

7 ci fgY 8 YHJ]`g I b]hg cZ7 fYX]h** Gi a a UfmcZh\Y 7 ci fgY

: ci f'cb`]bY'Ugg][ba Ybhg'k]``VY'fi b'h\fci [\ci hh\Y'hYfa 'hc'UggYgg'mci f'[fUgd'cZh\Y'ei UbhUh]h]j Y'UgdYWhg cZh\Y'Wti fgY'UbX'[]j Y'mci 'ZYYXVUW_'cb'mci f'dfc[fYgg"

GYj YfU``A ccX`Y`Zcfi a g`UfY`Uj U]`UV`Y`Zcfimci ihc`Ug_iei Ygh]cbg`UVci h`YWhifY`UbX`k cf_g\cd`a UhYf]U``]b [YbYfU`ž'UbX`U`gc`UVci hdUfh]W``Uf`Ugg][ba Ybhg"

5XX]hjcbU`7ci fgY +bZcfa Uhjcb

H\Y``YWi fY`bchYg`UfY`ZU]f`mg]a d`Y`UbX`UfY`df]a Uf]`mdfcj]XYX`gc`h\Uhighi XYbhg`\Uj Y`Ub`ci h`]bY hc`UbbchUhY`Xi f]b[\;h\Y``YWi fY"`5g`gi W\`h\YmXc`bchWcbhU]b`h\Y`ghcf]Yg`UbX`UbYWXchYg`h\Uhi=i gY`hc]``i ghfUhY`h\Y`h\YcfmUbX`h\Y`bi a Yf]WU``YI Ua d`Yg`h\Uhi=k cf_'h\fci [\`cb`h\Y`gWfYYb"`H\i g`]Zmci `a]gg`h\Y``]j Y``YWi fY`h\Yb`mci `UfY`YI dYWhYX`hc`k UhW\`h\Y``YWi fY`fYWcfX]b["

5ggYgga Ybh

:]bU`; fUXY.

 $FZWX_1^c S^{Y}dSVWX_2dfZ_2[e UagdeWi [^{Ac} ad_S^{K} TWTSeW a^c fZWeg_aXfZWeUadWe Xda_WSUZ aXfZWSeeWee_W ffSe] ez: ai WhWd af S^{f}ab[Ue i [^{A}TWSeeWeeW Tk fZWa^c] Wcg[I I Wel i Z[^{W}S^{f}ab[Ue _ SkbafW f[S^{K} TWSeeWeeW [^{C} fZWW] S_zFZWdWAdWfa W egdWfZSf kag ZShW_Wf fZW WSd [^{C} Y agfUa_We kag_gef SUZ[WhWS_Sd] aXSf WSef &" _ [^{C} fZWW] S_ [^{C} adVWd Xad fZWSee[Y^c_W f_Sd] e fa TW[^{C} U^{G}VWZ FZW 8[^{S^{7}} S_1] Sf[a^c [e i adfZ (" _ aXfZW8[^{S^{7}} Sd] [XfZWSee[Y^c_W f_Sd] e SdW[^{C} U^{G}VWZ FZW See[Y^c_W f_Sd] e SdW^c af [^{C} U^{G}VWZ FZWSee[Y^c_W f_Sd] e SdW^c af [^{C} U^{G}VWZ FZWSe$

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5 "Uf[Y'dcff]cb'cZk\Uhmci 'k]""YUfb']b'h\]g'Wci fgY'fY[UfXg'\ck 'hc'Udd'mei Ubh]hUh]j Y'hYWkb]ei Yg'hc'fYU' dfc YWfg"'\dc cfXYf'hc'UggYgg'mci f'UV]']lmhc'i bXYfghUbX'h\YgY'ei Ubh]hUh]j Y'hYWkb]ei Yg'UbX'Udd'mh\Ya 'hc dfc YWfg'U'gYf]Yg'cZUgg][ba Ybhg'k]""VY'UXa]b]ghYfYX'Ug'cb']bY'ei]nnYg"'H\Ymk]""YbUV'Y'mci 'hc'[Yh'U VYhYf'i bXYfghUbX]b['cZh\Y'XYhU]'']bj c'j YX']b'gca Y'cZh\Y'hcc'g'i gYX']b'Yb[]bYYf]b['YWcbca]Wg'UbX ZbUbW]U'a UbU[Ya Ybh'

H\]g^]g^bch'U^Hi fb]h]b^Ugg][ba Ybh

5XX]h]cbU`XYhU]`g

5WWgg]b[hYCb]bYEi]nnYg

FZWcg[IIWei [*TWSV_[[efWdW fZdagYZ ? aaV Wz]

 $FZWiWTTSeWV [`fWbSUWXadfZWcg[IIWei[^TWVW_a`efcSfWVVgd[`YfZWeWUa`V`WUfgdWaXfZWX[cefiWW] žIZWbWS cg[IZSeS_adWeabZ[ef[USfWVgeWd[`fWbSUWXadbSdf[Ug^SdcgWef[a`eSVW_a`efcSf[a`i[^TWVY]b'S[`WWZeWVS`V fZWSeeWee_W faXfZSfcgWef[a`i[^TWW]b'S[`WWZeWVS`V fZWSeeWee_W faXfZSfcgWef[a`i[^TWW]b'S[WZeWVS]] faXfZSfcgWef[a`i[^TWW]b'S[WWZeWVS]] faXfZSfcgWef[a`i[^TWW]b'S[WWZeWVS]] faXfZSfcgWef[a`i[^TWW]b'S[WZeWVS]] faXfZSfcgWef[a`i[^TWW]b'S[WWZeWVS]] faXfZSfcgWef[a`i[^TWW]b'S[W]b'S[WW]b'S[W]b'S[WW]b'S[W]b'S[W]b$

 $6\,WfS[WW~XWWWTSU]~Xad\,WSUZ~cgWef[a`i~[^TWbdah[VWW~fZdagYZ~fZWeS_~Wi~WT~TSeWW~[`fWdWSUWa`Wi~WW]~SXWdafZWcg[i~[e~VgWz~]$

5 hmy b X Ub WY F Yei] f Ya Yb hg

7ci fgY'GWXYXi `Y

J]Yk 'WUgg'ha YHUV'Y

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8 UhY	HmdY	7 cbhYbh
K YY_'% '%(': YVfi Ufm!		9Wcbca]W9j U'i Uhjcb. H\Y'H]a Y'J U'i Y'cZA cbYm
% : YVfi Ufm		Dfc YWi5ddfU]gU``7f]hYf]U
		K YV'E i]n'%F Y`YUgYX
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K YY_" . &, ": YVfi Ufm!		7 cghi9ghja Uhjcb
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 $GYj YfU``cZh\Y`hcd]Wg`Wcj YfYX`]b`h\]g`Wci fgY`UfY`XYhU]`YX`]b`a Ubm'hYl h\/cc_g`h\Uh'mci `WUb`Z]bX`]b`h\Y`[VfUfm'' \\$

$AccX^Y$

 $\label{eq:hammaccxyg} $$H^{"} H^{"} = CCXY^{"} H^{"} H^{"} + H^{"} UXX fY gg^{"} g^{"} + \frac{m}{2} CCXY^{"} H^{"} H^{"} + \frac{m}{2} CCXY^{"} + \frac{m}{2} CCXY^$

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Gi Va]gg]cb cZ5ggYgga YbhHUg_g

D`YUgY`fYZYf`hc`h\Y`A ccX`Y`dU[Y`cZh\Y`Wci fgY`Zcf`Z fh\Yf`[i]XUbW\`cb`UggYgga Ybhigi Va]gg]cb"

I BGK `\Ug`U`ghUbXUfX``UhY`gi Va]gg]cb`dYbU`hmcZ

•)ı 'dYf'XUmž'Zcf'U``'UggYgga Ybhg'k \YfY'U'dYbU'hm'Udd`]Ygž'WUddYX'Uh'Zjj Y'XUmg'f1%&\$`\ci fg\z'UZhYf k\]WX'U'ghi XYbh\WUbbchgi Va]h'Ub'UggYgga Ybhž'UbX'bc'dYfa]hhYX'j Uf]Uh]cb"

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

6Yk UfY "5 b 'Ugg][ba Ybhih Uh]bWi XYg 'd `U[]Uf]gYX 'a UhYf]U` 'k]```fYWY]j Y 'U`\$ı : U]`ž 'UbX 'ghi XYbhg 'k \c d`U[]Uf]gY 'UfY 'U`gc '`]UV`Y 'hc 'X]gW]d`]bUfm'UWf]cbž]bWi X]b[YI Wi g]cb 'Zfca 'Ybfc`a Ybh'

D`U[]Uf]ga `]g`h\Y`i gY`cZUbch\Yf`dYfgcb'g`k cf_`cf`]XYUg`Ug`]Zh\Ymk YfY`mci f`ck b"`K \Yb`]h`]g`bYWYggUfmcf XYg]fUV`Y`hc`i gY`ch\Yf`dYcd`Y'g`a UhYf]U``mci 'g\ci `X`UXYei UhY`mUW_bck `YX[Y`k \cgY`k cfXg`cf`]XYUg`h\Ym UfY`UbX`k \YfY`mci 'Zci bX`h\Ya 'f[]j]b['h\Y`Wca d`YhY`fYZYfYbWY`XYhU]`gž`]bWi X]b['dU[Y'bi a VYff'g\t\"H\Y @YUfb]b['7 YbhY'dfcj]XYg`Z fh\Yf`]bZcfa Uhcb`cb`k \UhWcbgh]hi hYg`D`U[]Uf]ga 'Uh

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:]bU``YI Ua g`]b`H%`&\$&&`k]```VY`\Y`X`cb`]bY`VYhk YYb`&- h\`5df]`!`%&h\`A Um`]bWi g]j Yž'UbX`gi dd`Ya YbhUfm YI Ua g`VYhk YYb`&' fX`!`&+h\`A Um`]bWi g]j Y"`Mci `UfY`fYei]fYX`hc`VY`Uj U]`UV`Y`cb`h\YgY`XUhYg"`D`YUgY`Xc bchhc`a U_Y`UbmdYfgcbU``cf`hfUj Y``UffUb[Ya Ybhg`Xi f]b[`h\]g`dYf]cX"`

5ddYbX]l. '9b[]bYYfg'5i ghfU`]U'f95Ł'DfcZYgg]cbU`'9b[]bYYf'7ca dYhYbWm GHJbXUfX

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D9%"('8]gWYfba YbhcZ_bck 'YX[Y'XYj Y`cda YbhUbX'fYgYUfW\'X]fYWf]cbg'k]h\]b'h\Y Yb[]bYYf]b['X]gW]d`]bY	
D9%) '? bck 'YX[Y'cZYb[]bYYf]b['XYg][b'dfUW]WY'UbX'WcbfYl fi U`'ZUWcfg']a dUWf]b['f\Y Yb[]bYYf]b['X]gW]d`]bY	
D9%"* I bXYfgHJbX]b['cZh\Y'gWcdYž'df]bWjd`Ygž'bcfa gž'UWVci bHJV]`]hjYg'UbX'Vci bXg'cZ gi gHJ]bUV`Y'Yb[]bYYf]b['dfUWfJWY']b'h\Y'gdYWjZJWX]gWjd`]bY	
9b[]bYYf]b['Udd`]WUh]cb'UV]`]hm	
D9&"%5dd`]WUh]cb`cZYghUV`]g\YX`Yb[]bYYf]b[`a Yh\cXg`hc`Wca d`Yl `Yb[]bYYf]b[`dfcV`Ya gc`j]b[
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