

### A ØbghYf'i bX'FK H<'5UWXYb.'=bbcj Uh]j Y 6i gVYgWX`Yi b][i b['Ub'XYf'K YgY`Yf GhfU» Y

D]`chdfc^Y\_h'j cb^GhUXh'A ØbghYf'i bX\*FK H<\*5UW\Yb VYgW\`Yi b][ h'6i gj Yf\_Y\f'a ]h'? ±? Ua YfUg'Ub'5a dY`b'V]g GYdhYa VYf'&\$&("

9]b']bbcj Uh]j Yg'D]`chdfc'Y\_h'ni f'6YgW\`Yi b][i b['XYg'6i gj Yf\_Y\fg k]fX'VU`X']b'A ØbghYf'K ]f\_`]W\\_Y]h'' \direction Ni gUa a YbUfVY]h'a ]h'XYf FK H<'5UW\Yb'k YfXYb'Ub'XYf'K YgY`Yf'GhfU» Y'nk Y]
5a dY`Ub`U[Yb'i a [YfØghYhž'i a 'XYb'J Yf\_Y\fgZi gg']bgVYgcbXYfY ZØf'6i ggY'XYi h']W\'ni 'j YfVYggYfb'''8]YgY'\direction ]h]Uh]j Y']gh'Y]b'k Y]hYfYf GW\'f]hh'ni f'Cdh]a ]Yfi b['XYg'ÒZZYbh`]W\Yb'BU\j Yf\_Y\fg']b'XYf GhUXh'i bX'ghUfhYh'Ua 'A ]hhk cW\'ž'\&, "'5i [i gh"

8]Y'5i Za Yf\_gUa \_Y]h'f]W\hYh'g]W\'Ui Z'X]Y'?fYi ni b['K YgY`Yf GhfU\strum Y#, Y]ghghfU\strum Y'gck]Y'K YgY`Yf'GhfU\strum Y#A c`h\_YghfU\strum Yžk c'bYi Y HYW\bc`c[]Yb'ni a '9]bgUhn'\_ca a Yb'''<]YfVY]'k]fX'Yk Y]`g'Y]bY?Ua YfU'a ]h'?Øbgh`]W\Yf'\delta hY``][Ybn'f?\delta]bghU``]Yfhž'X]Y'b]W\h'bi f X]Y'5a dY`ghYi Yfi b['cdh]a]Yfhž'gcbXYfb'Ui W\'XYb'JYf\_Y\fgZi gg ØVYfk UW\h''8]Y'?Ua YfU'gcf[h'XUZØfž'XUgg'X]Y'; fØbd\UgY'ZØf 6i ggY'j Yf`\Ab[Yfh'k]fXž'k Ybb'g]W\'Y]b'@]b]YbVi g'Ui Z'XYf'6i ggdi f b\A\Yfh''8]YgY'A U\strum bU\a Y'gc``X]Y'K UfhYnY]hYb'Ub'XYb'5a dY`b fYXi n]YfYb'i bX'X]Y': U\fh[YgW\k]bX][\_Y]h'XYf'6i ggY'Yf\`O\Yb''

# $9ZZ]n]YbnghY][Yfib[`XifWX`]bhY``][YbhYHYWXb]_$

8 Ugʻ6YgcbXYfYʻUbʻX]YgYfʻHYWkbc`c[]Yʻ]ghʻX]Yʻ6U`UbWYʻnk]gWkYb XYfʻ6YgWk`Yi b][i b[ʻXYgʻ6i gj Yf\_Y\fYgʻi bXʻXYfʻA]b]a ]Yfi b[ʻXYf 5i gk]f\_i b[YbʻUi ZʻXYbʻØVf][YbʻJYf\_Y\f"`K YbbʻVY]gd]Y`gkY]gYʻY]b GhUi 'cXYf'`Ub[Y'K UfhYnY]hYb'ZØf'UbXYfY'JYf\_Y\fghY]`bY\a Yf ZYgh[YghY``h'k YfXYbž'\_Ubb'X]Y'?Ua YfU'X]Y'5bdUggi b[Yb'XYf; fØbd\UgY'Ui hca Uh]gW\'j cfbU\a Ybž'i a 'X]Y'6i ggY'b]W\h'i bbÒh][ni 'df]cf]g]YfYb"'Gc'k]fX'Y]b'nØ[][Yf'JYf\_Y\fgZ'i gg'ZØf'U``Y [Yk À\f`Y]ghYh"

8 UgʻD]`chdfc Y\_hik ]fXij cfUi gg]W\h`]W\v]gʻ9bXYʻGYdhYa VYfʻ&\$&(`Ui ZYb"`K Ybbʻg]W\iX]YʻHYghgʻU`gʻYfZc`[ fY]W\iYfk Y]gYbʻi bXiY]bYbYbbYbgk YfhYʻJ YfVYggYfi b[ iXYgʻ6i gj Yf\_Y\fgʻZYgh[ YghY``hik ]fXž\_ObbhYʻX]YgYgʻGmghYa iUi W\iUi Zʻk Y]hYfYʻGhfYW\_YbʻUi g[ Yk Y]hYh k YfXYb"'8]YʻK YgY`YfʻGhfU» Yʻgd]Y`hiY]bYʻnYbhfU`YʻFc``Yʻ]a
OZZYbh`]W\YbʻDYfgcbYbbU\j Yf\_Y\fjcbiA ØbghYfžii bXiYgʻk ]fXYfk UfhYhžʻXUggʻX]YʻbYi YʻHYW\b]\_i]bgVYgcbXYfYʻX]YʻGhUXh!ii bX

8 Ugg 'VYfY]hg'Y]bY'YfghY'HYghd\UgY'9bXY'&\$&&'j]Y'jYfgdfYWXYbXY 9f[YVb]ggY'`]YZYfhYž'gdf]WXh'ZØf'X]Y'DchYbh]U'Y'X]YgYf' +b]h]Uh]jY'' 8 Ua U'g'k i fXY'ZYgh[YghY``hž'XUgg'6i ggY'Xi fWX'X]Y'dfcj]gcf]gWX Y]b[Yf]WXhYhYb'? Ua YfU!5a dY`Ub`U[Yb'XYi h`]WX'gWXbY``Yf'ZU\fYb \_cbbhYb' 'a ]h'Y]bYf'NY]hYfgdUfb]g'jcb'ØVYf'&\$'DfcnYbh''8]YgY 9fZc`[Y'a ch]j]YfYb'X]Y'GhUXh'ibX'X]Y'FK H<'5UWXYb'XUniž'XUg DfcY\_h'kY]hYf'jcfUbnihfY]VYb''

8]Y'JYfVYggYfi b['XYf'\DZfUghfi\_hi f'gd]Y`h'Y]bY'GWX`ØggY`fc``Y']a 6YghfYVYb'XYf'GhUXhz'XYb'ÒZZYbh`]WXYb'BU\j Yf\_Y\f'UhhfU\_h]j Yf'ni [YghU`hYb'i bX'X]Y'I a k Y`hVY`Ughi b[Yb'ni 'gYb\_Yb"'8]YgY A U» bU\a Yb'\_ÒbbhYb'Ui WX'XUni 'VY]hfU[Ybz'XUgg'a Y\f'A YbgWXYb Ui Z'XYb'6i g'i a ghY][Yb'i bX'XUa ]h'XYb'\DX]j ]Xi U`j Yf\_Y\f j Yff]b[Yfb"

#### $9]b 6 ]W_]b X]Y Ni _i bZh XYg J Yf_Y fg$

 $8 \ Ug^*D]^*chdfc^*Y_h^*Ub^*XYf^*K^*YgY^*Yf^*GhfU_*Y^*]gh^*b]W^*h^*bi^*f^*Y]bY^*hYW^*b]gW^*Y^*BYi^*Yfi^*b[^*z^*gcbXYfb^*Ui^*W^*Y]b^*NY]W^*Yb^*ZØf^*XYb^*ZcfhgW^*fY]hYbXYb^*K^*UbXY^**]a^*gh^Xh]gW^*Yb^*J^*Yf_Y^*f'^*A^]h^*XYf^*\( \dagger b^*HYW^*bc^*c[^]Yb^*k^]Y^*?^?\( \delta bhY^*)^*][^Ybn^*]b^*X]Y^*J^*Y^*fgghYi^*Yfi^*b[^*-\ObbhYb^*Gh^XhY^*k^Y^*hk^Y]h^*YfbYbz^*k^]Y^*g]Y^*ZZ]n]YbhYf^*i^*bX^*i^*a^*k^YhYk^*i^*ghYf^*U[^]YfYb^*_\ObbYb''^*8]Y^*$ 

FYU\_h]cbYb^Ui Z'X]Y^YfghYb^HYghg^k UfYb^j ]Y^j YfgdfYW\YbXži bX XYf^9fZc^[ 'X]YgYg^Dfc^Y\_hg^\_ÒbbhY^UbXYfY^GhÀXhY^]bgd]f]YfYbž À\b^]W\Y^GmghYa Y^ni ^]a d^Ya Ybh]YfYb"^

 $8 ]Y `6Y hY]`][ hYb `nY][ Yb `g]WX `cdh]a ]gh]gWX \ref{equation} XYG `gh]gWX \ref{equation} XYG `gh]gWX \ref{equation} XYG `gh]gWX hYb `gh]gWX hYb `gh]gWX hYb `XYG `gh]hYb `XYG `gh]hYb `Yhyb `ghXYb `JYG Y\G `ghY\f `]bg[ YgUa h']bhY``][ YbhYf `[ YghU`hYb "5i » YfXYa `_Ubb `Yg `U`g`A cXY``dfc `Y_h`ZØf`A\b`]WXYA U» bU\a Yb `]b UbXYfYb `GhAXhYb `X]YbYb "8]Y `_ca a YbXYb `A cbUhY `k YfXYb nY][ Yb \ref{equation} X]YgYg `D]`chdfc `Y_h`hUhgAWX`]WX `]gh `i bX `k Y`WXYdcg]h]j Yb `JYfAbXYfi b[ Yb `Yg`ZØf`X]Y `Bi hnYf`XYg`ÒZZYbh`]WXYb BU\j Yf_Y\fg`]b `A ØbghYf`a ]h`g]WX `Vf]b[ Yb `_Ubb"$ 

#### HYW bc c [ ]gW Y =bbc j Uh]cb Yb ]a 2 DB J

8]Y + hY [fUh]cb 'j cb '? Øbgh']W Yf + hY ``][Ybn'fl? + i]b 'XYb

ÒZYbh']W Yb BU | Yf\_Y\f'fl DBJ L'ghY ``h'Y]bY 'VYXYi hYbXY

hYW bc `c[]gW Y + bcj Uh]cb 'XUfž'X]Y 'b]W h'bi f'X]Y '9ZZ]n]Ybn'XYf

J Yf\_Y\fggmghYa Yžgcb XYfb 'Ui W 'X]Y 'Bi hnYfYfZU\fi b[ 'Yf\YV`]W

j YfVYggYfb '\_Ubb" '8 Ug'U\_hi Y``Y'D]`chdfc Y\_h']b 'A ØbghYf']gh'Y]b

6Y]gd]Y ``XUZØfž'k]Y 'a cXYfbY 'HYW bc `c[]Yb '[Ybi hnh'k YfXYbž'i a

J Yf\_Y\fgZ ØggY 'ni 'cdh]a]YfYb" '8]YgYf'HfYbX'nY][ h'g]W 'Ui W ']b

UbXYfYb 'GhAXhYb 'k Y 'hk Y]hž'k c']bhY ``][YbhY '5a dY `gmghYa Y 'i bX

J Yf\_Y\fga UbU[Ya Ybh'Ògi b[Yb 'ni f'5bk YbXi b['\_ca a Yb"'+b

j ]Y 'Yb 'A Yhfcdc `Yb 'k YfXYb 'VYfY]hg'A\b`]W Y 'GmghYa Y '[YhYghYhž

i a 'X]Y 'FY]gYnY]h'ZØf'DYbX 'Yf'ni 'j Yf\_ØfnYb'i bX 'GhUi g'ni

fYXi n]YfYb"

8 i fW. XYb '9]bgUhn'j cb'? #[YghØhnhYb'? Ua YfUg']gh'Yg'a Ò[`]W.ž
J Yf\_Y\fgghfÒa Y']b '9W.hnY]h'ni 'UbU`mg]YfYb 'i bX'[Y[YVYbYbZU``g
5bdUggi b[Yb'j cfni bY\a Ybži a 'X]Y'J Yf\_Y\fgYZZ]n]Ybn'ni
ghY][Yfb"'8]Yg'\_ObbhY'ni \_ØbZh]['Ui Zi a ZUggYbXYfY'K Y]gY'a ]h
UbXYfYb'J Yf\_Y\fgUfhYbž'k]Y': U\ffUX!'cXYf': i »[Àb[Yfj Yf\_Y\fž
\_ca V]b]Yfh'k YfXYb"' #b'j]Y`Yb'Yi fcdÀ]gW.Yb'GhÀXhYb'k]fX'XUfUi Z
[YUW.hYhž'XUgg'gc`W.Y'HYW.bc`c[]Yb'Ui W.Y]bY
i a k Y`hZfYi bX`]W.Y'A cV]`]hÀh'i bhYfghØhnYbž']bXYa 'g]Y'ni a
6Y]qd]Y`XYb'7C&!5i qghc» 'fYXi n]YfYb"

## 9f[YVb]ggY'j Yf[Ub[YbYf'Dfc^Y\_hY'i bX'XYfYb 6YXYi hi b[

 $8 ]Y''dcg]h]j Yb''9f[YVb]ggY'XYf'YfghYb''HYghd\UgY']a "$U\f'`&$&&z'X]Y Y]bY''ØVYf'`&$!dfcnYbh][Y'; YgWk]bX][_Y]hgghY][Yfi b['ZØf'6i ggY ni f': c`[Y'\UhhYbz'g]bX'Y]b'ghUf_Yg'5f[i a Ybh'XUZØfz'XUgg'gc`WkY D]`chdfc'Y_hY'Ui Wk']b''UbXYfYb''GhÀXhYb']a d`Ya Ybh]Yfh'k YfXYb gc``hYb'''Ghi X]Yb'nY][Ybz'XUgg'YZZ]n]YbhYfY'6i g`]b]Yb'b]Wk'h'bi f'X]Y 6Ybi hnYfnU\`Yb'Yf\O\Ybz'gcbXYfb''Ui Wk'X]Y'Ni Zf]YXYb\Y]h'XYf : U\f[AghY'ghUf_'ghY][Yfb'_ObbYb'''@Ui h'XYf'? fUZhZU\fnYi [!'i bX JYf_Y\fgghUh]gh]_'XYg'6i bXYgUa hYg'ZØf'GhUh]gh]_z'g]bX'X]Y Bi hnYfnU\`Yb'XYg'^2 DBJ']b'GhAXhYb'a ]h'cdh]a ]YfhYb JYf_Y\fgZ'ØggYb']b'XYf'FY[Y`'\O\Yf'_ObbHY'''8]Yg'j YfXYi h`]Wk'h'X]Y gcn]U`Y'i bX'k ]fhgWk'UZh`]Wk'Y'6YXYi hi b['gc`Wk'Yf'\b)]h]Uh]j Yb'ZØf 6Øf[Yf'i bX'GhUXhj'Yfk U`hi b[Yb'[`Y]Wk'Yfa U\b'Yb''$ 

8]Y '9fZU\fi b[Yb'Ui g'X]YgYb'DfcY\_hYb'\_ObbhYb'gc[Uf ghfUhY[]gW\Y'F]W\hi b[gk Y]gYb'ZØf'ni \_ØbZh][Y'=bj Ygh]h]cbYb']b'X]Y =bZfUghfi \_hi f'XYg'^2 DBJ'V]YhYb'i bX'XUni 'VY]hfU[Ybž'XUgg'Gh\XhYbUW\\U'h][Yf'i bX'UhhfU\_h]j Yf'ZØf']\fY'9]bk c\bYf'k YfXYb'''9]bhfUbgdUfYbhYg'A cb]hcf]b[ii bX'i a ZUggYbXY'8UhYbYf\YVi b[k\A\fYbX'XYg'[YgUa hYb'DfcY\_hg'\_ObbhYb'XUni 'VY]hfU[Ybž'Ub[Zf]gh][Y'D`Ubi b[Yb'i bX'9fk Y]hYfi b[Yb'a]h'k Yfhj c``Yb9f\_Ybbhb]ggYb'ni ii bhYfghØhnYb''

8 YhU1`a

6 Ygi W Yb G]Y i bg Ui Z b!U[ "XY