



ARTS3096

A YX]U'UbX'7`]a UhY'7\Ub[Y

7ci fgY'Cj Yfj]Yk

GHJZ:7cbHJWh8YHJ]`g

7cbj Ybcfg

B Ua Y	9a U]`	5j U]`UV]`]m	@cWJhjcb	D\cbY
5bXfYk 'Aifd\]Y		5ddc]bha YbhgʻVm UffUb[Ya Ybhj]U Ya U]`	B#5	B#5

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 8YW] g

7 fYX]hDc]bhg**

Gi a a UfmcZh\Y 7ci fgY

Gi VYWn5fYU. ? WW[Sł 5g/fgdWS` V FWUZ` a 'aYk

A YX]U UbX W]a UhY WX Ub[Y '\ UJ Y \ UX 'U '`cb[žYbhUb[`YX fY `Uh]cbg\]d" A YX]U 'd`Um_Ymfc `Yg]b 'h\ Y gW]YbWfg cZW]a UhY WX Ub[Y 'h\ Ya gY 'j Yg": cf Yl Ua d`YžW]a UhY WX Ub[Y 'gW]YbWfg i gY Wca di hY f'a cXY ``]b[Yl hY bg]j Y mž UbX 'U`gc 'fY `mcb' [`cvU``a YX]U bYk cf_g 'h\ UhV ch\ 'WfW `UhY 'Ybj]fcba YbhU``XUhU 'UbX 'U``ck 'Zcf Wc``UvcfUh]cb 'UbX 'X]gW gg]cb 'Ua cb['gW]Ybh]ghg" A YX]U 'U`gc 'd`UmU 'fc Y]b 'Vf]b[]b['W]a UhY 'WX Ub[Y 'gW]YbW hc 'h\ Y 'di V`]W" =b 'h\ Y 'dfcWfggža YX]U '\ Y 'd 'ZfUa Y 'h\ Y 'k UmW]a UhY 'WX Ub[Y ']g 'X]gW ggYX" A YX]U 'h\ i g 'd`UmU ZUgW]bUh]b[']Zc ZhYb 'WcbZ]WhY X 'gYf]Yg 'cZfc `Yg ']b 'gYh]b['__YmgcW]U` 'UbX 'dc `]h]WU` 'U[YbXUg'k]h\ 'fY[UfX 'hc W]a UhY 'WX Ub[Y" C b 'h\ Y 'ch\ Yf \ UbXz XYU `]b['k]h\ 'W]a UhY 'WX Ub[Y `\ Ug'WX U` `Yb[YX 'h\ Y 'k Umh\ Uha YX]U k cf_"" H\ Y 'a U]bghfYUa 'a YX]U \ Ug`\UX 'hc 'WX Ub[Y ']hg 'UddfcUWX 'hc 'k \ UhWci bhg 'Ug 'bYk gz 'UbX 'hc 'h\ Y 'k Um']h gYhg 'U[YbXUg" >ci fbU`]ghg '\ Uj Y `\ UX 'hc '[fUdd Y 'k]h\ Wca d`Yl 'gW]YbW' ']b 'bYk 'k Umg" '5 hh\ Y 'gUa Y 'h]a Yz bYk Yf'a YX]U 'hY WX bc`c[]Yg 'gi WX 'Ug 'gcW]U` 'a YX]U 'UbX 'V`c[[]b['d`UhZcfa g`\ Uj Y 'Ui [a YbhYX 'UbX 'cZhYb 'Vm dUggYX'a cfY 'hfUX]h]cbu` a YX]U 'd 'UhZcfa g" 'H\]g \ Ug 'hY bg 'Uf 'bg 'Ufci bX 'Ybj]fcba YbhU`

 $\label{eq:continuity} $$ YUfb]b[\ "UbX"hc"YI \ d`cfY"Ub"]ggi \ Y"cZh\Y]f"ck \ b"Wkccg]b[\ "k \]h\ "gca \ Y"f][\ ci \ f" \]h$

5ggYgga Ybh

D`YUgY`gYY`h\Y`7ci fgY`A ccX`Y`G]hY`Zcf`a cfY`]bZcfa Uh]cb"

5ggYgga Ybh'HUg_g'

5ggYgga Ybh'tUg_	K Y][\h	8i Y'8UHY	Gh XYbh@YUfb]b[Ci hWca Yg 5ggYggYX
:]bU``9ggUm) \$1	\$-#\$,#&\$&\$`\$).\$\$`DA	% <u>ž&</u> Ž
DYfgcbU`'7 ci fgY'5fWX]j Y'UbX F YZYW¶cbg') \$1	Bichi5dd`]WUV`Y	%ž&Ž ž(

5ggYgga Ybh'8YHJ]`g

5ggYgga Ybh% :]bU` 9ggUm

 $\textbf{GhUfhXUhY}. \ \texttt{Bch5dd']WUV'Y}$

@Yb[h\."\$\$\$"k cfXg

8YHJ]`g.

 $" $$\$ k cfXgžfi Vf]Wcb`mZYYXVUW_"$

5XX]h]cbU``XYhJ]`g.

 $\hbox{D'YUgY'gYY'h} \hbox{A'Y'Wc} \hbox{i fgY'A ccX'Y'g} \hbox{h'Y'Zcf'a cfY'XYhU} \hbox{j'g"}$

 $\label{eq:higher} \mbox{Hi fb]h]b"gYh]b"[."H\]g"Ugg][ba Ybh]g"gi Va]hhYX"h\fci [\ \ 'Hi fb]h]b"UbX"ghi XYbhg"Xc"bchgYY"Hi fb]h]b g]a]`Uf]hmfYdcfhg"$

5ggYgga Ybh& DYfgcbU`7ci fgY 5fWX]j Y UbX F YZYWNjcbg

GhUfh'XUhY.

Gi Va]gg]cb'bch'g. Mci 'bYYX'hc'gi Va]h'&!' 'V`c['dcghg Zcf'k YY_g'%ž&'UbX'' '`fh\ YgY'a i gh'VY gi Va]hh'X'Vmh\ Y'Gi bXUmž'Uh') da ž'Uh'h\ Y'YbX'cZh\ Y'k YY_]bj c`j YX gYY'Wci fgY'A ccX`Y'g]hY'Zcf XYhJ]`gt"'Gc'mci 'bYYX'hc'W\ccgY'k\ Yh\ Yfmci 'k]```Xc'&'cf'' 'dcghg'Xi f]b['h\ Y'Z]fghh\ fYY'k YY_g'cZ h\ Y'Wci fgY"'BchY'h\ Uh'h\ YfY'UfY'bc'hi hcf]U'g']b'k YY_&ž'Vi h'h\ YfY'k]```VY']a dcfhUbh`YWhi fY'UbX'ch\ Yf a Uh'f]U'g'cb']bY'Zcf'mci f'hc'Yb[U[Y'k]h\ "'Mci 'k]```fYWY]j Y'ZYYXVUW_cb'h\ YgY'dcghgžk]h\ 'U'a Uf_]bX]\WJh]b[\ck 'mci 'UfY'[c]b[ž'Vmh\ Y'YbX'cZk YY_'*"'H\ Y'a Uf_mci 'UfY'[]j Yb'Uh'h\]g'dc]bh']g'\ ghhc'`Yhmci '_bck '\ck h\]b[g'UfY'[c]b["'+ik]``cZWci fgY']bZi YbWY'mci f'Z]bU``a Uf_Zcf'h\]g'Ugg][ba Ybhž'Vi h']h'XcYg'bch[c']bhc'h\ YZfa U``I BGK 'gmghYa"

FYgci fWfg

DfYgWf]VYX F Ygci fWYg

GYY'7 ci fgY'A ccX`Y'g]hY'Zcf'fYgci fWYg"'H\YfY']g'bc'7 ci fgY'F YUXYf'Zcf'h\]g'Wci fgY"'5```fYUX]b[g'UbX'ch\Yf a UhYf]U`gžcf``]b_g'hc'h\YgYžWUb'VY'Zci bX'cb'h\Y'7 ci fgY'A ccX`Y'g]hY"

FYWca a YbXYX FYgci fWYg

D`YUgY`gYY`Wci fgY`A ccX`Y`g]hY`Zcf`XYhU]`g"

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

7 ci fgY'ZYYXVUW_'k]``'VY'[Uh\YfYX'h\]g'lf]a YghYf'j]U'X]gW'gg]cb'UbX'cVgYfj Uh]cb'Xi f]b['WUggYgžj]UUgg][ba Ybhk cf_ž'UbX'j]U'h\Y'A m9I dYf]YbW'gi fj Ymg"

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 Um'Udd'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 i]gii g]b[ih\Yik cfXgicfi]XYUgicZch\YfgiUbXidfYgYbh]b[ih\Ya iUgimci fick b"i=hWJbihU_Yia Ubm Zcfa gžZfca iXYi]VYfUhYiWXYUh]b[ihciUWW]XYbhU`mWcdm]b[iZfca iUigci fWYik]h\ci hiUW_bck iYX[Ya Ybh'

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

- i bXYfgfUbX mci f'f][\hg'UbX'fYgdcbg]V]`]hJYg'Ug'U'gh XYbhUhl BGK
- VY`Uk UfY`cZd`U[]Uf]ga ž`Wcdmf][\hz'l BGK `Gh XYbh7cXY`cZ7cbXi WhUbX`5VWWdhUV`Y`l gY`cZ I BGK `=\forall H`F Ygci f\W\g`Dc`]\m\m
- VY 'Uk UfY 'cZh\Y 'ghUbXUfXg 'cZVY\Uj]ci f'Yl dYWYX 'cZYj YfmcbY ']b 'h\Y 'l BGK 'Wca a i b]hm
- `cWUHY 'gYfj]WYg'UbX ']bZcfa UH]cb'UVci hI BGK 'UbX'I BGK '@]VfUfm

Gca Y'cZh\YgY'UfYUg'k]``VY'ZJa]`]Uf'hc'mci žch\Yfg'k]``VY'bYk"'; U]b]b['U'gc`]X'i bXYfgHJbX]b['cZU``h\YfY`UhYX'UgdYWhg'cZ9@&9'k]``\Y`d'mci 'a U_Y'h\Y'a cghicZmci f'ghi X]Yg'UhI BGK "'\\hd.##qi V'YWfi |XYg"`]VfUfm'i bqk "YXi "Ui #\`]qY#JVci hY`]qY