

1 DMXUDOZ DMU VKHUP DO UDGLDMRQ DVD J LJ DKHUM I UHTXHQA

6HJH 1 * DYUQQ

ORVFRW B VHYHRU L VQQ L QHHUL Q < DUR VO D YKRN R VHR V F B Z V V L D

\$ E V W U D K F W D G L D W L R Q G W H S P H S G B C D D A K Z D W L E D V K H
 W H P S H U D D V Q R J H H G H J U B H V Z V B V [S H U L P H Q W D O O \
 L Q Y H V W [S B W L F P H V Q X Z H C F H D U R I X N G L Q D G L R Z P H W K H U
 F H Q W U H D T O X H Q F +] 7 K H O X F W X D K W I H R C V R H Q G L M L Y L W \
 U D G L R Z P H W T X U D O Z L W K R Q V W H C C D W D M R L M R B H U G R H U
 R Q V H F R T C K G V K H U P R G Z Q D V M P H U P S H Z D W X D V X E U D I G
 F R Q W D K F W P R L P H W H I M O V G Z H W F R L D X P K Q P H D V X U H P H Q W V
 Z H U F H U R L X N G W G R T O P E L W G P S H B D W R X V H J U H H V
 & H O V S L Q R W L E H D F E B H D Y G E L R J K W Q P S V W U D E V R X U V H
 Z D G H W H L Q W H G H J U S H H O W L X P S H U D Q Z K H K D O L W D W L Y H
 F R L Q F L R G I W G H I S H U L F G D O W D W K H R U R Q M I D F O F O X O D W H G
 X V L Q J G H W R J U R L Q B V G H P R Q V W K U B E V M G E R L H G F L R G H Q F H
 H [S H U L F G D O W D W K H R U G D V M D N H O V R V V W R Z H H D D V G H G
 F R R Q Z H G M B U H D W H U P D D Q G D Q B G W K H R P L O O L P H W H U
 Z D Y H O H D Q W H K Q Q D E U Q V G H R F R Q G L T K L R D Q R R Q W U D V W
 Y D O R K I W K U H G L D W L R Q G W H S P H S G B C D D A K Z D W L E D V K H
 X Q G V H W X P E D N H B R V V W B O H W W H F M V Y P D D Q D R W W K Q G U R
 R E M N R K W M S F H L V Q L F L F O V R W D Z B W W H K H U P D Q D Q W K R Q
 U D Q R H J L J D K H U H T J X I F Q E H X V H G Z D W P R U Q L W B Q G Q J
 D F K L H Y R I P H K O W L U R Q R N Q W D R O I E W D O H W W O H P H Q W V
 . H \ Z R U Z B V W H T S H U L W H R S V H W D K M X U D B G D W L R Q

, Q W U R G X F W L R Q

: DMU D V D N H H O P H Q A R I D Q H F R O U L F O D X W A P L V W H V E M F A R I U H V D J K 2 Q H R I W H
 P D Q S U R S H W H V R I Z D M U L V L W D E L O W V R H P L V H O F W R P D J Q W F Z D Y H V L Q D Z I G H I U H T X C F
 U D Q J H W H U P D O U D G L D M R Q 7 K H V S F I L F I H D M U H R I Z D M U V R Z Q U D G R H P L W L R Q L V W H
 H W H Q W D C R Q D Q D U C D M U H R I W H G S H Q G C F H R I W H Z D M U U D G R E U J K Q H V W P S H U D M U H
 I U R P W H Z D M U W H U P R G C O P I F W P S H U D M U H 7 K H Z D M U U D G L D M R Q W P S H U D M U H G S H Q G C F H
 > @ J L Y H S R W E L O W V R G H M U P I G H Z D M U S D U P H M U / G H O F W I F F R Q M D O W W P S H U D M U H
 V O Q Q W E D H G R Q W H U X O V R I U P R M P H D X U P H O W > @ 7 K H S U R F W R I Z D M U U D G R
 H P L W L R Q L V D Q I P S R U D Q V S D V R I W H J H C H U D O S U R F W R I W H U P D O D Q G P D V H J F C Q J H R Q W H
 D U Z D M U V X U D F H > @ 7 K H Z D M U U D G L D M R Q W P S H U D M U H G S H Q G C F H J L Y H S R W E L O W V R V R O H
 V R P H D S S O H G S U R E O P V R I Z D M U D U H C H U \ H J F C Q J H > @ I G H M L Q J U D G R E U J K Q H V
 F R Q M D W R I K I G R R E M F W X U D F H V > @ 7 K H S X L S R H R I W M V Z R U N L V D Q H J S H U P H Q D O W G

& R U U H V S R K O V C R O U L L O L Q 6 1 # P J V X U X

RI VNH UGDNRQ WP SHDMUH G-SGG-QFH DAD I UHTX-HCF f * +] LQ VNH WP SHDMUH
UDQJHW . H&

0 D W H U L O D G H W K R G V

7KH RU

7KHEUJ KQH WP SHDMUH RI VNH Z DMU XUJDFH UGDNRQ LQ GHV LQ GE VNH UDNR > @

$7_{Euf} \mathbb{W}. \quad 7_{H1} > 5 f \mathbb{W}. \quad @ 5 f \mathbb{W}. \quad 7_{\S} .$

ZKHU

$$7_{H1} \int_0^{\infty} \gamma T(z) \exp\left[\int_0^z \gamma dz\right] dz$$

ZKHU

$5 f \mathbb{W}. \quad \pm VNHUH QFWRQFRH I LFLQ/RI VNH XUJDFH$

f, t^0 VNHDEVLSWRQFRH I LFLQ/RI HGFWRP DJQHWF UGDNRQ LQZ DMU

$7_{\S} .$ VNH WP SHDMUH RI DWR/SKHUF UGRI HP LWRQ

$T(z)$ VNHGHS SURLO RI Z DMU WP SHDMUH

. $\pm VNHQJ QHVR VNHKRUI RQ$

: LK YHUVFOMP SHDMUH SURLO

7] 7 FRQW

HIFWYHWP SHDMUH

7_{H1} 7

DQGH SUHWRQ VNH/VNHIRUP

$7_{Euf} \mathbb{W}. \quad 7 > 5 f \mathbb{W}. \quad @ 5 f \mathbb{W}. \quad 7_{\S} .$

\$ PP VNFN Q HU LV IRUPHG XCGU VNH XUJDFH RI VNH Z DMU ZKFK LV FDDG D
WP SHDMUH Q HU > @ 7KH WP SHDMUH Q HU RQ VNH Z DMU XUJDFH DUVV GX VR XUJDFH
WQMRQ IRUFV 7KH YHUVFOMP SHDMUH GLVWEXWRQ LQ VNH Z DMU Q HU 7] G-SGGV RQ
VHYUDOSDUP HMLV DU WP SHDMUH > @Z DMUJEXON WP SHDMUH > @KDV DQGP DWI QZ
D/VNH DUZ DMUJEXON > @7KH DP RXQ/RI K-DVNDQ HUD/VNH Z DMU DUJLQMUJDFH LV
SURSRWRQDOR JUDG 7]

7KH YHUVFOMP SHDMUH GLVWEXWRQ LQ VNH XUJDFH Q HU 7] G-SGGV RQ VNH UDNR RI DU
WP SHDMUH DQGP Z DMUJEXON WP SHDMUH 7KH WSHRI WP SHDMUH GLVWEXWRQ XCFWRQ 7]
LV NCRZ Q IRU VRP H H SHUP HQDDFRQGVWRQ/ ' HMLP LQDQ 7] JHCHDQ LV D FRP SQI
SK VIFDQSUREP

7KHUP DQGFWRP DJQHWF HP LWRQ > @VIRUP HG LQ D Q HUCQP HGDVNLQ Q HU /
7KH VNLQ Q HUGHMLP LQV/VNH YRXP HIURP ZKFK HGFWRP DJQHWF Z DYH/DUHIP LWWG 7KH
G-SK RI VNH VNLQ Q HULV/LQYHUFQ SURSRWRQDOR VNHDEVLSWRQFRH I LFLQ/RI VNH HP HGXP

γ \$ EVRLSWRQFRHILFHQV G-SHG/RQVHIUHTX-QF RI VHIHP LVMGHDFWRP DJQWIF ZDYH
DGGVHVMHZ DMUJMP SHUDMUHV

$$\delta = \frac{1}{\gamma(f, t^0)}, \quad (4)$$

7KHDEVRLSWRQFRHILFHQV

$$f, t^0 \frac{4\pi f}{c}, P, 0f, t^0$$

$0f, t^0$ VHGHDWFNIF FRQMDQVRI VHIHPGLXP

7KHGHDFNIF FRQMDQV @QVHIIRUP RI VHI' HE HHTXDNRQLV> @

$$0 \epsilon_{\infty} \frac{\epsilon_0 - \epsilon_{\infty}}{1 - i2\pi\tau f} \frac{1}{2\pi\sigma_0 f}$$

ZKHUH> @

ϵ_0 VDMF GHDFNIF FRQMDQV

ϵ_{∞} KLJKIHTX-QF GHDFNIF FRQMDQV

$\tau \pm$ UHQI DNRQWP HVF

f IHTX-QF RI VHZDYH

σ_0 SHUPHDELQVRI IUHVDFH

σ LRQF FRQGFVWLVW

F VSHGRI QKWLQYDFXP

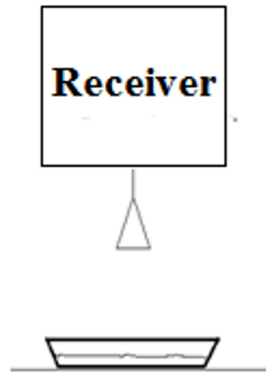
\$ QHWMP DMRI VHVNLQD HVMFNQHW/ DIHTX-QF RIF * +] IRUCDMUDQZ DMU
JLYHV VHYHODVQV/ RI D PLOP HNU 7KH VLENQHW RI VHI WP SHUDMUH QD HJLV VHYHOD
PLOP HNU/ 7KHUHUH UGGR HP LVRQRI ZDMUDVWJDKHVJVIHTX-QFHV/VRUP HGZLVMLQD
WP SHUDMUHQ HUKDYLQ DVMFNQHWRI DIHZ PLOP HNU/XCG-UVHV-FULHGFRRQVQV/

\$ VFDQEHVHQIURP VHIUDGREULJKQHW/WP SHUDMUH_{br} LV LQJHQHODDIXQFWRQ
RI VHI WP SHUDMUH RI VHI PGLXP 7KH HIFVYH FRQYHULRQ RI VHI VHIUP RG QDP LF
WP SHUDMUH RI VHI PGLXP VR VHI UGGR EUJKQHW WP SHUDMUH LV FKUDFNUJ HG E D
UDGDNRQWP SHUDMUH G-SHG-QFH DGG/LV G-HVUEHG E VHI GHULYDHYH $\frac{\partial T_{br}}{\partial T}$ 7KHFDQXDMRQ
RI VLVYDQXHV/GIIFXQVGHVRLQMIIFHQVQVRUP DNRQDERXVHI WP SHUDMUHSURLOH7] LQ
VHVXUDFHQD HUXQGHUJ SHUP HQVFRQWRQV/

7KH EUJKQHW WP SHUDMUH ZDV FDQXDMG XCG-U VHI DMXP SWRQ RI DQ LVRMHP DO
YHVFDQWP SHUDMUHSURLOH 7KHGHDFNIF FRQMDQV ZDVFDQXDMGXVQV VHVVRUULQP RG-H
> @

0 HMRG

\$ QH SHUPHQDDVMG RI VHI WP SHUDMUH UGGRQV G-SHG-QFH ZDV SHURUP HG DWD
IHTX-QF RI $f = 37.5$ * +] ZLVK D KRLQ DQMDQD QP HG DVMH QDGLU + RVZ DMUZLVK D
WP SHUDMUHRI DERXV f & ZDVSRXUHGQRDIRDP FXYHVV

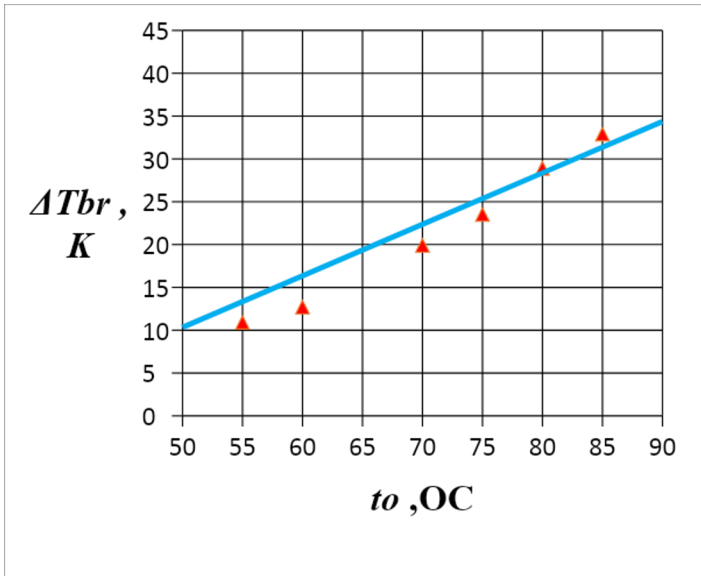


) L J 7 K M F K H P L Q V W X Y Z A B C D E F G H I J K L M N O P Q R S T U

0 H X U P H Q V R I V H U D G R E U J K Q H W V P S H D M U H Z H U H F D U I G R X V G X U I Q I V H F R R O J R I
 V H Z D M U V H W P S H D M U H R I Z K L K Z D V F R Q U R O G D W U F D U H X O P I Q J 7 K H I H U R O M H O
 U H D M Y H V R Z K L K V H E U J K Q H W V P S H D M U H L C F U P H Q V Z D V F D G X O M G Z D V I I Q H G E V H
 E U J K Q H W V P S H D M U H R I V H Z D M U D V P E I H Q V D U M P S H D M U H ^{air} = 24 °C 7 K H I O F M D M R Q
 V H U K R G R I V H U F H Y L Q I H T X L S P H Q V V H Q M Y L W Z D V V P H F R Q M D Q A 2 V F
 ' X U I Q I V H H S H U I P H Q V V H V J C O Z D V U F F R L G L Q U H D M R Q V R V H W P S H D M U H R I V H
 F D E U D M R Q W D G E L G 7 K H U F F R L G L Q I R I V H V J C O V R N S O F H Z L M L Q R C H P L Q X M 7 K H
 F D G X O M G U D G R P H U R U R I V H H S H U I P H Q V Z D V 7 K H H M P D M R I V H X V M P D M F H U R U
 Z D V D G Z D V G H M P L Q G S U I P D U I O E V H P H X U P H Q V H U R U R I V H U H U Q F H
 V P S H D M U H 7 K H L Q M Q W R I V H U F F L Y G U D G D M R Q Z D V F D E U D M G E E O F N E R G U D G D M R Q

5 H V X O W V

7 K H U H X O V D U H V K R Z Q I Q V H J U D S K I Q) L J



) L J 7 K I G H S H Q G H V Q E H L J K W E F S M B D M K Z H W H H P S H U D R V O L L G H
W K H R D U V N H H U S H U L F H R Q V E O V H O X W K R U

\$ V F D Q E H V H Q I U R P V H J U D S K Q R W F D E H L C F U D H I L Q U D G R F R Q U D W V G H M F M G D V Z D M U
W P S H U D M U H V W O V Q J I U R P W H & 7 K H U D G D M R Q W P S H U D M U H G S H Q G Q H L Q W H
W P S H U D M U H U D Q J H I U R P f & V R f & Y O U H G D V

$$\frac{\partial T_{br}}{\partial T} \left[\frac{K}{^{\circ}C} \right]$$

' L V F X V V L R Q

7 K H H S H U P H Q V G P R Q M D M V D V J Q I L F D Q V F K D Q J H L Q W H L Q M Q M V R I Z D M U W H U P D O
U D G D M R Q L Q W H W H U P R G Q D P I F W P S H U D M U H U D Q J H R I G H U H V & H O L X V Z L K D J U D G H Q V
R I X S V R . H O Y L Q S H U G H U H H

, W K R X G E H G R M G W D V R U V P D O U M P S H U D M U H V X F K D Q L Q M Q M V F K D Q J H F D Q E H D O P R W
W Q W P H V P D O U

7 K H H S H U P H Q V G P R Q M D M V D P R C R A R C R X V L C F U D H I L Q U D G R E U J K Q H W W P S H U D M U H
Z L K D Q L C F U D H I L Q W H U P R G Q D P I F W P S H U D M U H , W K R X G E H G R M G W D V R U R M H U Z D M U
W P S H U D M U H U D Q J H V W H G S H Q G Q H L V Q R W D Z D V P R C R A R C R X V 7 K X V I R U O Z H U
W P S H U D M U H V W H G S H Q G Q H F D Q G P R Q M D M D U H D V R I G F U D H I L Q U D G R E U J K Q H W
W P S H U D M U H Z L K D Q L C F U D H I L Q W H U P R G Q D P I F W P S H U D M U H 7 K H S U H M Q F H R I V X F K K X P S V
T X D O M Y H D F R U H S R Q G V R W H V M R U H M F O P R G H R I 6 V R U L Q

\$ V J Q I L F D Q V F K D Q J H R I W H Z D M U U D G R E U J K Q H W W P S H U D M U H Z L K D F K D Q J H R I
W H U P R G Q D P I F W P S H U D M U H F D Q V H Y H D V D E D M V I R U G H M F M Q J R I Z D M U R E M F W W P S H U D M U H
D Q R P D O H V

7 K H K J K V H Q M Y L W D G G V K R W H S R Q H W P H R I W H H S H U P H Q V D V H D O Z V V R U F R L G
F K D Q J H V R I W H Z D M U R E M F W W P S H U D M U H Z L K K J K D F X U F L Q W H J L D K H U M I U T X H Q F
U D Q J H

& R Q F O X V L R Q V

([S H U P H Q V D W X G R I W H Z D M U E U J K Q H W W P S H U D M U H G S H Q G Q H R Q W H W H U P R G Q D P I F
W P S H U D M U H I R U C D M U D O Z D M U L Q W H W P S H U D M U H U D Q J H R I G H U H V & H O L X V V K R Z V D
Q R W F D E H L C F U D H I R I Z D M U E U J K Q H W W P S H U D M U H V M O D D E R X W . H O Y L

: D M U E U J K Q H W W P S H U D M U H F D Q E H G H M F M G D M L J D K H U M I U T X H Q F H V Z L K K J K V H Q M Y L W
L Q W H W H U P R G Q D P I F W P S H U D M U H U D Q J H I U R P f & V R f & D V G P R Q M D M G L Q W H
H S H U P H Q V

7 K H R U H M F O H W P D M V K R Z W D W H C D M U D O Z D M U W H U P D O U D G D M R Q L Q W H J L D K H U M
U D Q J H L V I R U P H G L Q W H V N L Q O H U 7 K H M L E N G H W R I W H V N L Q O H U L V O W V M Q W H M L E N G H W
R I W H Z D M U W P S H U D M U H O H U

7 K H R E M L Q G G S H Q G Q H R I W H E U J K Q H W W P S H U D M U H R I Z D M U R Q W H W H U P R G Q D P I F
W P S H U D M U H P D N H L V S R W E G H V R X V H K D M G D G F R R O G Z D M U V R F U D M W H U P D O W D Q E D U G
I R U F D O E D M Q D M M O D V D M L J D K H U M I U T X H Q F H V L Q W H I L H G F R Q G W R Q V

7 K H H S H U P H Q V G P R Q M D M V W H S R W E L Q W R I Z D M U W H U P D O D Q R P D O H V U P R M
G H M F M R Q L Q W H J L D K H U M I U T X H Q F U D Q J H

5 H P R M P R Q V R U L Q J R I W H L Q M Q M V R I Z D M U V R Z Q W H U P D O U D G D M R Q L Q W H J L D K H U M
U D Q J H F D Q E H X V H D V D V R O I R U G H M F M Q J R I G H Y D M R Q V R I Z D M U R E M F W W P S H U D M U H I U R P
W O Q E D U G Y O D H V 5 H P R M P R Q V R U L Q J R I Z D M U W M P H Q V L Q W H J L D K H U M I U T X H Q F U D Q J H

FDQ EH DQ DGGVRCDDIQWXP HQVRI P RQVRIUQJ VNH Z DMU VDM DGG VR FRQVEXM VR VNH
DKLHYHP HQVRI VVMDCEGIGYHPS HQVRI FVWV DGG VHWBP HQV

5 H I H U H Q F H V

6 1 * DYUQQ - 3K V &RQ 6HU

KMSV LRSVLFHQHRS RJ DVNFOH SG

6 1 * DYUQQ (6 : HERI &RQ

KMSV GLRUJ H VFRQ

6 1 * DYUQQ (QJ - RI ' RQ

KMSV LYGRQUX HQP DJD LQH DJFKLYHQ \

4. 6 1 * DYUQQ 1 \$ 3DUHQMHD 1 \$ 3DUHQMH , ' % NRYND D (6 : HERI
&RQ

KMSV GLRUJ H VFRQ

5. , 7 %XENQ . 6 6VQNHLEK - &RPPXQ 7HFQRO (QVFRQ

KMSV GLRUJ 6 ;

6. , 7 %XENQ . 6 6VQNHLEK - &RPPXQ 7HFQRO (QVFRQ

KMSV GLRUJ 6 ;

6 =HCFKQR 7UDQVFRQ/RI VNH. U QY 6VDM5 HVDFK &HQNH ±

KMSV HDEVSEWUX GONUF SG GRZ QBDG

- %RMDQVDD ,(((7UDQV * HRVFL 5HP RM6HQV

KMSV GLRUJ 7* 56

< =KRX 5 + / DJJ (3 ' LQDWDGG' 0 / H9LQH ,(((7UDQV * HRVFL 5HP RM
6HQV

KMSV GLRUJ 7* 56

' 0 / H9LQH 5 + / DJJ < =KRX (3 ' LQDWDGG 7 0 HVXCHU ,(((7UDQV * HRVFL
5HP RM6HQV

KMSV GLRUJ 7* 56

1 5HXCHVDD 5HP RM6HQV (QYLRQ

KMSV GLRUJ MVH

* &DVRQH - 6SRCHU 6 7UXWR) 6DND 3K V &KHP &KHP 3K V ±

KMSV GLRUJ F FS G

(3 ' LQDWD 0 / 9LQH - %RMD 7 0 HVXCHU * / DJHQB 5HP RM6HQV

KMSV GLRUJ U/

' 0 / 9LQ (3 ' LQDWD 5HP RM6HQV

KMSV GLRUJ U/

3 - : ' HEH 3RDUO RQFXOV 1 HZ <RDN 1 < 86\$ 7KH &KHP LFDD &DQDQJ
&RP SDQ

KMSV RSHQDQD RJ ERRN/2/ 0 3RDUBP RQFXOV

\$ 6VWUQ,(((7UDQ/O LFURZ 7K-RU 7HKQ 0 77
KMSV GRLRJ 70 77
%XENLQ, 7 6VQNHFK. 6 - &RPPXQ 7HKCRO(QFWRQ ±
KMSV GRLRJ 6
18. 36 5D \$SSQHG2 SMFV
KMSV GRLRJ \$2
/ . QIQ & 6ZUW,(((7UDQDFWRQ/RQ\$ QMGQV/DG3URSDJDMRQ
KMSV GRLRJ 7\$3
\$ 6VWUQ,(((7UDQDFWRQ/RQ0 LFURZ DYH7K-RU DQG7HKQTXH
KMSV GRLRJ 70 77