

# **ARTS2125**

5Wjb["UbX"DYfZcfa]b[

# 7ci fgY'Cj Yfj ]Yk

# Ghuzz 7 cbhuWh8 Yhu]`g

## '7cbj Ybcfg'

B Ua Y	9a U]`	5j U]`UV]`] <b>m</b>	@cWUh]cb	D\cbY
AY[ʿAia ZcfX	a "a i a ZcfX4 i bgk "YXi "Ui	: f]XUmg`%\$!%&`fVm Uddc]bha YbhŁ	Fcca '‱ KYVghYf'6`X[	-',)'(,*)

### 'Hi hcfg'

B Ua Y	9a U]`	5j U]`UV]`]hm	@cWUh]cb	D\cbY
DUi`A UMNYkg	d"a Ulth\Yk g4 i bgk "YXi "Ui	D`YUgY'Ya U]`'DUi`` hc'UffUb[Y'U W:bgi`HUh]cb"	∉`AmYfg GhX]c	-',)')'+,
A Uf_'A ]H/XY``	a "a ]hW.Y``4 i bgk "YXi "Ui	D`YUgY'Ya U]`A Uf_ hc'UffUb[Y'U Wbgi`hUh]cb"	€ A mYfg Gh X]c	-',)'(,*'
Gi∵; c`XДg\	g"[c`XZ]g\4 i bgk "YXi "Ui	D`YUgY'Ya U]`'Gi 'hc UffUb[Y'U Webgi `HJh]cb"	€ A mYfg Gh X]c	-',)')*,(

# GWXcc~7cbHJWh~abZcfa Uhlcb

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

D\cbY.'f\$&E'-',)'(,)\*

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'h\Y'HfUX]tjcbU``7igtcX]Ubg\cong h\Y'6YXY[U'`fPYbg]b[hcb'WJadig\cong ix', UX][U'`fP]hmUbX'5fti/'8Yg][b'7UadigYg\cong iybUx'h\Y'B[ibbUkU`dYcd'Y'fbighfU`]Ub'8YZYbW': cf\w'5\\\XYam]b'7Ub\YffU\cozh\Y'`UbXg'k\YfY'YUW\\WJadig'cZIBGK']g`c\\Ully\X''$ 

# 7ci fgY 8YW] g

7 fYX]hDc]bhg\*\*

Gi a a UfmcZh\Y 7ci fgY

GIVYWN5fYU. HXWDffDWS`VBWdAd\_S`UWEfgV[We ‰

% %

.W .

‰ ‰

±0.1h.]g.'Wci fgY'mci k]``YI d`cfY'h.Ycf]Yg'UbX'dfUW]Wg'cZUW]b['UbX'dYfZcfa]b["'Mci k]```Wcbg]XYf'h.Y'k cf\_cZaU'cf'UWcf'hfU]bYfg']b'K YghYfb'h.YUhfY'UbX'dYfZcfaUbW'z'UbX'\ck'h.Y]f'UddfcUW.Yg'YaVcXmX]gh]bWhfYgdcbgYg'hc'h.Y'W'hifU`UbX'dc`]hJWD``WiffYbhg'cZh.Y]f'XUm''5Wcf'hfU]bYfg'aUm]bWiXY'GhUb]g'Ujg\_mzAYmYf\c'Xz'6fYW.hz'; fchckg\_]z'UbX#cf'6cU`"'Mci k]``'U`gc'Wcbg]XYf'\ck'acXyfb]ghacXYg'cZUW]b['\UjY VYYb'W.U``Yb[YX'UbX'hfUbgZcfaYX'VmdcghacXYfb'dYfZcfaYfg"'H\Y'Wci fgY'WcaV]byg``YWifY'UbX'hihcf]U`hYUW.]b['k]h.'ghiX]c!VUgYX'kcf\_g\cdg'h.UhXYjY`cd'mci f'g\_]``g']b'UW]b['UbX'dYfZcfa]b["'±iW'`a]bUhYg']b'U[fci d'dfygYbhUh]cb'YjYbhih.Uhg\ckWJgYg'U'X]jYfgY'fUb[Y'cZUddfcUW.Yg'hc'VY]b['U'dYfZcfaYf"'H\]g Wci fgY']g'dUfhcZh\Y'H\YUhYY'UbX'DYfZcfaUbW'GhiX]Yg'ghfYUa"

7 ci fgY @YUfb]b[ Ci hWca Yg

 $\label{thm:condition} $$ Y'd'gh XYbhg'ZcghYf'g_]`g']b'gY'ZX]fYWYX'UbX'[fci d!VUgYX`YUfb]b['h\fci [\'U'gYf]Yg'cZgh XYbh'YXfYUfgU'gž'W'a ]bUh]b[']b'U'dYfZcfa UbW'dfYgYbhUh]cb'UbX'Zcfi a "$ 

- %" Yj ]XYbWY'h\Uhmci '\Uj Y'fYUX'UVci hGHUb]g`Uj g\_m'g`]XYUg`fY. []j Yb'W]fW a gHUbWYgžgi dYfcVYWIj Yž cVYWIj Ygži b]hg'UbX'UWIjcbg/
- &" UWW fUWmUbX`UbU`mh]WU`ei U`]hmcZmci f`XYgWf]dh]cb`cZhZWb'Skie gi dYfcV'YWfj Y`UbX`cZh\Y WXUfUWYf'g`[]j Yb'W]fW a ghUbWg`UbX`gi dYfcV'YWfj Y`[ fZWb'Sk-
- ' "UbU`mh]WU``UbX`]a U[]bUh]j Y`ei U`]hmcZmci f`]bhYfdfYhUh]cb`cZh\Y`W\UfUWYf'g`cVYW1j Yg`UbX`UW1]cbg` |` fZWeUW W
- ("WUf]lmicZmci fik f]lthYbiYl dfYgg]cbifgdY``]b[ži[fUa a UfžgYbhYbWighfi WhifYžidi bWhiUt]cbžk cfX Wkc]WYt"

: YYXVUW\_. Mci k ]``fYWY]j Y`U'fi Vf]W]bX]WUh]b[ ``Yj Y``cZdYfZcfa UbWY`U[ U]bghYUWX`UggYgga Ybh'Wf]hYf]U UbX'dYfWbhU[ Y`[ fUXY"'`5gg][ ba Ybhgʻgi Va ]hh/X`cbʻh]a Y`k ]``fYWY]j Y`h\Y`UZcfYa Ybh]cbYX`ZYYXVUW\_k ]h\]b`&k YY\_g cZh\Y`Xi Y`XUhY"'5gg][ ba Ybhgʻgi Va ]hh/X``UhY`k ]``fYWY]j Y`h\Y`UZcfYa Ybh]cbYX`ZYYXVUW\_k ]h\]b`&k YY\_g`cZ gi Va ]gg]cb"

#### FUh]cbU`Y.

5```cZh\Y`a cXYfb]ghUWcf`HfU]bYfg`ghi X]YX`]b`h\]g`Wci fgY`Ug\_YX`UWcfg`hc`k cf\_`WUfYZi ``mik ]h\`d`UmhYI hg"'
H\]g`YI YfV]gY`[ ]j Yg`mci `Ub`cddcfhi b]mmhc`Yb[ U[ Y`k ]h\`gca Y`cZGHUb]g`Uj g\_mg`]bZi Ybh]U``UbX`\_Ym]XYUg
UVci h\ck `UWcfg`WUb`fYgdcbX`hc`U'd`UmhYI h\UbX`gWf]dhYX`W\UfUWhYf"``=\i]g`XYg][ bYX`hc`\Y`d`mci `bchcb`m
di h\]g`h\Ycf]Yg`]bhc`dfUWf]WYžVi h\U`gc`cVgYfj Y`\]g`UddfcUW\`hc`h\Y`fY`Uh]cbg`VYlk YYb`UWcf`UbX`hYI hz`UWcf
UbX`W\UfUWhYf"

Gi Va ]gg]cb bchYg.FYZYf hc A ccX`Y"

Hi fb]h]b gYh]b[. `H\]g Ugg][ ba Ybh]g gi Va ]hhYX h\fci [\`Hi fb]h]b UbX gh XYbhg Xc bchgYY Hi fb]h]b g]a ]`Uf]hmfYdcfhg"

5ggYgga Ybh& A U^cf 9ggUm

GhUfhXUhY. Bch5dd`]WUV`Y

@Yb[h\. &\$\$\$!&'\$\$kcfXgfW" (\fgdfYdUfUh]cbŁ

8 YHJ]`g. `&\$\$\$!&' \$\$`k cfXg"`Gh XYbhg`k ]```VY`dfcj ]XYX`k ]h\`U`fi Vf]W]bX]WUh]b[ ``Yj Y``cZdYfZcfa UbW\`U[ U]bgh YUW\`UggYgga Ybh'Wf]hYf]U/k f]hhYb`Zcfa Uh]j Y`ZYYXVUW\_/UbX`dYfW\bHJ[ Y`[ fUXY"`@UhY`YggUmg`k ]```fYW\]j Y fi Vf]WUbX`dYfWbHJ[ Y`[ fUXY`cb`m"

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

HUg\_ bghfi Whocbg.

H\Y'9ggUma i ghVY'&\$\$\$!&'\$\$k cfXg']b``Yb[h\fY!WiX]b['ZcchbchYg'UbX'V]V`]c[fUd\mz'UbX`WJb'VY'Y]h\Yf.

%" UʻfYgdcbgYʻhcʻcbYʻcZh\Yʻei Ygh]cbgʻ]bʻh\Yʻ`]ghX]ghf]Vi hYXʻj ]UʻA ccX`YʻC F &" UʻgY`ZXYj ]gYXʻei Ygh]cbž'h\Yʻh]hYʻcZk\]W\ \_ gef TWV[eUgeeWi [fZ fZWUagdeWUa` hW WdegT\_ [ffWw fa S`V SbbdahVW Tk ZWdSffZWI]' efgV[a e'afa` \$\$? SdJZž

@4, ? aVWefgVWfi ad Xta\_ bdWh[age kWSte [e ShS['ST'Wa`? aaV'W/5a`fWf DWeagdUWefi

5ggYgga Ybh7f]hYf]U. Mci k]``VY'UggYggYX'cb.

#### K 99?

MCI K < C 897 € 9 K < 5H CFA H < 9 F 9 < 95 F G 5 @ D F 9 G 9 B H 5 H € B K #@ H 5 ? 9 "

#### H]a Y A UbU[ Ya Ybh

Hc`\Y`d`mci``YIYW`hY`h\]g`[fcid`hUg\_žh\YfY`k]```VY`BC`hYUW\Yf!`YX`gYa]bUfg`cf`gYhWcifgY`fYUX]b[`Zfca K YY\_'\*`cbk UfXg"'`=bghYUXžmci``WUb`igY`h\Y`WUgg`g`chg`]b`YUW\`cZh\YgY`k YY\_g`hc`a YYhUbX`k cf\_'k]h\mcif`[fcid"'`=Zmci`bYYX`Ub`YIffU!W`ff]W``Uf`a YYh]b[#Y\YUfgU``gdUW`cf`ch\Yf`fYgcifW\gž'd`YUgY`Wcbgi`h k]h\`Gi`; c`XZ]g\ž'A UbU[Yf`cZh\Y`7fYUh]jY`DfUWf)W'`@UV`fl7D@Łžk\c`]g``]ghYX`]b`h\Y`YUf`mdU[Yg`cZh\]g WcifgY`cih]bY"

#### ; fci d'A UbU[ Ya Ybh

6mK YY\_\* mci k ]``bYYX'hc`\Uj Y'YghUV`]g\YX'U'7 ca a i b]\Whcf'k \c'k ]``fY[ i `Uf'm'\\cappa a i b]\WhY'k ]h\'h\Y 7 cbj YbYf'UVci hh\Y'bUhi fY'UbX'gYhi d'cZh\Y'DYfZcfa Ub\\"'''Mci k ]``U`gc'bYYX'hc'YghUV`]g\'ch\Yf'k cf\_

H\]g`Wci`X`VY`U`X]fYWrcf`Z][ifYž'k\caumcfaumbchZYUhffY`Ug`giW\]b`mcif`dfYgYbhUh]cb"``\\in\Wci`X`U`gcVY`U`W\cfYc[fUd\Yfž'g\c'k\c'Wci`X`VihbYYX`bchVY`U`XUbWffž'k\cgY`fc`Y`]g`hc`cVgYfjY`acjYaYbhcfV`cW]b[`cf`]bhYfUWlcb`k]h\`h\Y`UiX]ybWfYhW

+"G79BC; F5D<9F

H\]g`Z[[ifY`kci`X`kcf\_`WcgY`mk]h\`DUi``AUhh\Ykg`cb`UgdYWhg`cZj]giU``XYg][b`giW\`Ug`igY`cZWcghiaYžgdUWYžgYhžUbX`cVYWhg`YhW

, "GCIB85B8@= <H=B;

H\]g`Z[[ifY`kci`X`kcf\_`cb`gcibX`UbX``][\f]b[`XYg][b`UbX`WcbZYf`k]h\`AUf\_`A]hW\Y```cb`]ggiYg`giW\`Ug`h\Yd`Ubb]b[`UbX`YIYW f]cb`cZh\]g`XYg][b`h\fci[\`igY`cZUj`hYW\bc`c[]Yg"`

#### GHUZZF Ygci fW/g,

A Y[žA Uf\_'A]hW\Y```UbX`DUi``A Uhh\Yk gʻZca 'h\Y`7 D@UfY`h\YfY`UgʻfYgci fWrgʻZcfʻUXj]\WʻžUgʻgci bX]b[VcUfXgʻZcfʻmci fʻ]XYUgžUgʻUggYggcfgʻcZmci fʻWcbhf]Vi h]cbgʻhcʻh\Y`[fci dʻk cf\_'UbX`cZh\Y`Z]bU`dfYgYbhUh]cbg.'h\YmUfY`bchʻh\YfY`hcʻhY```mci 'k\Uhhcʻh\]b\_'cf`k\Uhhc`XcžVi hžUgʻmci ']XYbh]Zmk\Uhmci h\]b\_'UbX`k\Uhmci 'k]g\`hc`Xcž'h\YmUfY`h\YfY`hc'dfcj]XY`Wcbghfi WhjYYWf]h]W]ga 'UbX`\Y`d'mci ']a d`Ya Ybh h\]g"

A Uf\_'UbX'DUi ``k ]``gdYU\_'hc'mci ']b'h\Y'K YY\_') 'gh X]c'WUgg'UVci h'h\Y'i gY'cZ7D@fYgci fWYg"

B6. '€ 'A mYfg'Ghi X]c'k]``VY'Uj U]`UV`Y'Zcf'ci HcZlWUgg'fY\YUfgU`g"''Ghi XYbhg'WUb'Vcc\_']b'Vm Ya U]`]b[ 'Gi '; c`XZ]g\']b'UXj UbW'' 'Xc'[ Yh]b'YUf`]Yf'fUh\Yf'h\Ub''UhYf°''<Yf'Ya U]`'UXXfYgg']g. g"[ c`XZ]g\4 i bgk "YXi "Ui

Gca Y K cfXg cZK ]gXca.

- %" mci 'k ]```VY`YI dYWMYX'hc`Wca a i b]WUhY`UbX`fY\YUfgY`k]h\`mci f`[ fci d'a Ya VYfg`cb`U`fY[ i `Uf`VUg]g UbX`cZhYb`ci hg]XY`h\Y`gW\YXi `YX`WUgg`\ci fg"``H\Y`Wci fgY`\Ug`VYYb`XYg][ bYX`k]h\`h\]g`h]a Y Wca a ]ha Ybh]b`a ]bX"``: cf`YI Ua d`Yz`h\Y`ei Ubh]hmcZfYUX]b[ g`dYf`k YY\_`\Ug`VYYb`\_Ydh'hc`U a ]b]a i a `k \YfYj Yf`dcgg]V`Y/U```WUggYg`Zfca `K YY\_`\*`\Uj Y`VYYb`[ ]j Yb`cj Yf`hc`h\Y`dYfZcfa UbWY dfc^YWYh\Y`YggUmgi Va ]gg]cb`XUhY`\Ug`VYYb`d`UbbYX`gc`h\Uhh\Y`fYgYUfW\`Zcf`]hk ]```Wca d`Ya Ybh h\Y`bUh fY`UbX`h]a ]b[ `cZh\Y`dfc^YWh'k cf\_"
- &" h\]b\_`UVci hYbgYa V`Y`ghfi WhifYg.`k cf\_`ci hk \c`]g`Xc]b[`k\UhUg`gccb`Ug`mci `WUb"``7 c``UVcfUh]j Y XYW]g]cb!a U\_]b[`a UmVY`dc`]r]WU``mgci bXžVi h`]b`h\Y`g\cfhh]a Y`h\Uhmci `\Uj Yžk]h\`gc`a Ubm dYcd`Y`]ha UmVY`\UfX`hc`a UbU[Y`YZZYW]j Y`m"
- '"\UjY`dYcd`Y`k\c`fY[i`Uf`mkf]hY!id`]b`Vf]YZ`X]gWigg]cbgžXYVJg]cbg`a UXY`UbX`UWf]cbg`hc`VY`hU\_Yb WUfY`cZUZhYf`YUW\`[fcid`X]gWigg]cb"``H\YgY`'a]bihYg**'**`g\ci`X`VY`WJfW``UhYX`VmaYUbg`giW\`Ug YaU]`"```H\]g`dYfgcb`Wci`X`U`gc`aUbU[Y`h\Y; fcid`FcghYf"
- ("mci 'a Um'ZbX']hdYfgcbU``m'\Y`dZ ``hc'\_YYd'U'fi bb]b[ 'X]Ufmž'Ug'k Y```Ug'Ubm']a U[ Yg'cf'ch\Yf XcW a Ybhg'mci 'Wc``YWhXi f]b[ 'mci f'fYgYUfW\ž'Ug'k Y```Ug'U'V]V`]c[ fUd\m''
- ) "Iffmbchhc ``YUj Y'h\Y'Udd`]YX'dUfhhc'h\Y``Ugha ]bi hY/\_YYd']b'[ccX'WcbhJWhk]h\'h\Y'7D@'UbX'UV]XY Vmh\Y]f'fY[i `Uh]cbg'UbX'gW\YXi `Yq"

DfYdUfUhjcb UbX Gi Va ]gg]cb ≠bglfi Whjcbg.

DfYdUfUfJcb:XUfYg. .....K \_ '\* 'hc'k \_ '%

DfYgYbhJh]cb`XJhYg.```: f]XJmi&\*`5df]``fK \_'%\$łž-Ua 'hc '%da 'XfYgg`fY\YJfgJ`ž' !) da 'g\ck ']b`€ A mYfg`Gh X]c'

#### 5ggYgga Ybh

; fci d'DfYgYbhUhjcb.'&\$i

±bX]| ]Xi U``7 cbff]Vi h|cb hc DfcW/gg. '&\$i

5ggYgga YbhcZ; fci d DYfZcfa UbWY f&\$1 Ł

 $\label{thm:converse} $$H_Y^g WWgg^cZh_Y^DYfZ^fa UbW^XYdYbXg^idcb^mci^VY]b[^Wcaa]hhX^hc^kcf_]b[^k Y^*UbX^Wcbg]ghYbhm k_]h_YUW_ch_Yf^*BchY^k_]^*VY^hU_Yb^cZ^UhYbXUbW^hAfci[_\U'; fcidFcghYf^UbX^h,YY]hYbhhc^k_]W_dYcd^Y^UfY^Z^Z^]^]b[^fYgYUfW_UbX^ch_Yf^fYgdcbg]V]^]hJYg^U^*cWUhYX^hc^h_Ya^]b^h_Y^[fcid.UVgYbhYY]ga^UbX^hc^h_Y^Wc^UVcfUhJ_Y^dfcWygg^k_]^*VY^dYbU^]nYX''$ 

A Y['k]``a Uf\_'h\Y'; fci d'DYfZcfa UbWY'dfYXca ]bUbhm'Ug'U'DfcXi Wf'''<ck Yj Yfž'dfcWYgg'UbX'dfcXi Wh WUbbch'bcf'g\ci `X'bch'U'k Umg'VY'gYdUfUhYX''''<YbWYž'A Y['k]``h\\_Y'DYYf'F Yj ]Yk 'UbX'GY'ZI9j U'i Uhjcb'cZ h\Y'dfcWYgg']bhc'Wcbg]XYfUhjcb'k \Yb'ZjbU`]n]b['h\Y'; fci d'DYfZcfa UbWY'a Uf\_"''6ch\'ghUZZUbX'ghi XYbhg'k]``VY'Ug\_YX'hc'Yj U'i UhY'dfYgYbhUhjcbg']b'UWWcfXUbWY'k]h\'h\YgY'7 f]hYf]U.

- %" UʻgYf]ci gʻYb[ U[ Ya Ybhž'VYmcbX`W]W\Agž'k ]h\ʻgca YʻfY`Yj Ubh'h\Ycf]YgʻUbX#cf`\]ghcf]WU``fY\YUfgU` UbX`dYfZcfa UbW'dfUW]WygʻcZmci f`W\cgYb'dfUW]h]cbYffgŁ/
- &" Ub UV]]mmhc qy`YWhdyfh]bYbhYl Ua d`Yq`Zfca 'h\Y'dfUWfh]cbYf'q`Y[UWh/
- ' " U'WUf]Zm]b[ 'UbX']a U[ ]bUh]j Y'Zcfa 'cZWca a i b]WUh]cb'h\Uhg\ck gž'Ua cb[ gh'ch\Yf'h\]b[ gž'Uh\ci [ \hz ``UddfcUW\hc'fi X]a YbhUfmdfcdg'UbX'Wcgh a Y/
- $("U`XYa\ cbghfUh]cb`cZ\ck\ 'h\Y`dfUWf]h]cbYf'g`]XYUg`UbX`a\ Yh\cXg`UfY`VY]b[`i\ gYX`hc`]bhYfdfYhih\Y gWbY/$
- ) " h\Y`ei U`]mmcZU`k Y``!fY\YUfgYX`dYfZcfa UbWV`fZcfYl Ua d`Yž`]ZfY`Yj Ubhž``]bYg`g\ci `X`VY`XY`]j YfYX Zfca 'a Ya cfmt/
- \*" U'Webg]XYfUh]cb'cZh\Y'fY`Uh]cbfgŁ'VYhk YYb'cb'h\Y'cbY'\UbXžh\Y'dYfZcfa Yfg'UbX'dYfZcfa UbW\ž'UbX cb'h\Y'ch\Yf'\UbXžh\Y'gdYWUhcfg"
- +"Yj]XYbWY'h\Uh'h\Y'ci hWca Yg`\Uj Y'VYYb`XY`]j YfYX'h\fci [\`[fci d`]bhYfUWf]cb`UbX'dfcV`Ya!gc`j]b[/, "Z`Z]``]b['h\Y'fYa]hk]h\]b'h\Y'[]j Yb'h]a Y'ZfUaY"

E WŽ7 hS′gSf[a` S` V B WWd D Wh[W /E 7 B D fi cb 'A ccX`Y 'fl7 cb H/b h/ 'F Ygci fW gŁ 'mci 'k ]```Z]bX`U`G 9 D F 'Zcfa hc 'Z]``ci hfY[ UfX]b[ 'mci f`ck b`UbX`mci f`dYYf'g`Wcb hf]Vi h]cb 'hc 'h\Y`dYfZcfa UbW 'dfcW gg" '`H\Y`G 9 D F 'Zcfa ]g`hc 'VY`gi Va ]hHYX`hc '`mci f` 7 cbj YbYf`Uh h\Y`K YY\_'%\$`dYfZcfa UbW 'Yj Yb H'`H\Y`Zcfa ']g`bY]h\Yf`a UbXUhcfmž bcf`a Uf\_YXžVi hdfcj ]XYg`Ub`]a dcfhUbh'[ i ]XY`Zcf`mci f`a Uf\_Yfg"

$\sim$	
(	$\vdash$

; fci d'a Uf	 \$1
±bX]j]XiU`ghiXYbhlg'Wcblf]Vih]cb.	 -(
: ]bU`DYfZcfa UbWfa Uf	 ++1

 $H\ [g`UX^{\circ}gha\ Ybh]g`]bhYbXYX`hc`HU_Y`UWWci\ bhcZ]bghUbW'g`k\ YfY`Ub`]bX]j\ [Xi\ U`'g`Wcbhf]Vi\ h]cb`hc`h\Y`[\ fci\ d'g\ k\ cf_]g`WYUf`mk\ Y```UVcj\ Y`cf`k\Y``VY`ck\ h\Y``Yj\Y``Uhk\]W\ h\Y`[\ fci\ d`k\ Ug`k\ cf_]b[\ `Ug`U`k\c`Y''$ 

FZWE7BD Xad\_ i [^S'ea ZWb? WY fa SeeWee; V[h[VgS^5a`fd[Tgf[a` fa 9 dagb BWdXad\_S`UW/eWWTWai fiz

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%" 'Yj Y`cZUHY'bXUbW' 'Uh'W ff]W `Uf'fK \_g'%| %\$£'UbX'YI HfU!W ff]W `Uf'gYgg]cbg/
&" ei U`]mcZdUfh]W]dUh]cb'Xi f]b[ 'th\cgY'gYgg]cbg']"Y"'g][ bg'cZUXj UbW'dfYdUfUh]cbž'j YfVU``UbX
d\mg]WU`'dUfh]W]dUh]cbž'UHY'bh]j Y``]gHYb]b[ 'UbX'cVgYfj ]b[ ž'Yb[ U[ Ya Ybhk ]h\ 'dYYfg'UbX'h hcf/
' " Wcbhf]Vi h]cb'hc'h\Y'gYh[ fci d'HUg\_g'Zcf'K \_g'\*!%\$ 'UbX'h\Y'Z]bU``dfYgYbHUh]cbž'UbX'Z `Z]``a YbhcZ
[ fci d'fc`Y'fgYY'UVcj Y£"''A Y[ 'k ]```Wcbgi `hk ]h\ 'A Uf\_'UbX'DUi `ž'UbX'k ]```UbU`mnY'h\Y'G9DF 'Zcfa
k \Yb'Wcbg]XYf]b[ 'th\]g'hmdY'cZ]bX]j ]Xi U``Wcbhf]Vi h]cb"

F UhjcbU'Y. 'H\Y'; fci d'DYfZcfa UbW''U]a g'hc'XYj Y`cd'mci f'i bXYfghUbX]b['cZ\ck'\_YmidfUWjhjcbYfg'k cf\_YX k]h\'UWrcfg'cf'dYfZcfa Yfg']b'Ub'YbgYa V'Yž'Ug'k Y``'Ug'`Uf[Y!WUghgWrbYgž'UbX'[fci d'k cf\_']g'cbY'j U'i UV'Y a Yh\cX'cZYl d`cf]b['gi W\'k cf\_"''+b'UXX]hjcbž'h\Y'Wci fgY'U]a g'hc'\][\`][\h'UbX'XYj Y`cd'h\Y'hmdYg'cZg\_]``g h\Uh'UfY'j]hU``k\Yb'k cf\_]b[']b'hYUa']b'h\Y'k cf\_ZcfW'ž'dUff]W'`Uf'm]b'h\Y'dYfZcfa ]b['Uffg'UbX'h\Y]f ]bgh]h hjcbU``WcbhYl hg"'''''''

Gi Va ]qq]cb bchYq.FYZYf hc 'A ccX`Y"

Hi fb]hjb gYhjb[. H\]g ]g bchU Hi fb]hjb Ugg][ ba Ybh

		&\$\$(\timezidd"`))% )++"``GWf]dh`]g`]b`h\Y`FYgcifWYgg
K YY_'&.'&) ': YVfi Ufm!'' A UfWX	@YWn fY	K_`&`@YWn fY#Hi hcf]U`.`Hcd]W`GhUb]g`Uj g_m! DgmW.c`c[]WU`FYU`]ga / 'h\Y`7YbhfU`]nUh]cb`cZ 7\UfUWhYf
		JYbiY."KYVghYf" &+
		H]a Y. H\i fgXUm&, : YVž'‱!&
		#b k \ Uhik Umg k Ug G hUb]g `Uj g_mg `Uddfc UVX hc `UWf]b[]bZi YbWYX 'Vm `UhY b]bYhYYbh\!WYbh fm ZcfWYg cZ a cXYfb]nUh]cb `]b '9i fcdYž ]bWi X]b[ ''bYk gW]YbWYg' gi W `Ug dcg]h]j ]ga `UbX dgmWxcUbU`mg]g3 ``< ck `XcYg \]g k cf_ fY `UhY hc `Vch\ F ca Ubh]W]ga `UbX B Uhi fU`]ga 3 ``#b k \ Uhik Umg k Ug \]g k cf_ i bXYfd]bbYX 'Vmb]bYhYYbh\!WYbh fm`]VYfU``\i a Ub]gh ]XYc `c[ m3 ``K \ Uhik Ug h\ Y bUhi fY `cZ\]g j ]g]cb cZh\ Y dgmWx Y `UbX `cZ'bUhi fY'3 ``5 bX `]b k \ Uhik Umg k YfY `\]g VY`]YZg `UbX k cf Xj ]Yk g `fYZYWYX `]b `\]g `UddfcUWX hc h\ Y `UbU`mg]g `UbX `Vi ]`X]b[ `cZU `gWf]dhYX `WX UfUWYf3 ``
		9ggYbhJU`FYUX]b[.
		%L```G\Ufcb`AUf]Y`7Ufb]W_Yž'GHUb]g`Ujg_mg`GmgHYa. DUh\kUmg`Zcf`h\Y`UWcf'ž]b`5`]gcb` <cx[y`fyx"l` FiWf[WfZ5W`fgdk3UfadFdS[`[Y`f@cbXcb`UbX`BYk Mcf`FcihYX[Yž&amp;\$\$\$LZdd"`%% '*/</cx[y`fyx"l` 
		&L```7 cbghJbhjb`GhJbjg`Uj g_jž'l bjhg`UbX`CVYWhj Yg'ž 3` 3UfadBdWbSdWel hfUbg"`9`jnUVYh\`FYmbc`Xg <ud[ccx`fbyk`mcf`h\yuhfy`5fh6cc_gž'%(, łždd"<br="">%\$)!%%"</ud[ccx`fbyk`mcf`h\yuhfy`5fh6cc_gž'%(,>
		Cdh]cbU`FYUX]b[.
		%L'G\Ufcb'A Uf]Y'7 Ufb]W_Yž'%\$'5Wf]cb'UbX'h\Y \i a Ub'VcXm]b'h\Y'fc`Y'ž]b'EfS` [e'She] k [`8aUge, 3`3Uf[`Y? SefWdXadfZWFi W fkŽXfæf5W fgckž&bX YX"'ff@cbXcb'UbX'BYk 'Mcf_'Fci hYX[Yž&\$\$-Łždd" %)!&\$*ž&'!!'("
	Gh X]c	K_'&GHiX]c.`Hcd]W`GHJb]g`Ujg_mKcf_g\cd. 7fYUh]b[`h\Y`GHJhY`cZ`5g`-Z
		JYbiY."KYVghYf"' (
		H]a Y. H\i fgXUm'%'A UfW\ž''!) da
		BSdfA`W`FY`UI Uhjcb`UbX`'[Yhhjb[`]bhc`h\Y`f][\h ZfUaY`cZa]bX'/kcf_`cb`;]jYb`7]fW`aghUbWYgž 5ZZYWhjY`AYacfmžUbX`CVYWhjYg#HUg_g/h\Y`5Whjcb

		j g'5 Wfj ]lmiX]gh]bWf]cb"  BSdFFi a. 'GhUb]g`Uj g_]Ub'hYI hi U`'UbU`mg]g'cZcbY Yd]gcXY']b'3 6a ^: ageW  9ggYbh]U`FYUX]b[.  %" 6Y``U'A Yf`]bž'('DfUWf]WU`'9I YfW]gYg'žZfca A Yf`]bž'=a`efS`f[`EfS`[e'She]k'f@cbXcb UbX'BYk'McfFci hYX[Yž&\$\$' Łždd"
K YY_'' . '( 'A UfW.'! '%\$	@YWn fY	%%+!)(" &" D`UmhYIh < Ybf]_ ⇒\gYbž3 6a^: ageW fF YgcifWYg`gYWhcb`]b`AccX`YŁ  B6.7\UfUWhYf` ⇒hYfdfYhUh]cb`XiY`bYIhk YY_ VYZcfY`%%da`cb`K YXbYgXUm* AUfWX j`]U Hifb]h]b
A UfVX		

1	Hi fb]h]b Vm%%da "
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	JYbiY. KYVghYf" '(
	H]a Y. ': f]XUm, 'A UfW\ž' !) da
	BSdfA`W'7cadcfmaYbhiUbX'g]hiUhjcb'gWfbUf]cg/WfYUhjb['J!YZYWfg'-'Wfcgg!WUgh]bhYfj]Yk/g\ck]b[gcWjU''WjfWaghUbWfg'-'HUI]'f]XY/ZfUa]b['W ghcag'-[fYYhjb[g'UbX'ZUfYkY'`g/
	BSdfFi a. FY\YUfg]b[ 'U'6fYW\hhYIh-'3dd\$`YW_WfcZh\Y'fUdY'hf]U'gWrbY'fgWrbY') ŁZfca '6fYW\hg'FZW5SgUSe[S` 5ZS1] 5[dUW
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	%" G\ca]hA]hYfž'&"HC"69"5B8"BCH"HC"69.

	%E'''>Yfnm; fchck g_]žFai SdVe S BaadFZWSfdW f@cbXcb.'9mfY'A Yh\i Ybž'% +* Łž'dd"''%) !&) " &E'7\f]ghcd\Yf'=bbYgž'GYW\'Uf'FY'][ ]cbg'UbX D\mg]WU''Gd]f]hi U`]miž'3hS`f9SdVWFZVSfdW #*+\$Ž#++\$

	UVci himci fi[fci dfgi`cWUh]cbi]bih.YiK _i) i: f]XUmig`ch UbXij]Uih.YiFY\YUfgU`GW.YXi `YicbiA ccX`Y"
	: cfYUWX.cZh\YgY.kYY_g.mci.k]``VY.[]jYb.U.kcf_ hUg_`UbX.Ug_YX.hc'dfYgYbhmci.ffYgdcbgY.]b'h\Y H\ifgXUmg`ch]b'U'aYYh]b['k]h\'AY['UbX'igiU``m U`gc'AUf_'A]hWXY``UbX.DUi``AUhh\Ykg'Zca'h\Y 7fYUh]jY'DfUW]WY'@UV'f17D@Ł"
	DYfZcfa UbWY Dfc YWhHUg_ Zcf K _ *
	±b."h\Y."H\i fgXUmg`chmci ik]```bYYX'hc'Z bU`]nY'[fci d fc`Yg'Ug'kY``Ug'WUgh]b[']ZfY`Yj Ubh''Mci 'a i ghU`gc dfYgYbh[fci d'kcf_'cb'h\Y'Zc``ck]b['HUg_'hc'gHUZZ'
	8YacbghfuhYFYgYufWN]bhc'ubX'u'; fcidFYgdcbgY hc'hNYGYhDfcV'YafgŁ
	%" 8 Ya cbglfUlY Yj ]XYbWY cZfYgYUfVW ]bhc h\Y W\cgYb dfUWnjhjcbYf#Mca dUbmg UddfcUW\ hc UWnjb[#dYf7cfa]b[ UbX fY\YUfgU'/

		&" Ci h]bY`\ck 'h\Y`gdUW'`UbX`a UhYf]U`g`UfY [c]b['hc`VY`hfYUhYX"``: cf`YI Ua d`Yž`gdUh]U` UffUb[Ya Ybhg`f]bWi X]b['k \YfY`h\Y gdYWUhcf`k]``VY`dcg]h]cbYXŁ`UbX`dfcdg`UbX Wcghi a Yg`fW''%I '5('dU[Y`I'' Ł/ ' " Ci h]bY`HYW\b]WU``F Yei ]fYa Ybhg.``][\h]b[ž gci bXžUj 'fdfc^YWh]cbžhj ž`g`]XYgŁ`fW''%I '5( dU[Y`I'' Ł
	Gh X]c	K _'+'Gh X]c.'; fci d'DYfZcfa UbWY' 'FY\YUfgU`'( H]a Y.': f]XUm) '5df]'ž''!) da
		H\Y`[fcid'g\ci`X`Zfh\Yf'XYjY`cd'h\Y]f']XYUg'UVcih h\Y`gYeiYbW'cZYjYbhg'UbX'h\Y`XYg][b'WcbW'dh]b `][\hcZZYYXVUW_Zfca 'ghUZ'FYgYUfW\fc`Yg'UbX UWfj]h]Yg'Zcf'h\Y`K_', 'hUg_'g\ci`X'VY'U``cWJhYXž'UbX kcf_'cb'h\Uh'HJg_'VY'WcaaYbWYX"
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		GtU[Y'U'Z]fghk U`_!h\fci [\'cZh\Y'dYfZcfa UbW'f]hg gYei YbWrgž'UffUb[Ya Ybhg'UbX'YZZYWgŁk]h\'gHUZ fA Uf_ž'A Y['UbX'DUi `Ł'Ug'gdYWfUhcfg#Ugg]gHUbhg" H\Y'[fci d'g\ci `X'UhhYbX'U`gc'hc'h\Y'd`UWYa YbhcZ h\Y'Ui X]YbWr'UbX'Ubm'Ui X]YbWr'UWJcbg'cf dUff]W]dUh]cb"
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		H\Y'[fcidg\ci`X'Zfh\Yf'XYjY`cd'h\Y]f']XYUg'UVcihh\Y'ZbU`'dYfZcfaUbWY'UbX'h\Y'bUhifY`cZh\YUiX]YbWY'g'd`UWYaYbhUbX'dUff]WjdUhjcb']b'`][\hcZZYYXVUW_'Zfca'ghUZZ'FYgYUfW\fc`Yg'UbX'UWhjj]hjYgZcf'h\Y'K'-'hUg_'g\ci`X'VY'U``cWUhYXž'UbX'kcf_'cbh\UhHUg_'VY'WcaaYbWYX"
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		H\Y`[fcid'g\ci`X'dfYgYbh]hg'dYfZcfaUbWY`]b'Z`` WcghaY'UbX'k]h\'dfcdg'UbX'gYhd]YWYg'hc'ghUZZ'
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K YY_`%\$.`&&`5df]``!`&, 5df]`	Gh X]c	K? %\$ HYW / 8fYgg.: f]XUmA cfb]b[  J Ybi Y. € A mYfg Ghi X]c  H]a Y.: f]XUm&* 5df] ž%XYg][ bUhYX \ci f dYf [ fci d VYhk YYb - Ua 'UbX' %da  5g a Ubm[ fci d a Ya VYfg Ug dcgg]V Y g\ci `X 'UhhYbX h\Y [ fci d'g XYg][ bUhYX \ci f " \= Zmci `\Uj Y gWXYXi 'YX I BGK 'HYUW ]b[ 'UbX WUb'hUhYbXz'mci k]` bYYX hc ]bZcfa 'h\Y 7 cbj YbYf Uh YUghcbY k YY_ ]b 'UXj UbW cZh\]g 'HYW / 8fYgg Yj Ybh'   H<9F9 € BC 'H <i 'h<="" 'h<95bn57="" 'hc="" 'k="" 8i="" 9="" 99?="" <="" @5gg="" c@€5="" fg85="" m'<="" m7="" td="" €=""></i>
	Gh X]c	K_'%\$'DYfZcfa UbWY'9j Ybh': f]XUm5ZhYfbccb  J Ybi Y.' €'A mYfg'gh X]c  H]a Y': f]XUm&*'5df]'ž'!) da  D'YUgY'Uff]j Y'dfca dhmUh' da "''Mci 'g\ci 'X.  %" U'fYUXmVY']b'Wcgh a Y'UbX'a U_Y!i d'UbX\\Uj Y'U'`'dfcdg'UbX'gYhd]YW'g'fYUXm/ &" Vf]b['U'd'UhY'cZgk YYhcf'gUj ci fmZccX'Zcf\\mci f'Z\'`ck 'gh XYbhg'hc'Yb'cm]b'VYhk YYb\\\YUW'cZh\Y'('g\ck g/\\' "Vf]b['UbX'gi Va ]hmci f'Wca d'YhYX'GY'Z\\\9j U'i Uh]cb'UbX'DYYf'F Yj ]Yk 'Zcfa "'

F Ygci fWYg

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hY'Yd\cbY'9I hYfbU'Gi ddcfhcb'-', ) '''' %cf'Ya U]''h\Ya 'cb'YI 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'''#mci
UfY'i bUV'Y'hc'gi Va ]hmci f'Ugg][ ba YbhXi Y'hc'U'ZJi 'hk ]h\'Hi fb]h]b'mci 'a Um'Udd'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'hc
]bWi XY'Ug'Yj ]XYbWY'hc'gi ddcfhmci f'YI hYbg]cb'Udd']WUh]cb'''#mci 'Ya U]''9I hYfbU''Gi ddcfhmci 'k]''
Ui hca Uh]WJ''mfYWY']j Y'U'h]W\_Yhbi a VYfž'Vi h]Zmci 'hY'Yd\cbY'mci 'k]'''bYYX'hc'gdYW]ZWJ''mUg\_'Zcf'cbY''
Hi fb]h]b'U'gc'dfcj ]XYg'i dXUhYg'cb'h\Y]f'gmghYa 'gfUh' g'cb'Hk]hYf"

; YbYfU``mž'UggYgga YbhiHug\_g'a i ghVY'gi Va ]hhYX'Y`YVWfcb]\W)``mij ]U'Y]h\Yf'Hi fb]h]b'cf'U'A ccX`Y Ugg][ ba Ybh'' =b']bgHJb\W'g'k \YfY'h\]g']g'bchdcgg]V`Yž']hk ]``'VY'gHJhYX'cb'mci f'\\ci fgY'g'A ccX`Y'g]hY'k ]h\ U`hYfbUh]j Y'gi Va ]gg]cb'XYhJ]`g''

cfi]bZcfa Uh]cbicbi\ckihcigi Va ]hUgg][ ba Ybhgicbi]bYij ]UiA ccXiY.i\hdg.#gh XYbh'i bgk "YXi "Ui #\ck! qi Va ]hUgq][ ba Ybha ccXiY

# 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'

⇒ 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 bXYfglUbX`mci f`f][\hg`UbX`fYgdcbg]V]`]h]Yg`Ug`U`gh XYbh'Uhil BGK
- VY'Uk UfY'cZd`U[]Uf]ga ž'Wcdmf][\hzil BGK 'Gh XYbh7cXY'cZ7cbXi WhUbX'5WWdhUV`Y'I gY'cZ I BGK '= H'F Ygci fWfg'Dc`]Wh
- VY 'Uk UfY 'cZh\Y 'ghUbXUfXg 'cZVY\Uj ]ci f'Yl dYWhYX 'cZYj YfmcbY ']b 'h\Y 'l BGK 'Wcaaib]hm
- `cWUHY 'gYfj ]WYg'UbX `]bZcfa UH]cb'UVci hI BGK 'UbX'I BGK '@]VfUfm