i ghVY'gi Va]hhYX'Y`YVWfcb]\WJ``mij]U'Y]h\Yf'Hi fb]h]b'cf'U'A ccX`Y Ugg][ba Ybh''=b']bgHJb\W'g'k \YfY'h\]g']g'bchdcgg]V`Yž']hk]```VY'gHJhYX'cb'mci f'\\circ i fgY'g'A ccX`Y'g]hY'k]h\U`hYfbUh]j Y'gi Va]gg]cb'XYHJ]`g"

cfi]bZcfa Uhjcbicbi\ckihcigi Va]hUgg][ba Ybhgicbi]bYij]UiA ccXiY.i\hdg.#gh XYbhi bgk "YXi "Ui #\ck! gi Va]hUgg][ba Ybha ccXiY

5 WUXYa]W<cbYghmUbX D`U[]Uf]ga

D`U[]Uf]ga `]g`i g]b['h\Y`k cfXg`cf`]XYUg`cZch\Yfg`UbX`dfYgYbh]b['h\Ya `Ug`mci f`ck b"`±hWJb`hU_Y`a Ubm Zcfa gžZfca `XY`]VYfUhY`W\YUh]b['hc`UWW]XYbhJ``mWcdm]b['Zfca `U`gci fWY`k]h\ci hUW_bck `YX[Ya Ybh'

IBGK [fcidg'd'U[]Uf]ga]bhc'h\Y'Zc``ck]b['WUhY[cf]Yg.

 $7 \text{ cdm}b[...i g]b[...h\Y.gUa Y.cf.j Yfmig]a] \Uf'k cfXg'hc'h\Y.cf][]bU''hYl h'cf']XYU'k]h\ci h'U\V_bck `YX[]b[...h\Y.cf][]bU''hYl h'cf']XYU'k]h'cf']$



5 WUXYa]W±bZcfa Uh]cb

: cf'YggYbhJU`'gh XYbh']bZcfa UhJcb'fY`UhJb['hc.

- fYei Yghg 'Zcf'Yl hYbg]cb/
- `UhY`gi Va]gg]cbg`[i]XY`]bYg/
- fYi]Yk 'cZa Uf_g/
- I BGK '< YU`h\ 'UbX'GUZYhm'dc`]W[Yg/
- YI Ua]bUh]cb dfcWYXi fYg/
- qdYWJU``Wcbq]XYfUHjcb`]b`H\Y`Yj YbhcZ]``bYgg`cf`a]gUXj Ybh fY/
- gh XYbhYei]miUbX'X]qUV]`]m/
- UbX'ch\Yf'YggYbhJU`'UWUXYa]W]bZcfa UhJcbz'gYY

\hdg.#k k k "Ufhg"i bgk "YXi "Ui #W ffYbhgh XYbhg#UWJXYa]W]bZcfa Uh]cb#dfchcWc`g![i]XY`]bYg#

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⇒a U[Y'7fYX]h

D\chc Wci fhYgmcZF cXbYmHcXX! \https://thdg.#k k k "fcXbYmtcXX"\wca #

7F = 7CG

7F = 7CG Dfcj]XYf 7cXY. \$\$\$-,;

5W_bck `YX[Ya YbhcZ7ci bhfm

 $K Y : UW\underline{b} ck `YX[Y : h, Y : 6YXY[U : dY cd `Y : k \ c : UfY : h, Y : hfUX]h\underline{b} cb : `W ghc X]Ubg : c Z : h, Y ``UbXg : cb : k \]WX : I B G K ? Ybg]b[hcb : WUa di g :]g ``c WUhY X''$