

ARTS1782

7 cbhYa dcfUfm'9i fcdY ']b '7 f]g]g. 'Dck Yf 'UbX '7 i `hi fY

HYfa 'Hk c''##'&\$%

7ci fgY'Cj Yfj]Yk

'GhJZZ'7cbhJWh'8YhJ]`g'

'7cbj Ybcfg'

B Ua Y	9a U]`	5j U]`UV]`]hm	@cWUh]cb	D\cbY
>Ub [:] @Ub]WY_	^^`Ub]V_4 i bgk "YXi "Ui		A 6 '' * +) %(- +

'@YWhi fYfg'

B Ua Y	9a U]`	5j U]`UV]`]hm	@cWUh]cb	D\cbY
>Ub`@Ub]WY_	^^`Ub]V\Y_4 i bgk "YXi "Ui		5g [·] UVcj Y	

'Hi hcfg'

B Ua Y	9a U]`	5j U]`UV]`]hm	@cWUhjcb	D\cbY
@]Ua '? UbY	`"_UbY4 i bgk "YXi "Ui			

GWXcc`7cbHJWhi±bZcfa Uh]cb

GWkcc``cZ<iaUb]h]Yg'UbX'@Ub[iU[Yg

@c\\U|rankingcb. `G\\\cc``C\Z]\\Y\z`A\cfj\Yb`6fck\b`6i\]`\X]b[\z'@\j\Y``&z`&),

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D\cbY. 'Ž*%'&'-',)'%*,%

: UI . Ž*%'&'-',) ', +\$)

9a U]`. <u>\U`4 i bgk "YXi "Ui</u>

7ci fgY 8YHJ] g

7 fYX]hDc]bhg *

Gi a a UfmcZh\Y 7ci fgY

Gi VYWn5fYU. 7gdabWS` EfgV[We

5a`fW_bacSck 7 gcbW[` 5 de[e, Bai WdS` V 5 gfgdWYl d`cfYgʻh,Y`i bdfYWYXYbhYX`W,U``Yb[YgʻZJW]b[WbbHa dcfUfm9i fcdYžh\fci [\'UWJXYa]WUbU`mg]gždc`]h]WU`Wa a YbhUfmž'Z]`a 'UbX'bcj Y`g''H\Y'dfcWYggYg cZYWbbca]WUbX'dc`]h]WU``]bhY[fUh]cbž\YfU`XYX`Vmh\Y'9i fcdYUb'I b]cbž'UfY`i bXYf`Yl]ghYbh]U``h\fYUhž'UbX bUh]cbU`]ga ']g`cb'h\Y'f]gY''Hc'h\Y'k Yghž6f]h]g\`X]gUZYWIjcb'k]h\`dYfWY] YX``cgg`cZgcj YfY][bm\Ug``YX`hc'U fYZYfYbXi a 'dUgg]b['f6fYl]hž']bX]WUh]b['h\Y']bhYbh]cb'cZU'a Ya VYf`ghUhY'hc``YUJ Y'h\Y'91 'Zcfih\Y'Zfghh]a Y'' Hc']hg`gci h\ž9i fcdY']g XYU`]b['k\]h\`U'fYZ [YY'W]g]g\Vfci [\hcb'Vmk Ufg`]b'bcfh\`5ZJWU'UbX'h\Y'A] XX`Y 9Ugh''Cb']gygyhYfb'ZUb_ž'hYbg]cbg'k]h\`Fi gg]U'UfY'\Y][\hYbYXžYgdYW]U``mcj Yf`l_fU]bY''H\Y fY`Uh]cbg\]d'cZ9i fcdY'k]h\`h\Y'I G5`]b'h\Y'YfU'cZ8cbU'X'Hfi a dfg'dfYg]XYbWn]g'U`gc']b'Zi I'''5```h\]g']g hU_]b['d'UWY'k\]'Y'9i fcdY'\Ug'VYYb'fYY`]b['Zca'h\Y'[cVU`'Z]bUbW]U``Wf]g]gžk]h\`ghf]b[YbhUi ghYf]m a YUgi fYg']b'gca Y'Wbi bhf]Yg``YUX]b['hc'[fYUhgcW]U`XYdf]j Uh]cb'UbX'dc`]h]WU``i bfYgh''H\]g'\Ug'WYUhYX'U fYgi f[Ybhf][\hk]b['zk\]W\'Vua Yg'9i fcdYf\gb']``g'cb']a a][fUbhdcdi `Uh]cbgžYgdYW]U``mh\Y'=g`Ua]W Wba a i b]mm''9i fcdY'dfYgg]b['mgYY_g'hc'fYwbW]Y']mg`]VYfU`'UbX'gYW``Uf']XYU'g'k]h\h\Y'Wa dYf]b[XYu Wa dYf]b[XYu UbX'gcZbUh]cbU']ga 'UbX'fY'][]ci g'Z bXUa YbhU`]ga "'H\]g'Wbi fgY'k]`"]bhfcXi WY'h\Y'gcW]U'z'W``hi fU``UbX dc`]h]WU``Wf]g]g']b'WbhYa dcfUfm9i fcdY'h\fci [\'U'W'hi fU'`Ybg''

7ci fgY @YUfb]b[Ci hWca Yg

%" 91 d`U]b 'h\Y Wf]gYg ZJW[b['WcbhYa dcfUfm9i fcdY 'UbX 'h\Y]f W 'hi fU``]a dUWf

- &" 8 YgWf]VY 'h\ Y 'gcW]U``UbX 'W 'hi fU``WcbhYl hg ']b 'k \]W\ '9i fcdY '\ Ug 'fYgdcbXYX 'hc 'fYWYbhW\ U``Yb[Yg]bWi X]b['fYZ [YYgž'dc`]h\W]``UbX 'YWcbca]WZfU[a YbhUh]cbž'a i 'h\W 'hi fU`]ga 'UbX 'Ui ghYf]hm'
- ' " 5 bU`mgY`U`gY`YW]cb`cZ`]hYfUfmiUbX`W]bYa Uh]WhYI hg`h\UhXYU`k]h\`WcbhYa dcfUfmi9i fcdYUb`gcW]U` UbX`dc`]hWU``]aai Ya"
- ("8 Ya cbglfUlY fYgYUfW. 'g_]``g'h\fci [\'YZYW]j Y'k f]h]b[žcfU`dfYgYblUh]cb'UbX'gW.c`UfmfYZYW]cb"

HYUW]b[GhfUhY[]Yg

H\Y'WbhYbh'UbX'UddfcUW\"hc"YUfb]b[']b'h\]g'Wci fgY']g'XYg][bYX'hc'Yb[U[Y'ghi XYbhg']bhY'`YWi U``mž]a U[]bUhjj Y`mUbX'Wf]h]WU``m]b'h\Y'W\U``Yb[Yg'ZJW]b['WcbhYa dcfUfm9i fcdY"'=hk]```fY`mcb'h\Y'XY`]j YfmcZ WcbhYbh]b!WUggž'cb`]bY'UbX'`]VfUfmVUgYXž']bWcfdcfUhjb['V`YbXYX'UbX'ghi XYbh\WbhYX'`YUfb]b['k\YfY Uddfcdf]UhY"'Gi V'YWia UhYf'k]```bYYX'hc'VY'fYgdcbg]j Y'hc'h\Y'Yj Yf!g\]Zh]b['dc']h]WU``g]hi Uh]cb']b WcbhYa dcfUfm9i fcdY'UbX'k]```a]I 'W ffYbh'dc`]h]WU``UbU`mg]g'k]h\ fY`Yj Ubh\W'hi fU``UbX']a U[]bUh]j Y Yb[U[Ya Ybhgž']bWi X]b['Z]a 'UbX'Z]Wf]cb"'`5```ghi XYbhg'UfY'[]j Yb'h\Y'cddcfhi b]hm]b'hi hcf]U`g'hc'Wcbhf]Vi hY hi hcf]U`X]gW gg]cbg'UbX'hc'YI d'cfY'X]ZYfYbh'h\Ya Yg'Wcj YfYX']b'h\Y'`YWi fYg'k]h\ hYUW\]b['ghUZZUbX'k]h\ ZY``ck'ghi XYbhg''

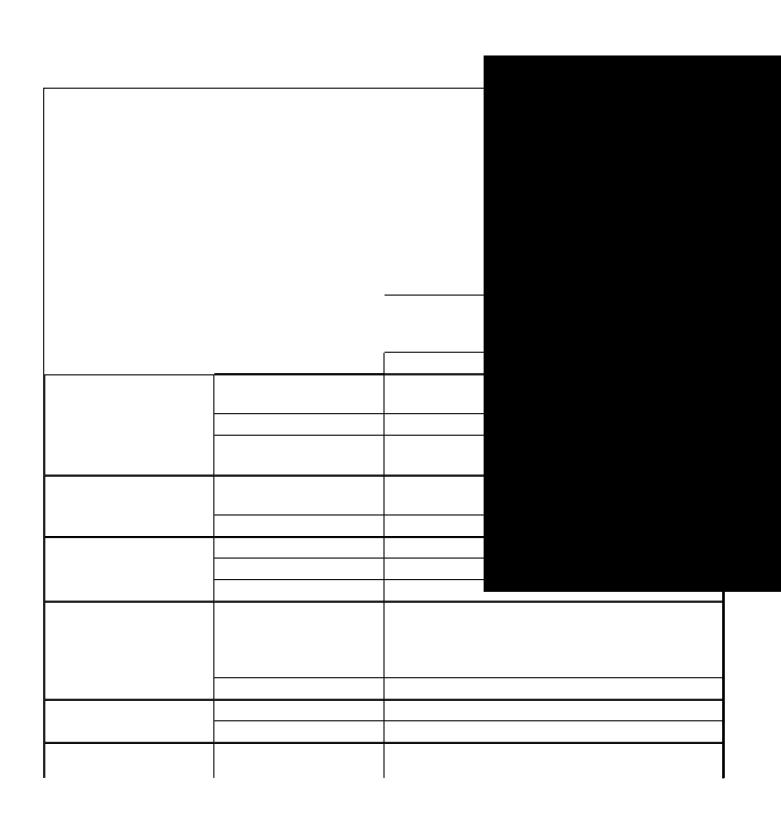
5ggYgga Ybh(.::]bU`hYgh

GHJfhXUhY. Bch5dd`]WUV`Y

8YHJ]`g. "\$!a]bi hY`]b!WUgg`hYgh"Bc`k f]hhYb`ZYYXVUW_ž`]b`WUgg`X]gW gg]cb"

5XX]h]cbU`XYhU]`g.

±o'mci f'fY[i`Uf'hi hcf]U`



5i [i gh		fYdUfUhjcb`Zcf`h\Y`ZjbU``hYgh'	
	5ggYgga Ybh	:]bU``HYgh`]b`mci f`fY[i`Uf`h hcf]U`g	

FYgci fWyg

DfYgWf]VYX F Ygci fWfg

 $\label{eq:hamiltonian} $$H\[g'WcifgY'k]^*dfcj]XY'kYY_mfYUX]b[g'Zcf'YWifYg\#ihcf]U'g'Ug'kY'dfcWYX''A cghk]^*VY'UjU]^UV'Y cb']bY'h\fci[\'I BGK'@]VfUfm'GhiXYbhg'bYYX'hc'W\Y_h\Y]f'Ya U]'fY[i'Ufm'Zcf'idXUhYg'cb'fYgcifW'g'UbXfYUX]b['a UhYf]U'''G]bW'h\]g'WcifgY'XYU'g'k]h\'WffYbhUZZJ]fg'zghiXYbhg'UfY'if[YUX'bYk gdUdYfg'UbXVY'UhhibYX'hc'ch\Yf'a U]bghfYUa 'a YX]U'Zcf'bYk g']hYa g'UbX'UbU'mg]g'fY'Uh]b['hc'WffYbh'UZJJ]fg'''GhiXYbhg g\ci'X'U'gc'Wcbgi'hh\Y'bYk g'k YVg]hY'9ICVgYfjYf'\hdg.##YicVgYfjYf'Wca#$

FYWca a YbXYX FYgci fW/g

H\YfY`UfY`gYj YfU``Vcc_g`h\Uhmci `WUb`fYUX`Xi f]b['h\Y`gYa YghYf"`A cghcZh\Y`a UhYf]U``]g`ei]hY`dc`Ya]\W\ž Vi hk Y`bYYX`hc`Yb[U[Y`Yj Yb`k]h\]XYUg`k Y`Xc`bchZ ``mgi ddcfhcf`U[fYY`k]h\"

A Ubi Y``7 UghY``q`fYX"Łž'9i fcdYfq'7 f]qYq'f&\$% Ł

K]``]Ua '8fcnX]U_ž: fUWh fYX'7cbh]bYbh'9i fcdYfgj'7f]gYg'UbX'h\Y': UhY'cZh\Y'K Yghf&\$%+Ł

8ci [`Ug'AiffUmž'H\Y'GhfUb[Y'8YUh\cZ'9ifcdY.'=aa][fUh]cbž'=XYbh]lmž'=g`Ua'f&\$%+Ł

; i mJ Yf\cZgHJXhž9i fcdYfgi@Ugh7\UbWY.K\mh\Y'9i fcdYUb'GHJhYg'A i gh: cfa 'U'A cfY'DYfZYWhI b]cb f&\$%+Ł

.

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

 $H\ [g'WcifgY'k]^*VY'Yj\ U'i\ UhYX'h\ fci\ [\ \ cb[c]b[\ 'X]gW\ gg]cb'UbX'Wcbgi\ 'hUh]cb'k\]h\ 'ghi\ XYbhg'UbX'`YWhi\ fYfg\ UbX'h\ fci\ [\ \ 'A\ m9!\ dYf]YbW'YbX'cZhYfa\ 'qi\ fj\ Ymq''$

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 'qYfj |WYq'UbX']bZcfa UHcb'UVci hI BGK 'UbX'I BGK '@|VfUfm

Gca Y'cZh\YgY'UfYUg'k]``VY'ZJa]`]Uf'hc'mci žch\Yfg'k]``VY'bYk"'; U]b]b['U'gc`]X'i bXYfgHJbX]b['cZU``h\YfY`UhYX'UgdYWhg'cZ9@&9'k]``\Y`d'mci 'a U_Y'h\Y'a cghicZmci f'ghi X]Yg'UhI BGK "'\\hd.##qi V'YWfi |XYg"`]VfUfm'i bqk "YXi "Ui #\`]qY#JVci hY`]qY

