



ARTS3052

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

7ci fgY'Cj Yfj]Yk

Ghuzz 7 cbhuWh8 Yhu]`g

'7cbj Ybcfg'

BUa Y	9a U]`	5j U]`UV]`]m	@cWJhjcb	D\cbY
9a a Uʻ>UbY	Yaa U"^UbY4 i bgk "YXi "Ui	-	‰) ž@YjY``%ž FcVYfh KYVghYf	

GWkcc~7cbhJWh~abZcfa Uh]cb

Fcca " &ž`Yj Y`" FcVYfhK YVghYf`6i]`X]b[

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

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

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

 $\label{eq:hamiltonian} $$HY'GWKcc``cZhY'5ftg'UbX'AYX]U'kci`X``]_Y'tc'FYgdYWM\cong \cong m5W_bck`YX[Y'h\Y'HfUX]tjcbU``7i gtcX]Ubg\cong h\Y'6YXY[U'`fPYbg]b[tcb'WJa di g\cong tz'; UX][U'`fP]tmUbX'5fth/ '8Yg][b'7Ua di gYg\cong tubX't\Y'B[i bbUk U` dYcd'Y'fbi gtfU']Ub'8YZYbW': cf\w'5\\WXYa m']b'7UbVYffU\cozh\Y'`UbXg'k\YfY'YUW\cozh\Y'YUW\cozh\Y''UbXg'k\YfY'YUW\cozh\Y'' \cozh\Y''\UbXg'k\YfY'YUW\cozh\Y'' \cozh\Y''\UbXg'k\YfY'YUW\cozh\Y'' \cozh\Y''' \cozh\Y''' \cozh\Y''' \cozh\Y''' \cozh\Y''' \cozh\Y''' \cozh\Y''' \cozh\Y''' \cozh\Y''' \cozh\Y'''\UbXg'k\YfY'YUW\cozh\Y''' \cozh\Y''' \cozh\Y'''' \cozh\Y''' \cozh\Y'''' \cozh\Y''' \cozh\Y'''' \cozh\Y''' \cozh\Y'''' \cozh\Y''' \cozh\Y''' \cozh\Y''' \cozh\Y'' \cozh\Y''' \cozh\Y''$

7ci fgY 8YHJ] g

7 fYX]hDc]bhg *

Gi a a UfmcZh\Y'7ci fgY

Gi VYWh5fYU. 7`Y/eZ

H\]g`Wci fgY`dfcj]XYg`mci `k]h\`Ub`cddcfh b]lmhc'i bXYfhU_Y`k cf_!]bhY[fUhYX`YUfb]b[`UbX`[U]b`]bXi ghfm YI dYf]YbW`k]h\`U`\cghicf[Ub]gUh]cb`WcgY`mfY`UhYX`hc`mci f`A U`cf`]b`9b[`]g\"'Mci `a Um'U`gc`Udd`mhc`k cf_cb`UhtUW\a Ybhcb`Ub`UWUXYa]WfYgYUfW\`dfc YWhcf`k cf_`]b`Ub`YX]ncf]U``fc`Y`Zcf`Ub`UWUXYa]Wci fbU`"

XYU``mz`mci `k]```i bXYfhU_Y`Ub`]bhYfbg\]d`UZhYf`mci `\Uj Y`Wca d`YhYX`%') `mYUfg`cZZ\``!h]a Y`ghi Xmfcf
Yei]j U`YbhL'UbX`Wca d`YhYX`U`a]b]a i a `cZ% `I C 7 `]b`h\Y`A U'cf"`5hh\Y`YbX`cZh\Y`]bhYfbg\]d`mci `k]``
dfcj]XY`U`gi a a Uh]j Y`fYdcfhcZmci fYI 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'rchU'`Wca a]ha YbhcZ%\$\$!%) \$\ci fg'cZk cf_'k]h\'U\\cghcf[Ub]gUh]cb'UbX'a Um bcfa U`mVY'hU_Yb']b'Z]fghžgYWcbX'cf'gi a a Yf'gYa YghYf''=bhYfbg\]d'cddcfhi b]h]Yg'UfY'UXj Yfh]gYX'j]U'h\Y GW\cc`'cZh\Y'5fhg'UbX'A YX]U'=bhYfbg\]d'BYk g'YhYf''5'hYfbUh]j Y`mmci 'a UmUddfcUW\'U'fY'Yj Ubh cf[Ub]gUh]cb'hc'Udd`mZcf'Ub']bhYfbg\]d'''Df]cf'hc'gYY_]b['Ub']bhYfbg\]dz'mci 'g\ci `X'UhhYbX'Ub']bhYfbg\]d |bZcfa Uh]cb'gYgg]cb'fi b'Vmh\Y'GW\cc`'cZh\Y'5fhg'UbX'A YX]U''

Hc VY Y`][]V`Y Zcf'h\]g Wci fgYzmci a i gh\Uj Y U a]b]a i a 'K 5A 'cZ*) "

7 ci fgY @YUfb]b['Ci hWca Yg

%" \Uj Y`[U]bYX`YI dYf]YbW`cZ]bXi ghfmdfc\WggYg`UbX`dfU\Wj\Wg &" Udd`mh\YcfYhj\Wb``Wcb\Wdhg`UbX`dfU\Wj\\Wb``g_]``g`[U]bYX`]b`h\Y`dfc[fUa `hc`fYU`!k cfX`\\chi\Y hg \\ ' " \Uj Y`Yb\Ub\\X'h\Y]f`\\Ud\\Jhm\Zcf`]bXYdYbXYbhYb[U[Ya Ybhk]h\`]bXi ghfmdfcj]XYfg

HYUW]b['GhfUhY[]Yg'

 $H\]g'Wci\ fgY'\ Ug'bc'Zcfa\ U`'hYUW\]b[\ 'Wca\ dcbYbh'''$

5ggYgga Ybh

5ggYgga Ybh'HUg_g

5ggYgga Ybh'hUg_	K Y][\h	8i Y'8UHY	Gh XYbh@YUfb]b[Ci hWca Yg 5ggYggYX
7 f]h]WU`F YZYWn]cb') \$1	&&#%#&\$% `\$).\$\$`DA</td><td>%ž&</td></tr><tr><td>K cf_'9j]XYbW'</td><td>) \$1</td><td>&&#%#&\$% `\$).\$\$`DA</td><td>%Z</td></tr></tbody></table>	

5ggYgga Ybh8YhJ]`g

- 7 ca d'Yh]cb'cZU'a]b]a i a 'cZ%\$\$'\ci fg'cZd'UWYa Ybh
- Gi Va]gg]cbg'cZUggYgga Ybh'lUg_g'%/ '&'XYa cbglfUh]b['U'gYf]ci g'UhlYa dh'hc'Ubgk Yf'h\Y'hUg_fYei]fYa Ybhg
- Gi Va]gg]cb cZVch\ h\Y \cghUbX gh XYbhZYYXVUW_Zcfa g

FYgci fWfg

DfYgWf]VYX F Ygci fWYg

 $H\YfY\UfY\bc\dfYgWf]VYX\fYgci\fWYg\Zcf\h\]g\Wci\fgY"$

FYWca a YbXYX FYgci fWYg

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

 $K Y fYgdcbX hc ZYXVUW_fYWY] YX j]UX]fYWhYa U] hc hY 7 ci fgY 7 cbj Ybcf UbX hY K @1 b]hz UbX bZcfa UhJcb dfcj]XYX jb hY gh XYbh UbX \cgh ZYXVUW_Zcfa g"$

KY\cdYmciYb&mmcif]bhYfbg\]d°

Gi Va]gg]cb cZ5ggYgga YbhHUg_g

Gi Va]gg]cb cZ5ggYgga YbhHUg_g

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

_Zmci YbWci bhYf'U'dfcV`Ya 'k \Yb'UhYa dhJb['hc'gi Va]hmci f'Ugg][ba Ybhh\fci [\ 'Hi fb]hJbž'd`YUgY
hY`Yd\cbY'9| hYfbU``Gi ddcfhcb'-',) '' ' ' %cf'Ya U]`'h\Ya 'cb'Y! hYfbU`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'' =Zmci
UfY'i bUV`Y'hc'gi Va]hmci f'Ugg][ba YbhXi Y'hc'U'ZUi 'hk]h\'Hi fb]hJb'mci 'a Um'Udd'mZcf'Ub'Y! hYbg]cbžVi hmci
a i ghfYhU]b'mci f'hJW_Yhbi a VYf'Zfca '9! hYfbU``Gi ddcfhfU'cb['k]h\'Ubmch\Yf'fY`Yj UbhXcW a Ybhgt'hc
]bWi XY'Ug'Yj]XYbW'hc'gi ddcfhmci f'Y! hYbg]cb'Udd`]WUhJcb'' =Zmci 'Ya U]`'9! hYfbU``Gi ddcfhmci 'k]``

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±iWUbihU_Yia Ubm Zcfa qžZfca iXYi]VYfUhYiW\YUh|b[ihciUVW]XYbhU`mWcdm]b[iZfca iUiqci fWYik]h\ci hiUW_bck iYX[Ya Ybh'i

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

7 cdm]b[.'i g]b['h\Y'gUa Y'cf'j Yfmg]a]`Uf'k cfXg'hc'h\Y'cf][]bU`hYl h'cf']XYU'k]h\ci h'UW_bck `YX[]b['h\Y gci fW'cf'i g]b['ei chUh]cb'a Uf_g"'H\]g'U`gc'Udd`]Yg'hc']a U[Ygž'Ufh'UbX'XYg][b'dfcYWhgž'Ug'k Y``'Ug dfYgYbhUh]cbg'k \YfY'gca YcbY'dfYgYbhg'Ubch\Yf'g']XYUg'cf'k cfXg'k]h\ci h'WfYX]h'

⇒ Uddfcdf]UhY 'dUfUd\fUg]b[...7\Ub[]b['U'ZYk 'k cfXg'UbX'd\fUgYg'k \]'Y 'a cghmfYhJ]b]b['h\Y'cf][]bU` ghfi Wh fY 'UbX#cf'dfc[fYgg]cb'cZ]XYUg'cZh\Y'cf][]bU'žUbX']bZcfa Uh]cb'k]h\ci hUW_bck `YX[Ya Ybh'H\]g'U`gc Udd`]Yg']b'dfYgYbhUh]cbg'k \YfY'gca YcbY'dUfUd\fUgYg'Ubch\Yf'g']XYUg'cf'k cfXg'k]h\ci hWfYX]hUbX'hc d]YW]b['hc[Yh\Yf'ei chYg'UbX'dUfUd\fUgYg']bhc'U'bYk 'k \c`Yžk]h\ci hUddfcdf]UhY'fYZYfYbW]b["

7 c``i g]cb. 'k cf_]b['k]th 'cth Yfg'Vi hidUgg]b['cZZth Y 'k cf_'Ug'U'dYfgcb'g']bX]j]Xi U``k cf_"'7 c``i g]cb'U`gc]bWi XYg'dfcj]X]b['mci f'k cf_'thc'Ubcth Yf'ghi XYbh'VYZcfY'th Y'Xi Y'XUHYZcf'Zcf'th Y'di fdcgY'cZth Ya

- 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 ž'ch\Yfg'k]``VY'bYk"'; U]b]b['U'gc`]X'i bXYfgHJbX]b['cZU``h\YfY`UhYX'UgdYWng'cZ9@+69'k]``\Y`d'mci 'a U_Y'h\Y'a cghicZmci f'ghi X]Yg'UhI BGK "'\\hd.##qi VYWfi |XYg"`]VfUfm'i bqk "YXi "Ui #\`]qY#JVci hY`]qY

5 WUXYa]W±bZcfa Uhjcb

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

- fYei Yghg Zcf Yl hYbg]cb/
- `UhY 'gi Va]gg]cbg'[i]XY`]bYg/
- fYj]Yk 'cZa Uf_g/
- I BGK '< YU'th 'UbX'GUZYhmdc']W]Yg/
- YI Ua]bUh]cb dfcWXi fYg/