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7ci fgY[·]8YHJ]`g

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Gi a a UfmcZhXY7ci fgY

H\YcfmcZhfUbg]YbhkY```HYgh]b["`DfUWf]WU``UgdYWfg`cZXYg][b`UbX`dYfZcfaUbWf`cZZ]Y`X`HYgh]bghfiaYbhUh]cb" DfYggifY`XfUkXckb`HYghg"`:U``!cZZHYghg"`A`i`h]!fUHY`HYghg"`;Ug`kY```HYgh]b["`:`ck!UZHYf!Zck"`=gcWkfcbU``UbX]gcWkfcbU``acX]Z]YX"`=bHYfZYfYbWf`HYgh]b["`Di`gY`HYgh]b["`8f]``gHYa`HYghg":fUWfifYX`fYgYfjc]f`HYghg" 5bU`mg]g`cZai``h]d\UgY`Zck`HYghg"

7 ci fgY 5]a g

H\Y'U]a 'cZh\]g'Wci fgY']g'rc'[]j Y'mci 'Ub']bg][\h]b'rc'k Y```dfYggi fY'hYgh]b['UbU`mg]g/rc']bhfcXi WY'mci 'rc]a dcfrUbhcZdfYggi fY'XUhU'W\UfUWYf]gh]Wg/UbX'rc'Ugg]ghimci 'rc'Ubgk Yf'_Ymei Ygh]cbg'rc'k Y```dfYggi fY hYgh]b['UbU`mg]g"

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- &" I bXYfgHUbX`\ck `X]ZZYfYbhifYgYfj c]f`dfcdYfh]Yg`k]``UZYWiH\Y`dfYggi fY`HUbg]YbhXUHU
- ' " A Uh\Ya Uh]WU``mYI dfYgg`X]ZYfYbhZck `VY\Uj]ci f`ffY[]a YgE]b`h\Y`fYgYfj c]f
- ("8YjY`cd`fYgYUfW\`UbX`Wcaaib]WUh]cb`g_]``g`UbX`glfUhY[]Yg`h\Uhik ci`X`giddcfhih\Y`FYgYUfW\ Dfc^YWiWcadcbYbhcZh\Y`dfc[fUa"

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D`YUgY'fYZYf'hc'h\Y']bZcfaUh]cb']b'AccX`Y

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GhufhiXUhY. Bchi5dd`]WUV`Y

8 YHJ]`g.

5gg][baYbhg`cb`X]ZYfYbhWUdhYfg`cZh\YWcifgY

5ggYgga Ybh&::]bU`Yl Ua

GhufhiXuhy. Bchi5dd`]WUV`Y

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:]bU``YI Ua

5ggYgga Ybh' . A]XhYfa 'Yl Ua

GHJfhXUHY.Bch5dd`]WUV`Y

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 $\label{eq:charged_states} GhJfhXUhY.~Bch5dd`]WUV`Y$

8YHJ]`g.

FYgYUfVX Dfc YWhich K Y HYgh 5 bU mgYg

FYgcifWYg DfYgWf]VYX`FYgcifWYg`

Gi Va]gg]cb cZ5ggYgga YbhHUg_g

H\Y'GW\cc``\Ug'XYjY`cdYX'U'[i]XY`]bY'hc'\Y`d'mci'k\Yb'giVa]hhjb['U'WcifgY'Ugg][baYbh'

K Y`YbWci fU[Y`mci `hc`fYHJ]b`U`WcdmicZYj YfmUgg][ba Ybhigi Va]HYX`Zcf`UggYgga YbhZcf`mci f`ck b`fYWcfX Y]h\Yf`]b`\UfXWcdmicf`Y`YWfcb]WZcfa "

5```UggYgga Ybhg`a i gh\Uj Y`Ub`UggYgga YbhWcj Yf`g\YYhUhUV&YX"

@UhY Gi Va]gg]cb cZUb 5gg][ba Ybh

: i ```a Uf_g`Zcf`Ub`Ugg][ba YbhUfY`cb`mdcgg]V`Y`k \Yb`Ub`Ugg][ba Ybh`]g`fYWY]j YX`Vmh\Y`Xi Y`XUhY"`

K Y'i bXYfgHUbX'H\Uh'Uh'h]a Yg'mci 'a Umbch'VY'UV`Y'hc'gi Va]h'Ub'Ugg][ba Ybh'cb'h]a Yž'UbX'H\Y'GV\\cc``k]`` UVWca a cXUHY'UbmZU]f'UbX'fYUgcbUV`Y'YI HYbg]cb"'K Y'k ci `X'fYVca a YbX'mci 'fYj]Yk 'H\Y'I BGK 'GdYV]U` 7 cbg]XYfUh]cb'[i]XY`]bYg'-gYVf]cb'VY`ck "

@UhY`gi Va]gg]cb`k]``bchVY`UVWYdhYX`UbX`k]``VY`Wcbg]XYfYX`Ug`bc`gi Va]gg]cb"

GdYWJU`7cbg]XYfUh]cb

Mci 'WUb'Udd`mZcf`gdYWJU`'Wcbg]XYfUh]cb'h\fci [\`<u>H\Y'Bi WYi g'Gh XYbh<i V</u>'k \Yb']``bYgg'cf'ch\Yf WJfW a gHUbWYg']bhYfZYfY'k]h\`mci f'UggYgga Ybh'dYfZcfa UbWY'''G]W_bYggž'a]gUXj Ybhi fY'cf'ch\Yf WJfW a gHUbWYg'VYmcbX'mci f'WcbHfc``a Um

- DfYj Ybhmci 'Zfca 'Wca d'Yhjb['U'Wci fgY'fYei]fYa Ybh
- ?YYdimci Zfca UHYbX]b[UbUggYggUVYYUWjj]hm
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K Y`Ug_`h\Uhimci `d`YUgY`WebhUWih\Y`7 ci fgY`7 cbj Ybcf`]a a YX]UhY`mcbWY`mci `\Uj Y`Wea d`YhYX`h\Y`gdYWJU` Webg]XYfUh]cb`Udd`]WUh]cbžbc``UhYf`h\Ub`cbY`k YY_`Zca `gi Va]gg]cb"

A cfY`XYfU]`g`cb`gdYWJU``Wcbg]XYfUHjcb`WUb`VY`Zci bX`Uh`<u>k k k "ghi XYbh'i bgk "YXi "Ui #gdYWJU`!Wcbg]XYfUHjcb</u>

Gh XYbhGi ddcfh

H\YʻI b]j Yfg]miUbXʻh\Yʻ: UW `midfcj]XYʻUʻk]XYʻfUb[YʻcZgi ddcfhigYfj]WfgʻZcf`gh XYbhgž`]bWi X]b[.

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

Mci f`YWi fYf`UbX'h\Y'I b]j Yfg]mik]``YI dYWinci f`gi Va]htYX'Ugg][ba Ybhg`UfY`hfi `minci f`ck b`k cf_''I BGK \Ug`j YfmWYUf`[i]XY`]bYg`cb`k \Uhd`U[]Uf]ga `]g`UbX`\ck `hc`Uj c]X`]h'`D`U[]Uf]ga `]g`i g]b[`h\Y`k cfXg`cf]XYUg`cZch\Yfg`UbX`dfYgYbh]b[`h\Ya `Ug`nci f`ck b''D`U[]Uf]ga `]g`U`mdY`cZ]bh'``YWi U``h\YZh'' #i`WUb`hU_Y a UbmZcfa gž`Zīca `XY`]VYfUh' 'W.YUh]b[`hc`UWW]XYbhU``mVcdm]b[`Zīca `U`gci fWY`k]h\ci hUW_bck `YX[Ya Ybh' H\Y'I b]j Yfg]mi\Ug`UXcdhYX`Ub`YXi WUh]j Y`UddfcUVV `hc`d`U[]Uf]ga `UbX`\Ug`XYj Y`cdYX`U`fUb[Y`cZ fYgci fWYg`hc`gi ddcfhigh XYbhg''`5```h\Y`XYhU]`g`cb`d`U[]Uf]ga ž`]bWi X]b[`gca Y`i gYZ ``fYgci fWYgž`WUb`VY Zci bX`Uhi<u>k k k "qh XYbh'i bgk ''YXi "Ui #d`U[]Uf]ga</u>."

5```A]b]b[`'9b[]bYYf]b[`'ghi XYbhg`UfY`fYei]fYX`hc`Wcad`YhY`U'ghi XYbhXYWUfUh]cb`Zcf`UWUXYa]W]bhY[f]hm k\]W\`]g`cih]bYX`]b`h\Y`Ugg][baYbhWcjYf`g\YYhg"`6mig][b]b[`h\]g`XYWUfUh]cbž`mci`U[fYY`h\Uhimcif`kcf_`]g mcif`ckb`cf][]bU``kcf_"

Zmci bYYX'gca Y'UXX]h]cbU`gi ddcfhik]h\ mci f`k f]h]b['g_]``gžd`YUgY'WcbhUWfih\Y'@YUfb]b['7 YbhfY`cf`j]Yk gca Y'cZh\Y'fYgci fWfg`cb'h\Y]f`k YVg]hY. <u>k k k "`Wi bgk "YXi "Ui %</u> cbQ XYbhg` f] ['7 YbhfY`cf

5WUXYa]W=bZcfaUh]cb

7 ci fgY FYgi `hg

: cf^{*}XYHJ]`gʻcbʻI BGK ^{*}UggYgga Ybhdc`]Whž'd`YUgY`j]g]h<u>'k k k "gh XYbh'i bgk "YXi "Ui #UggYgga Ybh</u>

=b`gcaY`]bgHJbWfg`mcif`Z]bU``WcifgY`fYgi`haUmVY`k]h\\Y`X`UbX`bchfY`YUgYX`cb`h\Y`IBGK`d`UbbYX`XUhY" H\]g`]g`]bX]WJhYX`VmU`WcifgY`[fUXY`fYgi`hcZY]h\Yf.

• @9'-']bX]WUHYg'mci '\UjY'bchWca d'YHYX'cbY'cf'a cfY']HYa g'cZUggYgga Ybh/cf

- VfcUXVUbX'WcbbYWfjcb'f&) * '_V]h#gYWcf'ZJghYfŁ
- UV]`]hmihc`j`]Yk`ghfYUa`]b[`j`]XYc`fN][\`cf``ck`XYZ]b]h]cb`l_BGK``HJ`cdh]cbgŁ

A cfY`]bZcfa Uh]cb'UVci hgmghYa 'fYei]fYa Ybhg']g'Uj U]`UV`Y Uh<u>k k k "ghi XYbh'i bgk "YXi "Ui #a ccX`Y!gmghYa !fYei]fYa Ybhg</u>

$5WWWgg]b[^7cifgYAUHYf]UgH\fci[\^AccXY]$

7 ci fgY'ci h]bYgžgi ddcfha UhYf]U`gʻUfY'i d`cUXYX'hc`A ccX`Yž'h\Y'i b]j Yfg]hrighUbXUfX'@YUfb]b[A UbU[Ya YbhGmghYa 'f@A GŁ"'±b`UXX]h]cbžcb!`]bY`Ugg][ba Ybhgi Va]gg]cbg`UfY'a UXY'i g]b['h\Y Ugg][ba YbhXfcdVcI 'ZJW]`]hridfcj]XYX']b`A ccX`Y"'5``Ybfc``YX'ghi XYbhg`UfY'Ui hca Uh]WU``m`]bWi XYX']b $\label{eq:constraint} \begin{array}{l} K = Y^{-1}UW_bck^{-1}X[-Y^{-1}h_{-}Y^{-1}dYcd^{-}Y^{-}k_{-}(-1)fY^{-1}h_{-}Y^{-1}fUX]h]cbU^{-1}W_ghcX]Ubg^{-}cZh_{-}Y^{-}UbXg^{-}cb^{-}k_{-}]W_{-}(-1)fY^{-}h_{-}Y^{-}h$