HUa dU A ci fbg DUgg]b[cZ7]hm 7ci bW]` GhUf; k YbXc`mb < YbXYfgcb Uh * \$

HUa dU'7]hm'7ci bW]`a Ya VYf'; k YbXc`mb'< YbXYfgcbž'* \$ž dUggYg'Uk Um/'gdYW]U`'Y`YWh]cb'hc'Z]``'\Yf'8]ghf]Wh') 'gYUh Zcfh\Wca]b["



(\$%'9"'CU_'5j Yž'HUa dUž': @ž'I G5'!'HUa dU g'Wca a i b]hm']g a ci fb]b['h\Y'`cgg'cZ'; k YbXc`mb'< YbXYfgcbž'U'XYX]WUhYX'W]hm Wci bW]`a Ya VYf'k \c'dUggYX'Uk Um'Uh'h\Y'U[Y'cZ'*\$'Xi Y'hc bUhi fU`'WUi gYg'Uh'\Yf'\ca Y'''< YbXYfgcb g'i bYI dYWhYX'XYa]gY k Ug'WcbZ]fa YX'Vm'W]hm'cZZ]W]U`g'UbX'\Ug'`YZh'U'dfcZci bX'j c]X Ua cb['Zf]YbXgž'ZUa]`mž'UbX'\Yf'Wcbgh]hi Ybhg']b'8]ghf]Wh') ž'k \]W\YbWca dUggYg'Xck bhck b'HUa dUž'MVcf'7]hmž'UbX'HUa dU'< Y][\hg"H\Y'HUa dU':]fY'FYgW'Y'hYUa 'ei]W_`m'fYgdcbXYX'hc'Ub Ya Yf[YbWm'WU``'Vi h'i bZcfhi bUhY`mž'XYgd]hY'h\Y]f'YZZcfhgž`]ZYgUj]b['a YUgi fYg'ZY``'g\cfh"

6cfb 'UbX'fU]gYX']b 'HUa dU g'7Ufj Yf'7]hm'bY][\Vcf\ccXž < YbXYfgcb 'k Ug'U'dUgg]cbUhY'UXj cWUhY'Zcf'YXi WUh]cb 'UbX

$5 \text{ @}]\text{ZY cZGYfj}]WW UbX @YUXYfg\]d$

<YbXYfgcb g'Wca a]ha Ybh'hc'di V`]WgYfj]WW'YI hYbXYX'VYmcbX'\Yf
hYUWX]b['fc`Y"'G\Y'k Ug'fYWWbh`m'Y`YWhYX'hc'h\Y'HUa dU'7]hm
7ci bW]``cb'A Um'%ž'&\$&' ž'UbX'g\cfh`m'h\YfYUZhYf'hcc_'cb'h\Y
fYgdcbg]V]`]hm'cZ'WXU]f]b['h\Y'7ca a i b]hm'FYXYj Y`cda Ybh
5[YbWh'''H\]g'dcg]h]cb'U``ck YX'\Yf'hc'g\UdY'h\Y'Zi hi fY'cZ'\Yf
Wca a i b]hm'UbX'UXXfYgg'dfYgg]b['i fVUb']ggi Yg'''< Yf'`YUXYfg\]d
k Ug'U`gc'fYWc[b]nYX'k]h\'\Yf'Uddc]bha Ybh'Vm'A Umcf'*JbY'7Ughcf
Ug'U'VcUfX'X]fYWhcf'Zcf'h\Y'<]``gVcfci [\'5fYU'FY[]cbU``HfUbg]h
5i h\cf]hm'fk 5FHt"</pre>

#D 'UXX]h]cb'hc'\Yf'dc`]h]WU``UbX'YXi WUh]cbU``YbXYUj cfgž
< YbXYfgcb'ck bYX'h\Y'6`UW_'9b[`]g\'Vcc_ghcfY'`cWUhYX'Uh'(\$%'9"
CU_'5j Y"'H\]g'i b]ei Y'YghUV`]g\a Ybh'ZcW' gYX'cb'dfca ch]b['k cf_g
Vm'6`UW_'Ui h\cfg'UbX'ZYUhi fYX'h]h`Yg'cZhYb'VUbbYX']b'ch\Yf
j Ybi YgžfYZYWh]b['\Yf'XYX]WUh]cb'hc'X]j Yfg]hm'UbX'fYdfYgYbhUh]cb
]b'`]hYfUhi fY"</pre>

<YbXYfgcb g']bZi YbW'Yl hYbXYX'ZUf'UbX'k]XY/\Yf'a Ya VYfg\]d
]b'8Y`hU'G][a U'H\YhU'Gcfcf]hmž' \(\delta\) W'g\ck WUgYX'\Yf'Wca a]ha Ybh
hc'g]ghYf\ccX'UbX'gcW]U`'UWh]cb"'H\Y'HUa dU':]fYZ][\hYfg'@cWU`
+) ('Yl dfYggYX'h\Y]f'WcbXc`YbWYg'UbX'fYWc[b]nYX'\Yf'dUgg]cbUhY
XYX]WUh]cb'hc'\Yf'fc`Y']b'di V`]WgYfj]WY''Gi WX'gYbh]a Ybhg
\][\`][\h'h\Y']a dUWh'g\Y'\UX'bch'cb`m'cb'\Yf'X]ghf]Wh'Vi h
h\fci [\ci h'h\Y'W]hm'Ug'U'k\c`Y''</pre>

@cc_]b['5\YUX

 $\label{eq:hamiltonian} $H\Y^7]$hm^cZ^HUa~dU^]g^U^fYUXm^WccfX]bUh]b[~d^Ubg^hc^Lcbcf]$

<YbXYfgcb g``Y[UWm"'=b`h\Y`Wca]b[`XUmgž`XYhU]`g`k]```VY
Ubbci bWXX`fY[UfX]b[`hf]Vi hYg`hc`WY`YVfUhY`\Yf`g][b]Z]WUbh
Wcbhf]Vi h]cbg"'5XX]h]cbU``mž`\Yf`dUgg]b[`k]```]bYj]hUV`m``YUX`hc`U
gdYW]U``Y`YWh]cb`hc`Z]```\Yf`gYUhž`k\]WX`\Ug`%) `a cbh\g``YZh`]b`\Yf
hYfa "'H\]g'Y`YWh]cb`Zc``ck g`h\Y`W]hm`WXUfhYf g`fYei]fYa Ybhg'UbX
k]```XYhYfa]bY`k\c`k]```WUffm`cb`\Yf`k cf_'UbX`j]q]cb"</pre>

5g`\Yf`ZUa]`m`UbX`Zf]YbXg`[f]YjYž'h\Y`Wcaaib]hm`fYZYWhg`cb`h\Y fYaUf_UV`Y``]ZY`cZ; kYbXc`mb`<YbXYfgcb U``YUXYfž'YXiWUhcfž UbX`UXjcWUhY`Zcf`\Yf`VY`cjYX`W]hm"<Yf`^cifbYm`Zfca`h\Y WUggfccag`cZ'<]``gVcfci[\`7cibhm`hc`h\Y`\U``g`cZ'h\Y`W]hm`WcibW]`]g`U`hYghUaYbh`hc`\Yf`ibkUjYf]b[`Wcaa]haYbh`hc`]adfcj]b[`h\Y `]jYg`cZ'h\cgY`g\Y`gYfjYX"

H\Y`Wcaaib]hm`k]```a]gg`\Yf`XYYd`mž`UbX`Ug`h\Ym``cc_`ZcfkUfX`hch\Y`ZihifYž'h\YfYg`U`WYUf`gYbgY`h\Uh; kYbXc`mb`<YbXYfgcbg`Y[UWm`k]```Wcbh]biY`hc`]bgd]fY`aUbm`Zcf`mYUfg`hc`WcaY"`8YhU]`YXd`Ubg`Zcf`\cbcf]b[`\Yf`k]```gccb`VY`UjU]`UV`Yž`Ybgif]b[`h\Uh`\YfWcbhf]Vih]cbg`UfY`WY`YVfUhYX`Ug`Ub`]bhY[fU``dUfh`cZ`HUadUg\]ghcfm"

8 YhU]`g	
Cfh	(\$%'9"'CU_'5j Yž'HUa dUž': @ž'l G5
EiY``Yb	• dUhWX "Wca
	• k k k "Zcl %' b Y k g "Wca

6 Y gi W Y b 'G | Y 'i b g 'U i Z 'a Y | b ! k | Y b "b Y h