

ARTS3124

7 c``UVcfUhjj Y'DYfZcfa UbWY'A U_]b[

GYa YghYf'CbY''##'&\$%

7ci fgY⁻Cj Yfj]Yk

'GhUZZ'7cbhUWh'8YhU]`g'

'7cbj Ybcfg'

B Ua Y	9a U]`	5j U]`UV]`] m	@cWUh]cb	D\cbY
H\Yfcb [·] GWa]Xh	h'gVXa]Xh4 i bgk "YXi "Ui	H\ifgXUmg %&!&cf VmUddc]bhaYbh	KYVghYf*‰%	I)'&%

GWkcc~7cbhJWh~abZcfa Uh]cb

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

D\cbY. f\$&Ł'-',) '(,) *

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

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

 $\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'WJadi gtž; UX][U'`fP]tmUbX'5fth' '8Yg][b'7Uadi gYgt'UbX'thY'B[i bbUkU' dYcd'Y'fbi gtfU']Ub'8YZYbW': cfW'5WJXYam']b'7UbVYffUt'cZthY'`UbXg'k\YfY'YUWX'WJadi g'cZl BGK ']g`cWJtYX''$

5 http://bxubwww.Fyei]fya Ybhg

: cf ⁻ YggYbhJU`-ghi XYbh']bZcfa l	ปทู่cb"fY`Uhjb["hc."fYe	i YghgʻZcfʻYl hYbg]cb/f	Yj]Yk cZa Uf_g/cW	∛dUħjcbU``\YU`h\

7ci fgY 8YW] g

7 fYX]hDc]bhg**

Giaa UfmcZh\Y 7ci fgY

Gi VYWh5fYU. FZWSfdWS` V BWdAd_S` UWEfgV[We

7 c``UVcfUhji Y`DYfZcfa UbW'`A U_]b[']bj]hYg`mci 'hc'k cf_'hc[Yh\Yf'k]h\ 'ch\Yfg'UWfcgg'U'fUb[Y`cZX]ZZYfYbh WfYUhji Y`Zcfa g'hc'XYj Y`cd'Ub'cf][]bU``&\$!a]bi hY ga U``![fci d'dYfZcfa UbW'žk \]W\ 'k]```\Uj Y`U'di V`]W dfYgYbhUhjcb'Uhh\Y'YbX'cZhYfa 'gi ddcfhYX'Vmh\Y'7 fYUhji Y'DfUWfW'@UV"'`Mci 'k]```VY``YX'h\fci [\ 'k YY_`m k cf_g\cdg'h\UhW\U`Yb[Y'h\Y'ZJa]`]Uf'UbX'Yl dUbX'mci f']a U[]bUhjcb'''Mci 'k]```YUfb'bch'\ghth\fci [\ 'W'_]b['UVci ha U_]b[žVi hh\fci [\ 'UWfj Y`ma U_]b[/UbX']b'Xc]b['gc'mci 'k]``gi fdf]gY'mci fgY`Zk]h\ 'k \Uh

5ggYgga Ybh

H\]g'WcifgY'fYei]fYg'mci 'hc'UhhYbX.

- U'HYWXb]WU`FY\YUfgU`cb'HiY'cf'KYX'cZKYY_'% ž'lc'VY'UffUb[YX
- U'8 fYgg'F Y\YUfgU'ž)!-da žcb'K YXbYgXUm'Yj Yb]b[']b'h\Y'Z]bU'k YY_cZh\Y'Wci fgY'fl \$'A Um'' G\ck 'ghUfng'Uh'+"' \$da ž'€'A mYfg
- DYfZcfa UbWY'Yj Yb]b[ž)!%\$da žcb'H\i fgXUm]b'h\Y'Z]bU'k YY_'cZh\Y'Wti fgY'fl %A Umt"'G\ck gtUftg'Uh'+"' \$da ž € 'A mYfg
- DYfZcfa UbWYYj Yb]b[ž)!%\$da žcb: f]XUmi]b'h\Y'Z]bU`k YY_'cZh\Y'Wci fgY'f%'>i bYŁ"'G\ck 'ghUfhg'Uh +"' \$da ž'€'A mYfg
- DYfZcfa UbWYYj Yb]b[ž)!%\$da žcb'GUh fXUm]b'h\Y'Z]bU'k YY_cZh\Y'Wti fgY'f&'>i bYŁ"'G\ck 'ghUfhg Uh'+"'\$da ž'€'A mYfg

5ggYgga Ybh'Wf]hYf]U.

• I gY'cZUddfcdf]UhY'XfUa Uhi f[]\W\`'UbX'\\f\]h\W\`'`Ub[i U[Yž\XfUk]b['cb'\W\Ugg'X]g\\ gg]cbg'\UbX'\Zfca mci f'fYUX]b[g

DfYdUfUlcfmiHJg_g. ``bcb!UggYggYX`Vi hZJWlcfYX`]blc`a Uf_'Zcf`Z]bU``HJg_

HUg_"%ž"Xi Y"k YY_"-

Gi Va]gg]cb cZ5ggYgga YbhHUg_g

Gh XYbhg UfY Yl dYWYX hc di hh\Y]f bUa Yg UbX gh XYbhbi a VYfg cb Yj YfmdU[Y cZh\Y]f Ugg][ba Ybhg"

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

Imagi YbWci bhYf'U'dfcV'Ya 'k \Yb'UthYa dr]b['rc'gi Va]hmci f'Ugg][ba Ybht\fci [\'Hi fb]r]bž'd'YUgY hY'Yd\cbY'9I hYfbU'Gi ddcfhcb'-',) "''' %cf'Ya U] hYa 'cb'<u>Yl hYfbU'hY'hgi ddcfh4 i bgk "YXi "Ui"</u> "Gi ddcfh \ci fg'UfY', .\$\$Ua '-'%\$.\$\$da 'cb'k YY_XUmg'UbX'-.\$\$Ua '-') .\$\$da 'cb'k YY_YbXg'fl *) 'XUmg'U'mYUft'" Imai UfY'i bUV'Y 'rc'gi Va]hmci f'Ugg][ba YbhXi Y'rc'U'ZJi 'hk]h\ 'Hi fb]h]b'mci 'a UmUdd'mZcf'Ub'YI hYbg]cbž'Vi hmci a i ghfYhJ]b'mci f'h]\W_Yhbi a VYf'Zfca '9I hYfbU''Gi ddcfhfU'cb['k]h\ 'Ubmch\Yf'fY'Yj UbhXcW a Ybhgt'rc]bWi XY'Ug'Yj]XYbW' 'rc'gi ddcfhmci f'Yl hYbg]cb'Udd']\WJhjcb"'\Imai 'Ya U]''9I hYfbU''Gi ddcfhmci 'k]'`Ui hca Uh]\WJ'`mfY\W']j Y'U'h]\W_Yhbi a VYfž'Vi h]Zmci 'hY'Yd\cbY'mci 'k]'`'bYYX'rc'gdY\WZ\WJ'`mUg_'Zcf'cbY" Hi fb]h]b'U'gc'dfcj]XYg'i dXUhYg'cb'h\Y]f'gmghYa 'ghUh' g'cb'Hk]hYf"

; YbYfU`mž'UggYgga YbhitUg_g'a i ghiVY'gi Va]lth/X'Y`YWfcb]WU`mj]U'Y]th\Yf'Hi fb]h]b'cf'U'A ccX`Y Ugg][ba Ybh''=b']bgtUbW'g'k \YfY'th\]g']g'bchdcgg]V`Yž']hk]```VY'gtUhYX'cb'mci f'Wci fgY'g'A ccX`Y'g]hY'k]th\U`hYfbUh]j Y'gi Va]gg]cb'XYhU]`g''

@UhY 5ggYgga YbhDYbU`h]Yg

5b'UggYggYX'HUg_']g'XYYa YX``UhY']Z]h']g'gi Va]hhYX'UZhYf'h\Y'gdYW]Z]YX'h]a Y'UbX'XUhY'Ug'gYhci h']b'h\Y Wti fgY'@YUfb]b['A UbU[Ya YbhGmghYa 'f@A GŁ"

K cf_'gi Va]hhYX'Zci fhYYb'fl%(Ł'XUmg'UZhYf'h\Y'Xi Y'XUhY'k]``VY'a Uf_YX'UbX'ZYYXVUW_'dfcj]XYX'Vi hbc'a Uf_ k]``VY'fYWcfXYX"' ₹h\Y'k cf_'k ci `X'\Uj Y'fYWr]j YX'U'dUgg'a Uf_'Vi hZcf'h\Y``UhYbYgg'UbX'h\Y'k cf_']g'U Wca di `gcfm'Wci fgY'Wca dcbYbhz'U'gh XYbh'k]``VY'XYYa YX'hc'\Uj Y'a Yhih\UhfYei]fYa Ybh''H\]g'XcYg'bch Udd`mhc'U'hUg_'h\Uh']g'UggYggYX'Vi h'bc'a Uf_']g'Uk UfXYX"

K cf_'gi Va]hh/X'hk YbhnlcbY'f&&XUmg'UZhYf'h\Y'Xi Y'XUhY'k]``'bchVY'UWWdhYX'Zcf'a Uf_]b['cf'ZYYXVUW_UbX'k]``'fYWY']j Y'bc'a Uf_'cf'[fUXY"'=Zh\Y'UggYgga YbhHUg_']g'U'Wca di `gcfmWca dcbYbhcZh\Y'Wci fgY'Ugh XYbhk]``'Ui hca UhJWU``mZJ]`'h\Y'Wci fgY"

GdYWJU`7cbg]XYfUhJcb55dd`]WUhJcbg

 $\label{eq:linear_continuity} $$Mc_i = W_0 - W_$

G]W_bYggža]gUXj Ybhi fY'cf'ch\Yf'W]fW a ghUbWrg'VYmcbX'mci f'Wcbhfc``a Um

ł DfYj Ybhimci Zfca Wca d`Yhlb[U.Wci fqY fYei]fYa Ybhž

ł? YYd mci Zfca 'UthYbX]b['Ub 'UggYggUV'Y 'UWnji]tmž

ł Ghod moi gi Va]hh]b['UggYggUV'Y k cf_ Zcf'U Wci fgYž

ł `G][b]Z]\WbhmUZZY\Wimci f`dYfZcfa Ub\Wr`]b`UggYggUV`Y`k cf_ž`VY`]h'U`Zcfa U``YbX!cZgYa YghYf`Yl Ua]bUh]cbž`U \WUgg`hYghž`U``UVcfUhcfmhYghž`U`gYa]bUf`dfYgYbhUh]cb`cf`Ubmch\Yf`Zcfa 'cZUggYgga Ybh'

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"'\lefi\Wb'hU_Y`a Ubm Zcfa gžZfca `XY`]VYfUhY`W\YUh]b['hc`UVW]XYbhU`mWcdm]b['Zfca `U`gci f\W' k]h\ci hUW_bck `YX[Ya Ybh'

IBGK [fcidgdu[]uf]ga]bhch\YZc``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'

±DUddfcdf]UhY`dUfUd\fUg]b[.'W\Ub[]b['U'ZYk'kcfXg'UbX'd\fUgYg'k\]`Y`acghmfYhJ]b]b['h\Y`cf][]bU`ghfi WhifY`UbX`]bZcfaUh]cb`k]h\ci hUW_bck`YX[YaYbh'H\]g'U`gc'Udd`]Yg`]b'dfYgYbhUh]cbg'k\YfY`gcaYcbYdUfUd\fUgYg`Ubch\Yf'g`]XYUg`cf'kcfXg'k]h\ci hWfYX]h''±iU`gc'Udd`]Yg`hc'd]YW]b['hc[Yh\Yf'ei chYg'UbXdUfUd\fUgYg`]bhc'U'bYk'k\c`Yžk]h\ci hfYZ/fYbW]b['UbX'U'ghi XYbh'g`ck b'UbU`mg]g`hc'Vf]b['h\Y`aUhYf]U`hc[Yh\Yf''

7 c``i g]cb. 'k cf_]b['k]h\ 'ch\ Yfg'Vi h'dUgg]b['c\Z'h\ Y 'k cf_'Ug'U'dYfgcb'g']b\X]j]\Xi U``k cf_"'7 c``i g]cb'U`gc]b\Wi XYg'dfcj]\X]b['mci f'k cf_'hc'Ubch\ Yf'ghi XYbh\ VYZcfY'h\ Y 'Xi Y 'XUhYzcf'Zcf'h\ Y' di fdcgY'cZh\ Ya d`U[]\Uf]g]b['Uh\Ubmh]a Yz'dUm]b['Ubch\ Yf'dYfgcb'hc'dYfZcfa 'Ub'U\WUXYa]\Wh\Ug_z'ghYU']b['cf'U\\ello i]f]b[Ubch\ Yf'dYfgcb'g' U\WUXYa]\Wk cf_'Ub\X'\\ello dm]b[']hz'c\ZYf]b['hc'\\ello a d`YhY'Ubch\ Yf'dYfgcb'g' k cf_'cf'gYY_]b[d\una Ybh\Zcf'\\ello a d`Yh\beta d`

±bUddfcdf]UhY`W]hUh]cb.`7]h]b[ˈgci fW/gˈk \]WX`\Uj Y`bchVYYb`fYUXžk]h\ci hUW_bck`YX[]b[ˈh\Y`″gYWcbXUfm″gci fW/Zfca k \]WX_bck`YX[Y`cZh\Ya`\Ug'VYYb`cVhU]bYX"

8 i d`]\WUh]cb`ff`gY`Zld`U[]\Uf]ga "Ł`gi Va]\h]b[`mci f`ck b`k cf_ž]b`k \c`Y`cf`]b`dUfhžk \YfY`]h`\Ug`dfYj]ci g`m VYYb`dfYdUfYX`cf`gi Va]\hYX`Zcf`Ubch\Yf`UqqYqqa Ybhcf\Wci fgY`UhI_BGK_`cf`Ubch\Yf`i b]\Yfq]\m"

7 cffYWhfYZYfYbWb[dfUWhWyg.

• VYHYfa UbU[Ymcifh]a Y

7ci fgY GWX YXi `Y

<u>J]Yk "WUgg"hja YHUV"Y</u>

H]a YHJV`Y

8UhY	HmdY	7cbh/bh	
K YY_"%"&*": YVfi Ufm!"(A UfVX	Hi hcf]U`	K_cf_g\cd.'GYY]b['h\Y'a_]fUW`ci_g	
K YY_^&.^) ^A UfVX '!^%% A UfVX	Hi lcf]U`	Hitlag <u>ri</u> % i Siaho Volod[ifolgdha] VIUh iac alld gm al fYsgY þinhe Xsi Joh Walagord	raphica
K YY_" ."‰"A UfVX "!"% A UfVX			
	<u> </u>		
	<u> </u>		
	<u> </u>		
1			

FYgci fWyg

DfYgWf]VYX F Ygci fWYg

H\YfY`k]``VY`g\cfh`VfYU_g`Uh`gi]hUV`Y`dc]bhg`Xi f]b[`YUW\`k YY_`m`WUgg"`I gY`cZd\cbYg`UbX``Udhcdg`k]`` bch`VY`dYfa]hhYX`Xi f]b[`WUgg"``6f]b[`hc`YUW\`WUgg.`VchhY`cZk UhYf`UbX`U`gbUW_ž`Wca Zcfh'UV`Y`Wch\Yg`Zcfa cj Ya Ybhž`UbX`U`bchYVcc_`UbX`dYb"`

GYY cb`]bY fYUX]b[``]ghUh

.

FYWca a YbXYX FYgci fWyg

 $\hspace{1cm} \hspace{1cm} \hspace{1cm}$

\htdg.##Ud\$%\U"U`a\U"Y\\"\]\f]g[fci\d"\Wca\#Y[\Ubhc\#Y\UX]b[\`]gh\#]ghg\\&\\)\(\&\tau^-\tau^\\$\\$\$\\$\\"\'3]\bgh\ht\\1\tau\\B\GK\S=\B\GH\/\Ui\h\\1\ellin\\1\ellin\\1\ellin\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\1\ellin\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\\1\ellin\\1\ellin\\1

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

 $H\setminus g$ Wci fgY k]``VY Yj U`i UhYX'h\fci [\'U'A m θ I dYf]YbWY'gi fj Ym'Uh'h\Y'YbX'cZh\Y'Wci fgY"

a U[Y'7fYX]h

=a U[Y'Zfca '&\$%+'di V']Wg\Uf]b[ž'AdV[`Sdx? [dSUWe"``D\chc'Vm'<Y]Xfi b'@Ò\f

7F = 7CG

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