







7 ci fgY⁻Cj Yfj]Yk

GHJZZ7cbHJWh78YHJ]`g

7cbj Ybcfg

BUa Y	9a U]`	5j U]`UV]`]hm	@cWUh]cb	D∖cbY
@]b`]b`; Y	<u>`"[Y4 i bgk "YXi "Ui</u>			Ž*‰-',)(%++

GWXcc`7cbHJWhr=bZcfaUh]cb

<u>9b[]bYYf]b[_`Ghi XYbhGi ddcfhGYfj]WYg</u>`-'H\Y`Bi WYi g`!`Ybfc`a Ybhž`dfc[fYgg]cb`W\YW_gž`WUg\`fYei Yghgž Wci fgY`]ggi Yg`cf`dfc[fUa !fY`UhYX`ei Yf]Yg`

<u>9b[]bYYf]b[`⊕Xi ghf]U``HfU]b]b[</u>`–`⊕Xi ghf]U``HfU]b]b[`ei Ygh]cbg`

<u>I BGK 'Gh Xm5VfcUX</u>'-gh XmUVfcUX'gh XYbhYbei]f]Yg'fZcf']bVci bX'gh XYbhgŁ'

<u>IBGK '91 W.Ub[Y</u>'-'ghi XYbhYI W.Ub[Y'Ybei]f]Yg'fZcf']bVci bX'ghi XYbhgŁ'

LBGK :: i h fY'Gh XYbhg'-'dchYbh]U``gh XYbhYbei]f]Yg'Y"["'UXa]gg]cbgž'ZYYgž'dfc[fUa gž'WfYX]hhfUbgZYf'

D\cbY'

fŽ*%*&Ł-',)`,)\$\$`-BiWYig`GhiXYbh<iV`

fŽ*%`&Ł'-',)`+**%`**-**`9b[]bYYf]b[`⊕Xi gHf]U``HfU]b]b[`

fŽ*%`&Ł'-',)`'%+-`<mark>-</mark>`IBGK `GhiXm5VfcUX`UbX`IBGK `9IWXUb[Y`fZcf`]bVcibX`ghiXYbhgŁ`

7ci fgY[·]8YHJ]`g

l b]hg`cZ`7fYX]h`*`

Gi a a UfmcZh\Y'7ci fgY

Defrex Wijcb 'hc 'h\Y' [Yea Yhf]WUbX'gdYWfU`'dfcdYfh]Yg'cZfYa chY'mgYbgYX'fbUhY``]hYžUYf]U``cf'hYffYghf]U'Ł]a U[Yg'cZh\Y'9Ufh\fbj'gi fZJWY'cf'cVYWbg''8YgWf]dh]cb'cZUbU'c[i Y'UbX'X][]hU``]a U[Yg'! d\chc[fUd\nž Y'YWfc!cdh]WU``UbX'a]Wfck Uj Y'gmghYa g''H\Y'd\mg]Wg'cZj]g]V'Yž']bZfUfYX'UbX'a]Wfck Uj Y'fYa chY'mgYbgYX]a U[Yfmž]bWi X]b[`Uha cgd\Yf]WYZYWbg'' = U[Y'[Yca Yhfm! `WYbhfU``dfc YWf]cbžgWUb`UbX'a]Wfck Uj Y gmghYa g''H\Y'df]bW]d`Yg'cZghYfYcj]g]cb'' = bYf'cf]YbhUh]cb'cZWYbhfU``dfc YWf]cbž'Wc``]bYUf]mYei Uh]cbg'UbX XYj]Uh]cbg'Zca `Wc``]bYUf]m''9I hYf]cf'cf]YbhUh]cb'cZgYbgcf'gmghYa g''C V'YWi[Yea YhfmiZea 'cj Yf`Udd]b[]a U[Ygž'Zcf'V'cW_'d\chc[fUd\mZcf'UYf]U``UbX'WcgY`fUb[Y'Udd`]WUh]cbg''8][]hU``d\chc[fUa a Yhf]W k cf_ghUh]cbg'UbX'h\Y]f'Z bWf]cbg''D\chc[fUa a Yhf]Wdfc'YWid`Ubb]b["`= U[Y']bhYfdfYhUh]cb"

7 ci fgY 5]a g

Hc:YId`cfY`UbX`[U]b`Zfh\Yf`ibXYfgHUbX]b[`cZfYachY`gYbg]b[`Zcf`9Ufh\`CVgYfjUh]cb`h\fci[\`h\Y]bjYgh][Uh]cb`cZgUhY``]hY`fYachY`gYbg]b[`XUHUžUg`kY``Ug`X][]HU``d\chc[fUd\]W]aU[]b[`UbX`gWUbb]b[hYW\bc`c[]Ygž`k]h\`U`X]fYWhYad\Ug]g`cb`h\Y]f`Udd`]WUh]cb`hc`aUdd]b[`UbX`Ybj]fcbaYbHU``acb]hcf]b["

 $\begin{aligned} & \mbox{Hc}^{d}fYgYbhih, Y'df]bWJd'Yg'cZdfcWYgg]b[~UYf]U^{U}bX'gUhY^{H}YZUa Y'UbX'di g_Vfcca 'VUgYX'X][~]hU^{}]a U[YgZg'Ug'k Y^{U}g'WcgY'fUb[Y'ZUa Y']a U[Yg'Zcf'XYhYfa]b]b[~UWW/fUhY'a Yhf]WXYhU]`g'cZYI hfUWhYX'cV'YWg'cf'9Ufh ZYUh fYg'Zcf']bdi h]bhc'X][~]hU^{}a Udd]b[~z'; ~~G'XUhUVUgYg'UbX'UbU`mgYgz'UbX'Zcf'WcgY'fUb[Y'Udd`]WUh]cbg'' \\ \end{aligned}$

Hc`dfYgYbhih\Y`VUg]Wdf]bW]d`Yg`cZUWei]g]h]cb`UbX`dfcWYgg]b[`cZ@]XUf`XUHU`Zcf`h\Y`XYhYfa]bUh]cb`cZ89Ag UbX`ch\Yf`]bZcfaUh]cb`YIhfUW]cb"

7cifgY`@YUfb]b[`CihWcaYg

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%"`≢ojYgh][UhY`fYachY`gYbg]b[`UbX`d∖chc[fUaaYhf]Wcdh]cbg`Zcf]XYbh]Z]YX`Udd`]WUh]cbg	D9%"%žD9%"&žD9%" žD9%"(ž D9'"(
&"`5dd`mih\Ycfmihc`h\Y`]a d`Ya YbhUh]cb`cZh\Y`W\cgYb`cdh]cb	D9%") žD9&"%žD9&"' žD9' "' ž D9' ")
' "`5ddfYWJUHY`H\Y`Wcad`YaYbHUfmbUhifY`VYHkYYb`fYacHY gYbg]b[žd\chc[fUaaYhfmUbX`gifjYm]b[D9%"' žD9%"(žD9%")
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) "`7 fYUHY`X][]HU``a Udg	D9&"&žD9' "&žD9' "(

$\label{eq:heat} HMWWJ0]b{\timeshfluthg[]}b{\timeshfluthg[]}Yg^{\rm T}$

5 j Uf]YhmicZhYUVX]b[`UVVfjj]h]Ygik]``VYiVcbXiWhYXihciaUI]a]gYihYUVX]b[`UbX``YUfb]b[`cihWcaYgž]bWiX]b[.

5ggYgga Ybh

5ggYgga YbhHJg_	K Y][\h	8iY`8UHY	7cifgY`@YUfb]b[CihWcaYgʻ5ggYggYX
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5HYbXUbW/FYei]fYaYbhg

Ghi XYbhgʻUfYʻghfcb[`mYbWci fU[YX`hcʻUhhYbX`U```WUggYgʻUbX`fYj]Yk ``YWhi fY`fYWcfX]b[g"

7 ci fgY GWX YXi `Y

J]Yk WUgg'ha YHJVY

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8 UHY	Hmd Y	7 c bhYbh		
C!K YY`) 'GYdHYa VYf'! - 'GYdHYa VYf				
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		9`Y₩fc; bYhjWFUX b—8YZjb]hjcb7`C_y]Wg		
K YY_`&`% `GYdhYa VYf !`&' `GYdhYa VYf	6`YbXYX	@YWnifY`!`GdYWnfU``F .whUbWY`UbX`5hac Yf]W 5hhYbiUh]cb		
		@JV`!`cdh]WU`fYachY`gYbg]b[
K YY_'' .`&*`GYdHYa VYf !'' \$`GYdHYa VYf				

K_YY_`%\$.`%(@UgYf`GWUbb]b[žFYachY`GYbg]b[ž D∖chc[fUaaYhfmi∕; =G/DWh[e[a`łUagdeW egSdk
	5ggYgga Ybh	@UV`5gg][ba Ybh'' !`D\chc[fUa a Yhfm

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H\Y'WcifgY'k]``'VY'aU]b`mVUgYX'cb'D8: 'Z]`Yg'cZDckYfdc]bh`YWfifY'g`]XYg'UjU]`UV`Y'UhH\Y'WcifgY'AccX`Y g]h'''

H\Y'a UhYf]U``k]``VY'i d`cUXYX'k YY_'Vmk YY_"

H\Y'Zc``ck]b['UfY'fYWca a YbXYX'fYUX]b['a UfYf]U`g.

. . . .

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&" "Df]bW]d`Yg`cZFYachY`GYbg]b["žDUi``>"`7iffUb"``@cbXcb/BYk`Mcf_`.`@cb[aUbž`%,)"

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(""+əhfcXiWijcbinciacXYfbid\chc[fUaaYhfm?žA]_\U]`9"ž>"6Yh\Y`žUbX`>"7"`AW`cbYžK]`Ymž&\$\$%")" "9`YaYbhqicZd\chc[fUaaYhfm?žDUi``F"`Kc`ZžAWfUk!<]``ž%,'"

*" H\Y`I BGK @]VfUfmk YVg]hY.``\htd.##jbZc"`]VfUfm'i bgk "YXi "Ui #k YV#gYfj]WYg#gYfj]WYg"\ha`

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]XUbWY`cb`UggYgga Ybhigi Va]gg]cb"

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

)ı 'dYf'XUnž'Zcf'U``UggYgga Ybhg'k \YfY'U'dYbU'hmUdd`]Ygž'WUddYX'Uh'Z]j Y'XUng'f1&\$\$`\ci fgłz'UZhYf k \]W\'U'ghi XYbh'WUbbchigi Va]hUb'UggYgga Ybhž'UbX'bc'dYfa]hhYX'j Uf]Uh]cb"

5WUXYa]W<cbYghmUbX^D`U[]Uf]ga

6Yk UfY**5b*Ugg][ba Ybhh\Uh']bWi XYg*d`U[]Uf]gYX*a UhYf]U`*k]```fYVW]j Y*U*\$i ---: U]`ž*UbX*ghi XYbhg*k \c

5₩UXYa]W≠bZcfaUh]cb

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b

5ddYbX]I. '9b[]bYYfg'5ighfU`]U'f195ŁDfcZYgg]cbU`'9b[]bYYf'7cadYhYbWm GHJbXUfX

Dfc[fUa +bhybXYX @YUfb]b[Cihwca Yq ? bck `YX[Y 'UbX'q_]``'VUqY D9%"%7cadfY\Ybq]iYžh\YcfmVUqYXibXYfqHUbX]b[cZh\YibXYfd]bb]b[bUhifU`UbX d/mg]WU`:gW]YbWYg`UbX`h\Y`Yb[]bYYf]b[`Z bXUa YbHU`g`Udd`]WUV`Y`hc`h\Y`Yb[]bYYf]b[`X]gW]d`]bY D9%"& 7 cbW/dhiU`i bXYfqHUbX]b[cZh\Y`a Uh\Ya Uh\Wažbi a Yf]WU`UbU`mg]qžqHUh|qh\WažUbX Weadi hYf'UbX']bZcfaUh]cb'gW]YbWYg'k\]WX'i bXYfd]b'h\Y'Yb[]bYYf]b['X]gW[d`]bY D9%" + + XYdh i bXYfqHbX]b[cZqdYWU`]qhVcX]YqcZ bck YX[Yk]h bhY'Yb[]bYYf]b[X]qWd`]bY D9%"('8]qWFfba YbhcZ_bck YX[YXY]Ycda YbhUbXfYqYUfWXX]fYWfcbg'k]h.jb'h.Y Yb[]bYYf]b[`X]gWJd`]bY D9%") ? bck `YX[Y`cZYb[]bYYf]b[`XYg][b`dfUW]WY`UbX`WcbhYl hi U``ZJW/cfg`]a dUWf]b[`h\Y Yb[]bYYf]b['X]qWjd`]bY D9%"* I bXYfqHJbX]b[cZh\Y'qWcdYždf]bW]dYgžbcfa gžUWVci bHJV]]]h]Yg'UbX'Vci bXg'cZ qi qHU]bUV`Y`Yb[]bYYf]b[`dfUWfWY`]b`H\Y`qdYW[Z]WX]qW[d`]bY 9b[]bYYf]b['Udd`]WUh]cb'UV]`]m D9&"%5dd`]WUhjcb`cZYghUV`]g\YX'Yb[]bYYf]b[`a Yh\cXg`hc`Wca d`YI 'Yb[]bYYf]b[`dfcV`Ya qc`i]b[D9&"&: `i YbhUdd`]WUhcb'cZYb[]bYYf]b['hYWkb]ei Ygžhcc`g'UbX'fYgci fWfg D9&" 5dd`]WUhjcb`cZgmghYa UhjWYb[]bYYf]b[`gmbh\Yg]g`UbX`XYg][b`dfcWYggYg D9&"('5dd`]WUHcb'cZgmghYaUHWUddfcUWXYg'hc'h\Y'WcbXiWiUbX'aUbU[YaYbhcZYb[]bYYf]b[dfc Y₩q DfcZYgg]cbU`UbX dYfgcbU`Uhf]Vi hYg D9' "%'9h\]WU``WcbXi WiUbX'dfcZygg]cbU``UVWci bHUV]`]hm D9' "&'9ZYW)j Y'cfU`'UbX'k f]HYb'Wca a i b]WUh]cb']b'dfcZygq]cbU`'UbX'`UmXca U]bg D9' "' 7 fYUhi Yžibbci Uhi YUbX dfc!UWi YXYa YUbci f D9' "(DfcZygg]cbU`i gY'UbX'a UbU[Ya YbhcZ]bZcfa Uhcb D9' ") CfXYfma UbU[Ya YbhcZgYZzUbX dfcZygq]cbU`WcbXi Wh D9' "* 9ZYWAJ Y HYUa 'a Ya VYfg\]d UbX HYUa 'YUXYfg\]d