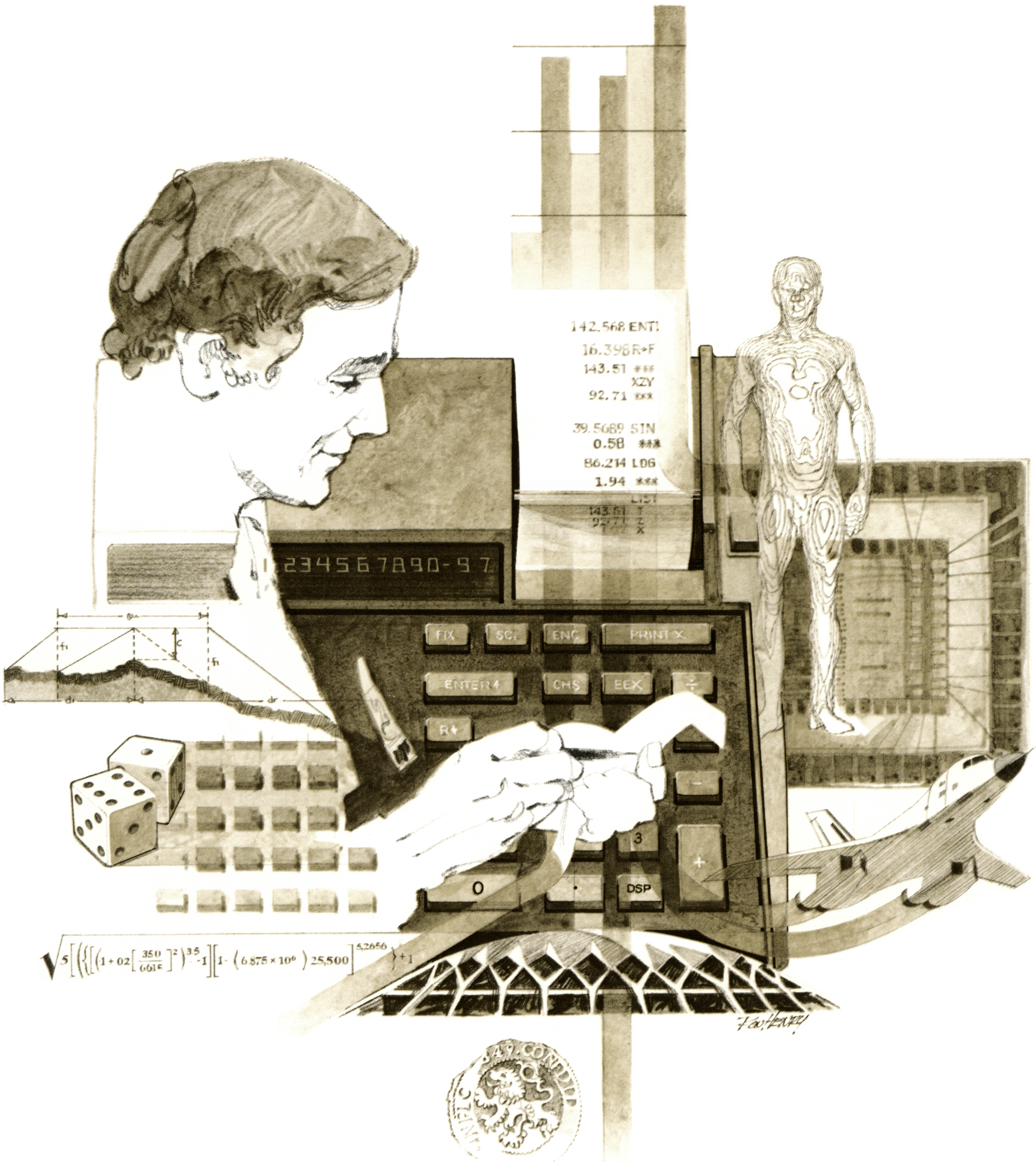
HEWLETT-PACKARD

HP-67/HP-97

Users' Library Solutions

Earth Sciences



INTRODUCTION

In an effort to provide continued value to it's customers, Hewlett-Packard is introducing a unique service for the HP fully programmable calculator user. This service is designed to save you time and programming effort. As users are aware, Programmable Calculators are capable of delivering tremendous problem solving potential in terms of power and flexibility, but the real genie in the bottle is program solutions. HP's introduction of the first handheld programmable calculator in 1974 immediately led to a request for program **solutions** — hence the beginning of the HP-65 Users' Library. In order to save HP calculator customers time, users wrote their own programs and sent them to the Library for the benefit of other program users. In a short period of time over 5,000 programs were accepted and made available. This overwhelming response indicated the value of the program library and a Users' Library was then established for the HP-67/97 users.

To extend the value of the Users' Library, Hewlett-Packard is introducing a unique service—a service designed to save you time and money. The Users' Library has collected the best programs in the most popular categories from the HP-67/97 and HP-65 Libraries. These programs have been packaged into a series of low-cost books, resulting in substantial savings for our valued HP-67/97 users.

We feel this new software service will extend the capabilities of our programmable calculators and provide a great benefit to our HP-67/97 users.

A WORD ABOUT PROGRAM USAGE

Each program contained herein is reproduced on the standard forms used by the Users' Library. Magnetic cards are not included. The Program Description I page gives a basic description of the program. The Program Description II page provides a sample problem and the keystrokes used to solve it. The User Instructions page contains a description of the keystrokes used to solve problems in general and the options which are available to the user. The Program Listing I and Program Listing II pages list the program steps necessary to operate the calculator. The comments, listed next to the steps, describe the reason for a step or group of steps. Other pertinent information about data register contents, uses of labels and flags and the initial calculator status mode is also found on these pages. Following the directions in your HP-67 or HP-97 **Owners' Handbook and Programming Guide,** "Loading a Program" (page 134, HP-67; page 119, HP-97), key in the program from the Program Listing I and Program Listing II pages. A number at the top of the Program Listing indicates on which calculator the program was written (HP-67 or HP-97). If the calculator indicated differs from the calculator you will be using, consult Appendix E of your **Owner's Handbook** for the corresponding keycodes and keystrokes converting HP-67 to HP-97 keycodes and vice versa. No program conversion is necessary. The HP-67 and HP-97 are totally compatible, but some differences do occur in the keycodes used to represent some of the functions.

A program loaded into the HP-67 or HP-97 is not permanent—once the calculator is turned off, the program will not be retained. You can, however, permanently save any program by recording it on a blank magnetic card, several of which were provided in the Standard Pac that was shipped with your calculator. Consult your **Owner's Handbook** for full instructions. A few points to remember:

> The Set Status section indicates the status of flags, angular mode, and display setting. After keying in your program, review the status section and set the conditions as indicated before using or permanently recording the program.
>
> REMEMBER! To save the program permanently, **clip** the corners of the magnetic card once you have recorded the program. This simple step will protect the magnetic card and keep the program from being inadvertently erased.

As a part of HP's continuing effort to provide value to our customers, we hope you will enjoy our newest concept.

TABLE OF CONTENTS

Program Description I

Program Title Earthquake Magnitude - Energy Conversion

Contributor's Name Hewlett-Packard

Address 1000 N.E. Circle Blvd.

City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables

Given an Earthquake Magnitude, compute the energy in ergs

Richter Energy equation: $\text{Log } E = 11.3 + 1.8\ M$

Hodgson Energy equation: $\text{Log } E = 11.4 + 1.5\ M$

Gordons Energy equation: $\text{Log } E = 12.2 + 1.44\ M$

} E (ergs)

In addition the program converts from ergs to:

B.T.U. = Ergs * 9.4805×10^{-11}

ft-lbs = Ergs * 7.3756×10^{-8}

Joules = Ergs * 1×10^{-7}

Operating Limits and Warnings None.

Program Description II

Sketch(es)

Sample Problem(s)

1. Find the energy in a magnitude 6 Earthquake.

2. Using Richter's equation convert from ergs to B.T.U.s, ft-lbs and joules.

Solution(s)

1. 6[D][A] → 1.258925412 + 22
   [B] → 2.511886431 + 20
   [C] → 6.918309709 + 20

2. 1.258925412 [EEX] 22 [E] → 1.193524237 + 12
   [R/S] → 9.285330269 + 14
   [R/S] → 1.258925412 + 15

Reference(s) This program is a modification of the User's Library Program No. 00430A, submitted by G. B. Young, 2550 Yeager Rd. Apt. 19-3, W. LaFayette, Ind. 47906.

Jacobs, J.A., R.D. Russell and J.T. Wilson, Physics and Geology 2nd ed, McGraw-Hill, International Series in the Earth And Planetary Sciences.

Hodgson, J.H., Earthquakes and Earth Structure, Prentice Hall, Inc. 1964

Schaums Outline Series, Mathematical Handbook of Formulas and Table.

User Instructions

EARTHQUAKE MAGNITUDE - ENERGY CONVERSION

1 ◀ ▶ 2

RICHTER | HODGSON | GORDON | MAGNITUDE | CONVERT

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter Magnitude	Magnitude		D	Magnitude
2	Calculate Richter Energy		A		
	Calculate Hodgson Energy		B		
	Calculate Gordons Energy		C		
3	Energy Conversion	Energy/ Ergs	E		Energy/ B.T.U
			R/S		Energy/ ft-lbs
			R/S		Energy/ Joules
	To obtain ergs go to "2"				
	to enter new magnitude go to "1"				

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLD	21 14	Magnitude
002	SCI	-12	
003	DSP9	-63 09	
004	STO2	35 02	
005	RTN	24	
006	*LBLA	21 11	Richter
007	1	01	
008	1	01	
009	.	-62	
010	3	03	
011	STO1	35 01	
012	1	01	
013	.	-62	
014	8	08	
015	STO4	35 04	
016	GTO9	22 09	
017	*LBLB	21 12	Hodgson
018	1	01	
019	1	01	
020	.	-62	
021	4	04	
022	STO1	35 01	
023	1	01	
024	.	-62	
025	5	05	
026	STO4	35 04	
027	GTO9	22 09	
028	*LBLC	21 13	Gordon
029	1	01	
030	2	02	
031	.	-62	
032	2	02	
033	STO1	35 01	
034	1	01	
035	.	-62	
036	4	04	
037	4	04	
038	STO4	35 04	
039	*LBL9	21 09	
040	ENT↑	-21	
041	RCL2	36 02	
042	×	-35	
043	RCL1	36 01	
044	+	-55	
045	10^x	16 33	
046	ENT↑	-21	Energy (Ergs)
047	STO3	35 03	
048	PRTX	-14	
049	RTN	24	
050	*LBLE	21 15	
051	STO3	35 03	
052	9	09	
053	.	-62	
054	4	04	
055	8	08	
056	0	00	

STEP	KEY ENTRY	KEY CODE	COMMENTS
057	5	05	
058	EEX	-23	
059	1	01	
060	1	01	
061	CHS	-22	
062	×	-35	
063	STO5	35 05	Energy (B.T.U.mean)
064	PRTX	-14	
065	R/S	51	
066	RCL3	36 03	
067	ENT↑	-21	
068	7	07	
069	.	-62	
070	3	03	
071	7	07	
072	5	05	
073	6	06	
074	EEX	-23	
075	8	08	
076	CHS	-22	
077	×	-35	
078	STO6	35 06	Energy (ft-lbs)
079	PRTX	-14	
080	R/S	51	
081	RCL3	36 03	
082	ENT↑	-21	
083	1	01	
084	EEX	-23	
085	7	07	
086	CHS	-22	
087	×	-35	
088	STO7	35 07	Energy (Joules)
089	PRTX	-14	
090	R/S	51	
091	RTN	24	
092	R/S	51	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	2

REGISTERS

0	1	2	3	4	5	6	7	8	9
	Used	Magnitude	Energy Ergs	Used	Energy B.T.U.	Energy ft-lbs	Energy Joules		

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title P and S Seismic Wave Velocity Determination

Contributor's Name Hewlett-Packard

Address 1000 N.E. Circle Blvd.

City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables

$$\text{P Velocity} = \sqrt{\frac{4/3\ \mu + \beta}{\rho}}$$

$$\text{S Velocity} = \sqrt{\frac{\mu}{\rho}}$$

μ = Shear modulus (dynes/cm^2)

β = Bulk modulus (dynes/cm^2)

ρ = Density (gm/cm^3)

P Velocity = Compressimal wave velocity (cm/sec)

S Velocity = Shear wave velocity (cm/sec)

Conversion to km/sec = cm/sec * 0.00001

ft/sec = cm/sec * 0.032808399

Operating Limits and Warnings Density can not be zero.

Program Description II

Sketch(es)

Sample Problem(s) Given:

Density = 3.28 gm/cm^3

Bulk Modulus = 1.27 x 10^{11} dynes/cm^2

Shear Modulus = 1.18 x 10^{12} dynes/cm^2

1) Compute

V_p and V_s (cm/sec)

2) Convert to (kilometers/sec)

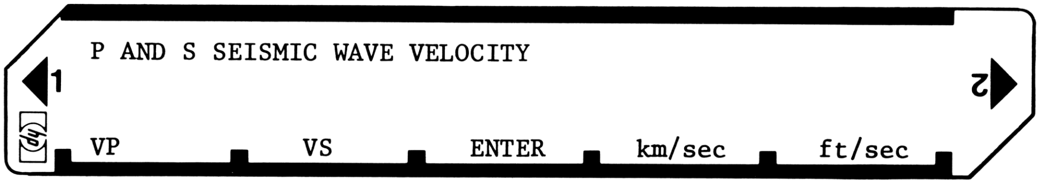
3) Convert to (ft/sec)

Solution(s)

1)	3.28 [ENTER ↑]	→	3.28000
	1.27 [EEX] 11 [ENTER ↑]	→	1.270000000 11
	1.18 [EEX] 12 [C]	→	3.28000
	[A]	→	719996.0478 ***
	[B]	→	599796.7136 ***
	[D] [A]	→	7.19996 ***
	[B]	→	5.99797 ***
	[E] [A]	→	23621.91761 ***
	[B]	→	19678.36990 ***

Reference(s) This program is a modification of the Users' Library Program No. 00879A, submitted by G. B. Young .

User Instructions



STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter Program				
2	Enter Density	gm/cm^3	Ent↑		Density
	Enter Bulk Modulus	$dynes/cm^2$	Ent↑		Bulk modu.
	Enter Shear Modulus	$dynes/cm^2$	C		Shear Modulus
3	Calculate V_p		A		V_p (cm/sec)
	Calculate V_s		B		V_s (cm/sec)
4	Convert to km/sec (V_p)		D	A	V_p(km/sec)
	Convert to km/sec (V_s)			B	V_s(km/sec)
5	Convert to ft/sec (V_p)		E	A	V_p(ft/sec)
	Convert to ft/sec (V_s)			B	V_s(ft/sec)
	To change units, go to 3 or 4 or 5.				
	To load new data, go to 2.				

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLC	21 13	
002	DSP5	-63 05	
003	STO3	35 03	Shear Modulus
004	R↓	-31	
005	STO2	35 02	Bulk Modulus
006	R↓	-31	
007	STO1	35 01	Density
008	SF1	16 21 01	
009	SF2	16 21 02	
010	RTN	24	$V_p = \sqrt{\frac{4/3\ \mu + \beta}{\rho}}$
011	*LBLA	21 11	
012	1	01	
013	F1?	16 23 01	
014	STO4	35 04	
015	SF1	16 21 01	
016	RCL3	36 03	
017	ENT↑	-21	
018	4	04	
019	×	-35	
020	3	03	
021	÷	-24	
022	RCL2	36 02	
023	+	-55	
024	RCL1	36 01	
025	÷	-24	
026	√X	54	
027	ST×4	35-35 04	
028	RCL4	36 04	
029	PRTX	-14	
030	RTN	24	
031	*LBLB	21 12	$V_S = \sqrt{\mu/\rho}$
032	1	01	
033	F2?	16 23 02	
034	STO5	35 05	
035	SF2	16 21 02	
036	RCL3	36 03	
037	ENT↑	-21	
038	RCL1	36 01	
039	÷	-24	
040	√X	54	
041	ST×5	35-35 05	
042	RCL5	36 05	
043	PRTX	-14	
044	RTN	24	
045	*LBLD	21 14	km/sec
046	CF1	16 22 01	
047	CF2	16 22 02	
048	.	-62	
049	0	00	
050	0	00	
051	0	00	
052	0	00	
053	1	01	
054	STO4	35 04	
055	STO5	35 05	
056	RTN	24	
057	*LBLE	21 15	ft/sec
058	CF1	16 22 01	
059	CF2	16 22 02	
060	.	-62	
061	0	00	
062	3	03	
063	2	02	
064	8	08	
065	0	00	
066	8	08	
067	3	03	
068	9	09	
069	9	09	
070	STO4	35 04	
071	STO5	35 05	
072	RTN	24	
073	R/S	51	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	5

REGISTERS

0	1	2	3	4	5	6	7	8	9
	Density (gm/cm^3)	Blk Mod $dynes/cm^2$	Shear/mod $dynes/cm^2$	V_p	V_s				

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title ELECTROMAGNETIC SEISMOGRAPH FREQUENCY RESPONSE

Contributor's Name Hewlett-Packard

Address 1000 N.E. Circle Blvd.

City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables Equations of motion of coupled seismometer and galvanometer:

$$\ddot{\theta} + 2\lambda_s\omega_s \dot{\theta} + \omega_s^2 \theta = \frac{1}{\ell} \ddot{u} + 2\lambda_s \omega_s \sigma_s \dot{x}$$

$$\ddot{x} + 2\lambda_g \omega_g \dot{x} + \omega_g^2 x = 2\lambda_g\omega_g \sigma_g \dot{\theta}$$

Where: u = Ground Displacement

θ = Seismometer pendulum displacement

x = Recording galvanometer displacement

ω_s, ω_g = Seismometer, galvanometer natural frequencies

λ_s, λ_g = Seismometer, galvanometer damping factors

σ_s, σ_g = Seismometer, galvanometer coupling constants

Given ω_s, ω_g, λ_s, λ_g, and $\sigma^2 = \sigma_s \sigma_g$, the program calculates the amplitude A (within an arbitrary gain factor) and phase ϕ of the ratio x/u as a function of the angular frequency ω. Keystroke functions calculate $2\pi x$ and $2\pi / x$ for frequency (f) - angular frequency (ω) - period (T) conversions ($\omega = 2\pi f = 2\pi / T$) and convert amplitudes to decibels. The y register is preserved in R_8 for comparing responses at different frequencies.

Operating Limits and Warnings This program neglects the inductance of the seismometer, and therefore cannot be used for instruments with Benioff variable - reluctance transducers.

The phase response is in degrees, radians, or grads, depending on the angular mode setting of the calculator.

Program Description II

Sketch(es)

Sample Problem(s) The long-period instruments of the World-Wide Standard Seismograph Network (WWSSN) have the following parameters:

$\omega s = 2\pi/15s$; $\omega g = 2\pi/100s$; $\lambda s = 0.93$; $\lambda g = 1.00$

Magnification	6000	3000	1500	750	375
σ^2	0.805	0.204	0.047	0.013	0.003

When operated at a magnification of 6000, what is the amplitude response at 300 sec period, relative to that at 15 sec, expressed in decibels? What is the phase difference? What is the gain at a frequency of 5 h_z relative to that at a period of 15 sec, in decibels?

Solution(s) 15 [C] [STO] [1] 100 [C] [STO] [2] .93 [STO] [3] 1 [STO] [4] .805 [STO] [5]

15 [C] [A] 300 [C] [A] [RCL] [8] [÷] [E]→ -41.12 (A(300s)/A(15s), db)

15 [C] [A] [R/S] 300 [C] [A] [R/S] [RCL] [8] [-] → -133.95 (ϕ(300s)-ϕ(15s), deg.)

15 [C] [A] 5 [D] [A] [RCL] [8] [÷] [E] → - 32.29 (A($5h_z$)/A(15s), db.)

Reference(s) Willmore, P.L., The Detection of Earth Movements, in Methods and Techniques in Geophysics, 230-276, New York, Interscience, 1959.

This program is a translation of the HP-65 Users' Library Program No.s 04840A and 00879A, submitted by Bruce R. Julian.

User Instructions

ELECTROMAGNETIC SEISMOGRAPH FREQUENCY RESPONSE

		$2\pi/x$	$2\pi x$	db

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Load Program				
2	Enter Instrument Constants:				
	Natural Frequencies	ω_s $\frac{\text{Rad.}}{\text{sec.}}$	STO	1	
		ω_g $\frac{\text{Rad.}}{\text{sec.}}$	STO	2	
	Damping Factors	λs	STO	3	
		λ_g	STO	4	
	Coupling Constant	σ^2	STO	5	
3	Calculate Instrument	ω $\frac{\text{Rad.}}{\text{sec.}}$	A		A (ω)
	Response at frequency ω.		R/S		ϕ (ω)
	Repeat 3 if desired.				(phase
					lead)
	NOTE: The value in the y register when A				
	was pressed is saved in R_8 .				
4	Convert periods, frequencies	T sec.	C		ω $\frac{\text{Rad.}}{\text{sec.}}$
		T sec.	D	C	f h_z
		ω $\frac{\text{Rad.}}{\text{sec.}}$	C		T sec.
		f h_z	D		ω $\frac{\text{Rad.}}{\text{sec.}}$
5	Convert amplitude to decibels	A	E		db

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	
002	STO6	35 06	
003	GSBB	23 12	
004	STO7	35 07	
005	R↓	-31	
006	STO8	35 08	
007	GSBB	23 12	
008	RCL8	36 08	
009	R↑	16-31	
010	STO8	35 08	
011	R↓	-31	
012	RCL7	36 07	
013	→P	34	
014	R↓	-31	
015	R↓	-31	
016	→P	34	
017	X⇄Y	-41	
018	R↓	-31	Complex Multiply and change sign
019	×	-35	
020	R↓	-31	
021	+	-55	
022	R↑	16-31	
023	CHS	-22	
024	→R	44	
025	RCL5	36 05	
026	RCL1	36 01	
027	×	-35	
028	RCL2	36 02	
029	×	-35	
030	RCL3	36 03	
031	×	-35	
032	RCL4	36 04	
033	×	-35	
034	4	04	
035	×	-35	
036	RCL6	36 06	
037	X²	53	
038	÷	-24	
039	-	-45	
040	X⇄Y	-41	
041	→P	34	
042	1/X	52	
043	RCL6	36 06	
044	÷	-24	
045	R/S	51	Display A (ω)
046	*LBL0	21 00	
047	X⇄Y	-41	Exchange A(ω),φ(ω)
048	R/S	51	Display
049	GTO0	22 00	
050	*LBLB	21 12	
051	CLX	-51	
052	RCL3	36 03	
053	RCL4	36 04	
054	STO3	35 03	Exchange R_3, R_4
055	R↓	-31	
056	STO4	35 04	
057	2	02	
058	×	-35	
059	RCL1	36 01	
060	RCL2	36 02	Exchange R_1, R_2
061	STO1	35 01	
062	R↓	-31	
063	STO2	35 02	
064	RCL6	36 06	
065	÷	-24	
066	×	-35	
067	LSTX	16-63	
068	X²	53	
069	1	01	
070	-	-45	
071	RTN	24	
072	*LBLC	21 13	2π/x
073	1/X	52	
074	*LBLD	21 14	
075	Pi	16-24	
076	×	-35	
077	2	02	2π x
078	×	-35	
079	RTN	24	
080	*LBLE	21 15	A → db
081	LOG	16 32	
082	2	02	
083	0	00	
084	×	-35	
085	RTN	24	
086	R/S	51	
090			
100			
110			

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☑	DEG	☑	FIX	☑
1	☐	☑	GRAD	☐	SCI	☐
2	☐	☑	RAD	☐	ENG	☐
3	☐	☑			n 2	

REGISTERS

0	1	2	3	4	5	6	7	8	9
	ωs	ωg	λs	λg	$\sigma^2=\sigma s \sigma g$	ω	Used	Used	

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title EARTHQUAKE SEISMIC WAVE RADIATION PATTERN: SHEAR FAULT

Contributor's Name Hewlett-Packard

Address 1000 N.E. Circle Blvd.

City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables The compressional (P) and vertically (SV) and horizontally (SH) polarized shear wave radiation patterns for a point double couple without moment are calculated from

$$Ap = 2\ (\hat{a}\cdot\hat{e}_r)\ (\hat{n}\cdot\hat{e}_r)$$

$$Asv = (\hat{n}\cdot\hat{e}_r)\ (\hat{a}\cdot\hat{e}_\theta) + (\hat{a}\cdot\hat{e}_r)\ (\hat{n}\cdot\hat{e}_\theta)$$

$$Ash = (\hat{n}\cdot\hat{e}\ )\ (\hat{a}\cdot\hat{e}_\phi) + (\hat{a}\cdot\hat{e}_r)\ (\hat{n}\cdot\hat{e}_\phi)$$

Where $\hat{a}$ and $\hat{n}$ are the unit normals to the p wave nodal planes. ($\hat{a}$ is parallel to the slip vector; $\hat{n}$ points toward block which moves in the $\hat{a}$ direction. See sketch.) $\hat{e}_r$, $\hat{e}_\theta$ and $\hat{e}_\phi$ are the conventional spherical coordinate unit vectors (see sketch) and define the directions of positive Ap, Asv, and Ash, respectively. The total s wave amplitude and polarization angle are calculed from

$$As = [A_{sh}^2 + A_{sv}^2]^{1/2} \qquad \varepsilon = \tan^{-1}\ Ash/_{Asv}$$

The unit vectors $\hat{a}$, $\hat{n}$, and $\hat{e}_r$ are specified by the user in terms of their plunges and trends (Azimuths, measured clockwise from north through east.)

Operating Limits and Warnings Note that the radiation patterns are normalized to maximum values of 1.0. In terms of absolute displacement, the maximum amplitude of S exceeds that of P by the factor ($^{Vp}/_{Vs})^3$. (Vp, Vs are the compressional and shear wave speeds, respectively.)

Program Description II

Sketch(es)

Sample Problem(s) The San Fernando, California earthquake of Feb. 9, 1971, had the following nodal plane poles:

	Plunge	Trend
$\hat{a}$	46°	64°
$\hat{n}$	38°	206°

Evaluate the radiation patterns in the direction of La Paz Bolivia (Plunge = 70°, Trend = 128°.)

Solution(s) 46[↑] 64 [A] 38[↑]206 [A] 70[↑]128 [B] → 0.99 (Ap) [R/S] → 0.02 (A_{sv}) [R/S]→ -0.21 (Ash) [R/S] → 0.21 (A_s) [R/S] → -84.79 (ε,deg)

Reference(s)

Ben-Menahem, Ari, Stewart W. Smith, and Ta-Liang Teng, a procedure for source studies from spectrums of long-period seismic body waves, Bull. Seismol. Soc. Amer., 55, 203-235, 1965.

This program is a translation of the HP-65 Users' Library Program No. 04839A, submitted by Bruce R. Julian.

User Instructions

DOUBLE COUPLE

1 ◀ ▶ 2

Poles $P \uparrow T$ | $\hat{e}_r$ $P \uparrow T$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter Program				
2	Store â	Plunge	↑		
		Trend	A		
3	Store n̂	Plunge	↑		
		Trend	A		
4	Enter $\hat{e}_r$ (Direction of radiated wave) and	Plunge	↑		
	calculate radiation patterns.	Trend	B		Ap
	Repeat step 4 as many times as desired.		R/S		Asv
			R/S		Ash
5	For new focal parameters, go to step 2		R/S		As
			R/S		ε
	Note: The program operates in any angular				
	mode.				

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	
002	STO1	35 01	Store $\hat{a}$ or $\hat{n}$ and
003	R↓	-31	exchange
004	STO2	35 02	
005	GSBE	23 15	
006	RTN	24	
007	*LBLB	21 12	
008	STO5	35 05	
009	X⇄Y	-41	
010	STO6	35 06	Calculate $\hat{a}\cdot\hat{e}_r$
011	GSBD	23 14	
012	STO7	35 07	
013	GSBD	23 14	Calculate $\hat{n}\cdot\hat{e}_r$
014	STO8	35 08	
015	x	-35	
016	2	02	
017	x	-35	
018	R/S	51	Display Ap
019	1	01	
020	SIN^{-1}	16 41	Calculate plunge
021	ST+6	35-55 06	of $\hat{e}_\theta$, put in R_6
022	GSBD	23 14	Calculate $\hat{a}\cdot\hat{e}_\theta$
023	RCL8	36 08	
024	x	-35	
025	GSBD	23 14	Calculate $\hat{n}\cdot\hat{e}_\theta$
026	RCL7	36 07	
027	x	-35	
028	+	-55	
029	R/S	51	Display A_{sv}
030	0	00	0 (Plunge of $\hat{e}_\phi$)
031	STO6	35 06	→ R_6
032	RCL5	36 05	
033	1	01	
034	SIN^{-1}	16 41	Trend of $\hat{e}_\phi$
035	-	-45	→ R_5
036	STO5	35 05	
037	R↑	16-31	Calculate $\hat{a}\cdot e_\phi$
038	GSBD	23 14	
039	RCL8	36 08	
040	x	-35	
041	X⇄Y	-41	Store A_{sv}
042	STO8	35 08	
043	X⇄Y	-41	
044	GSBD	23 14	Calculate $\hat{n}\cdot e_\phi$
045	RCL7	36 07	
046	x	-35	
047	+	-55	
048	R/S	51	Display A_{sh}
049	RCL8	36 08	Recall A_{sv}
050	→P	34	
051	R/S	51	Display A_s
052	X⇄Y	-41	
053	RTN	24	Display ε
054	*LBLD	21 14	
055	RCL1	36 01	
056	RCL5	36 05	

STEP	KEY ENTRY	KEY CODE	COMMENTS
057	-	-45	
058	COS	42	
059	RCL2	36 02	
060	COS	42	
061	x	-35	Dot vectors in
062	RCL6	36 06	(R_1, R_2) and
063	COS	42	(R_5, R_6)
064	x	-35	
065	RCL6	36 06	
066	SIN	41	
067	RCL2	36 02	
068	SIN	41	
069	x	-35	
070	+	-55	
071	*LBLE	21 15	
072	RCL1	36 01	
073	RCL3	36 03	
074	STO1	35 01	Exchange R_1, R_3
075	R↓	-31	
076	STO3	35 03	
077	R↓	-31	
078	RCL2	36 02	
079	RCL4	36 04	
080	STO2	35 02	
081	R↓	-31	Exchange R_2, R_4
082	STO4	35 04	
083	R↓	-31	
084	RTN	24	
085	R/S	51	

REGISTERS

0	1	2	3	4	5	6	7	8	9
	Trend of $\hat{a}$	Plunge of $\hat{a}$	Trend of $\hat{n}$	Plunge on $\hat{n}$	Trend of $\hat{e}_r$, $\hat{e}_\theta$, $\hat{e}_\phi$	Plunge of $\hat{e}_r$, $\hat{e}_s$, $\hat{e}_\phi$	Used	Used	
S0	S1	S2	S3	S4	S5 θ	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title Plate - Tectonic Velocities

Contributor's Name Hewlett-Packard

Address 1000 N.E. Circle Blvd.

City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables This program calculates the relative velocity vector between two lithospheric plates at any point on their common boundary, given their relative angular velocity vector and the latitude and longitude of the boundary point. The northward and eastward components of the relative velocity are:

$$V_n = \omega_x \sin\lambda - \omega_y \cos\lambda \qquad V_e = -[\omega_x \cos\lambda + \omega_y \sin\lambda]\sin L + \omega_z \cos L$$

where ω_x, ω_y, ω_z are the components of the relative angular velocity vector (units of velocity at 90° distance from the pole) and L and λ are the latitude and longitude of the boundary point. The program also calculates the magnitude and azimuth of the velocity

$$V = [V_n 2 + V_e 2]^{1/2} \qquad Z = \tan^{-1}(Ve/Vn)$$

Keys to convert angular velocity vectors from geographic (L_ω, λ_ω, ω) to cartesian (ω_x, ω_y, ω_z) form and vice-versa are also included:

$$\omega_x = \omega \cos L_\omega \cos\lambda_\omega \qquad \omega = [\omega_x 2 + \omega_y 2 + \omega_z 2]^{1/2}$$

$$\omega_y = \omega \cos L_\omega \sin\lambda_\omega \qquad L_\omega = \tan^{-1}\left\{\omega_z/[\omega_x 2 + \omega_y 2\ ]^{1/2}\right\}$$

$$\omega_z = \omega \sin L_\omega \qquad \lambda_\omega = \tan^{-1}(\omega_y/\omega_x)$$

Operating Limits and Warnings

North latitude and east longitude are positive.
South latitude and west longitude are negative.
Calculator must be in degree mode.

Program Description II

Sketch(es)

Plate	ω_x	ω_y	ω_z	Plate	ω_x	ω_y	ω_z
Pacific	0.0	0.0	0.0	Indian	7.044	-0.246	12.109
N. Amer.	2.114	-4.816	6.472	Antarctic	0.751	-4.092	10.671
S. Amer.	0.935	-3.211	6.542	Nazca	0.770	-10.009	15.224
African	2.691	-4.550	9.985	Cocos	-5.243	-16.040	14.825
Eurasian	1.460	-3.968	9.193	Arabian	5.260	-4.159	11.551

Sample Problem(s)

1. Given the above table of angular velocities in units of cm/yr at 90° (after Minster, et.al., 1974), find:
   (a) The latitude and longitude of the pole, and the angular velocity, for the motion of Europe relative to North America.
   (b) The components, magnitude, and direction of this motion on the mid-Atlantic ridge at latitude 45°N, longitude 28°W.
2. The so-called hot-spots (Hawaii, etc.) rotate relative to the Pacific plate at a rate of 9.23 cm/yr at 90° about an axis located at 67.3°N, 59.4°W, according to the above reference. What are the components of this angular velocity vector?

Solution(s)

1. [CL REG] 1.46 [↑] 3.968 [CHS][↑] 9.193 [D]
   2.114 [↑] 4.816 [CHS][↑] 6.472 [C] [D]
   (a) [RCL] [1] [RCL] [2] [RCL] [3] [B] → 2.92 (ω, cm/yr)
   [R↓] → 127.64 ($\lambda\omega$, deg) [R↓] → 68.52 (L_ω, deg)
   (b) 45 [↑] 28 [CHS] [E] → - 0.44 (V_n, cm/yr)
   [R/S] → 2.61 (V_e, cm/yr) [R/S] → 2.65 (V, cm/yr)
   [R/S] → 99.59 (Z, deg)
2. [CL REG] 67.3 [↑] 59.4 [CHS] [↑] 9.23 [A] → 8.52 (ω_z)
   [R↓] → -3.07 (ω_y) [R↓] → 1.81 (ω_x) (All cm/yr at 90°.)

Reference(s)

This program is a translation of the HP-65 Users' Library Program No. 03775A, submitted by Bruce R. Julian.

Minster, J.B., T.H. Jordan, P. Molnar, and E. Haines, Numerical modeling of instantaneous plate tectonics, Geophys, J.R. astr. Soc., 36, 541-576, 1974.

User Instructions

1 PLATE VELOCITIES 2

Geog → cart	Cart→ geog	CHS $\bar{\omega}$	$\Sigma\ \bar{\omega}$	$\bar{V}$ (L,λ)

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program.				
2	Clear angular		f	CL REG	
	velocity vector ($\bar{\omega}$).				
3	Enter $\bar{\omega}$ of plate 1.				
	Cartesian form	ω_x cm/yr at 90°	↑		
		ω_y "	↑		
		ω_z "			
	or geographic form	L_ω deg.	↑		
		λ_ω deg.	↑		
		ω cm/yr at 90°	A		
4	Add into memory		D		
5	Enter $\bar{\omega}$ of plate 2				
	(as in Step 3).				
6	Subtract from memory.		C	D	
7	Enter latitude, longitude	L deg.	↑		
	of boundary	λ deg.	E		V_n cm/yr
	point and calculate		R/S		V_e "
	velocity of plate 2		R/S		V "
	relative to plate 1.		R/S		Z deg.
	(Repeat for				
	additional points.)				
8	For new plates go to 2.				
9	To retrieve $\bar{\omega}$ from		RCL	1	ω_x cm/yr at 90°
	memory.		RCL	2	ω_y "
			RCL	3	ω_z "
10	To convert $\bar{\omega}$ from		B		ω "
	cartesian to		R↓		λ_ω deg.
	geographic form.		R↓		L_ω deg.

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	Convert $\bar{\omega}$ from geographic (L,λ,ω) to cartesian $(\omega_x,\omega_y,\omega_z)$ form
002	R↓	-31	
003	X⇄Y	-41	
004	R↑	16-31	
005	→R	44	
006	X⇄Y	-41	
007	R↓	-31	
008	→R	44	
009	X⇄Y	-41	
010	R↑	16-31	
011	RTN	24	
012	*LBLB	21 12	
013	R↓	-31	Convert $\bar{\omega}$ from cartesian$(\omega_x,\omega_y,\omega_z)$ to geographic (L,λ,ω) form
014	X⇄Y	-41	
015	→P	34	
016	R↑	16-31	
017	X⇄Y	-41	
018	→P	34	
019	R↓	-31	
020	X⇄Y	-41	
021	R↑	16-31	
022	RTN	24	
023	*LBLC	21 13	
024	CHS	-22	
025	R↓	-31	Change sign of $\bar{\omega}$ (cartesian form)
026	CHS	-22	
027	R↓	-31	
028	CHS	-22	
029	R↓	-31	
030	R↓	-31	
031	RTN	24	
032	*LBLD	21 14	
033	ST+3	35-55 03	
034	R↓	-31	Add $\bar{\omega}$ (cartesian form) into R_1, R_2, R_3
035	ST+2	35-55 02	
036	R↓	-31	
037	ST+1	35-55 01	
038	R↓	-31	
039	R↓	-31	
040	RTN	24	
041	*LBLE	21 15	
042	X⇄Y	-41	
043	STO4	35 04	
044	X⇄Y	-41	
045	STO5	35 05	
046	RCL1	36 01	
047	→R	44	
048	RCL5	36 05	
049	RCL2	36 02	
050	→R	44	
051	R↑	16-31	
052	-	-45	
053	CHS	-22	
054	ENT↑	-21	
055	R/S	51	Display V_n
056	R↓	-31	
057	R↓	-31	
058	+	-55	
059	RCL4	36 04	
060	1	01	
061	→R	44	
062	R↓	-31	
063	×	-35	
064	R↑	16-31	
065	RCL3	36 03	
066	×	-35	
067	-	-45	
068	CHS	-22	
069	R/S	51	Display V_e
070	X⇄Y	-41	
071	→P	34	
072	R/S	51	Display V
073	X⇄Y	-41	
074	0	00	
075	X⇄Y	-41	
076	X>Y?	16-34	
077	RTN	24	Display Z if +
078	3	03	
079	6	06	Add 360° to Z if negative
080	0	00	
081	+	-55	
082	RTN	24	Display Z
083	R/S	51	
090			
100			
110			

REGISTERS

0	1	2	3	4	5	6	7	8	9
	ω_x	ω_y	ω_z	L	λ				

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title Plunge and Rake of Faults

Contributor's Name Hewlett-Packard

Address 1000 N.E. Circle Blvd.

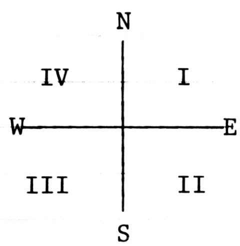
City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables

Tan Plunge Angle = (Tan of true dip angle) (Sin angle between strike and plunge directions).

Cos Rake Angle = (Cos angle between plunge direction and strike of fault) (cos plunge angle).

Quad Code

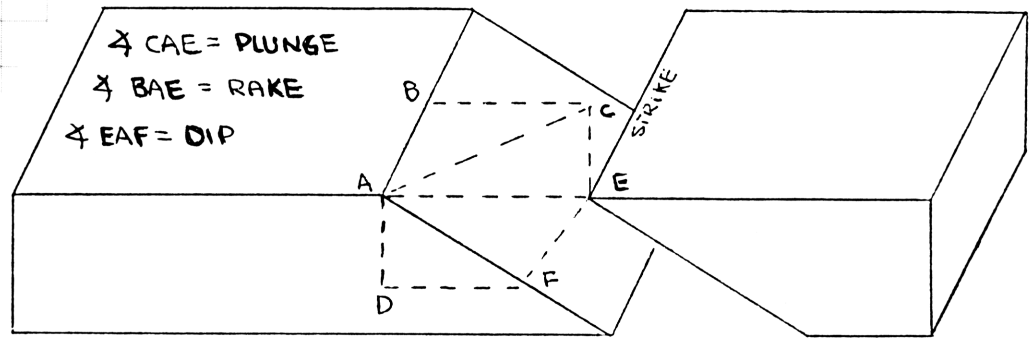


* Angles are entered and displayed as degrees and decimals of degrees.

Operating Limits and Warnings Since the rake angle soln. is dependent upon the value to the plunge angle, the plunge angle soln. must always precede the rake angle soln.

Program Description II

Sketch(es)



Sample Problem(s) It is found that a fault that strikes east-west and dips 55° due south intersects a dike. The plunge of the intersection is in a direction S72°E. Find the plunge angle and the rake angle.

Solution(s) 90 [ENTER ↑] 1 [A] 72 [ENTER ↑] 2 [B] 55 [C] [D] → 23.81° (Plunge)

[E] → 29.53° (Rake)

Reference(s) Dennison, John M., Analysis of Geologic Structures, P. 112, W. W. Norton, 1968.

This program is a translation of the HP-65 Users' Library Program No. 03441A, submitted by Michael L. Everts.

User Instructions

1 PLUNGE AND RAKE OF FAULTS 2

Stk. Brg Qd	Plg. Brg Qd	T Dip	Plunge	Rake

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter Program				
2	Input strike of fault bearing	Brg.	ENT↑		
3	Input quad code	Quad	A		
4	Input bearing of plunge	Brg.	ENT ↑		
5		Quad	B		
6	Input true dip of fault	True dip	C		
7	Compute plunge angle		D		Plunge
8	Compute rake angle		E		Rake

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	
002	2	02	Enter strike bearing and quad.
003	÷	-24	
004	ENT↑	-21	
005	INT	16 34	
006	X≠Y?	16-32	
007	GTO1	22 01	
008	R↑	16-31	
009	R↑	16-31	
010	CHS	-22	
011	R↑	16-31	
012	R↑	16-31	
013	*LBL1	21 01	
014	R↓	-31	
015	INT	16 34	
016	1	01	
017	8	08	
018	0	00	
019	×	-35	
020	+	-55	
021	STO1	35 01	
022	RTN	24	
023	*LBLB	21 12	Enter plunge bearing and quad.
024	2	02	
025	÷	-24	
026	ENT↑	-21	
027	INT	16 34	
028	X≠Y?	16-32	
029	GTO2	22 02	
030	R↑	16-31	
031	R↑	16-31	
032	CHS	-22	
033	R↑	16-31	
034	R↑	16-31	
035	*LBL2	21 02	
036	R↓	-31	
037	INT	16 34	
038	1	01	
039	8	08	
040	0	00	
041	×	-35	
042	+	-55	
043	STO2	35 02	
044	RTN	24	
045	*LBLC	21 13	Enter true Dip.
046	STO3	35 03	
047	RTN	24	
048	*LBLD	21 14	Compute plunge
049	RCL3	36 03	
050	TAN	43	
051	RCL1	36 01	
052	RCL2	36 02	
053	X>Y?	16-34	
054	X⇄Y	-41	
055	-	-45	
056	STO5	35 05	
057	SIN	41	
058	×	-35	
059	TAN⁻¹	16 43	
060	STO4	35 04	
061	PRTX	-14	
062	RTN	24	
063	*LBLE	21 15	Compute rake
064	RCL5	36 05	
065	COS	42	
066	RCL4	36 04	
067	COS	42	
068	×	-35	
069	COS⁻¹	16 42	
070	PRTX	-14	
071	RTN	24	
072	R/S	51	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n 2	

REGISTERS

0	1	2	3	4	5	6	7	8	9
	Strike (AZ)	Plunge (AZ)	True Dip	Plunge X	Used				

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title Depth of Strata

Contributor's Name Hewlett-Packard
Address 1000 N.E. Circle Blvd.
City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables

1 - For hor. ground surface & S measured ω RT ∡ 's

$d_1 = S \tan \delta$

2 - For sloping G.S. in same direction of bed & S measured ω RT ∡ 's

$d_2 = S(\cos\sigma \tan\delta - \sin\sigma)$

3 - For slope & dip in opposite directions

$d_3 = S(\cos\sigma \tan\delta + \sin\sigma)$

4 - For dip & slope in opposite directions and S not ω right angles $d_4 = S(\tan\delta \cos\sigma \sin\alpha + \sin\sigma)$

5 - For dip & slope in same direction & S not @ RT 's $d_5 = S(\tan\delta \cos\sigma \sin\alpha - \sin\sigma)$

d = Depth of bed

S = Dist along surface of ground between the outcrop and the point @ which the depth of the bed is to be calculated.

δ = ∡ of dip of bed

σ = ∡ of slope of ground

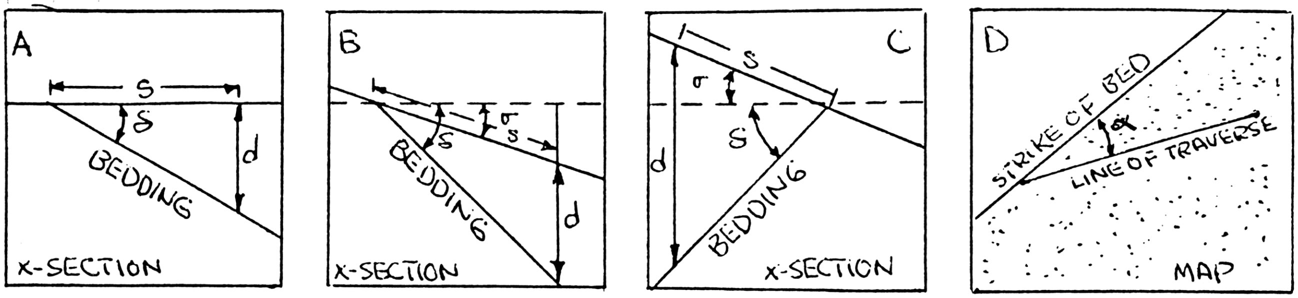
α = Azimuth of traverse (that is the Hor. ∡ between the strike of the bed & the direction of traverse)

Operating Limits and Warnings

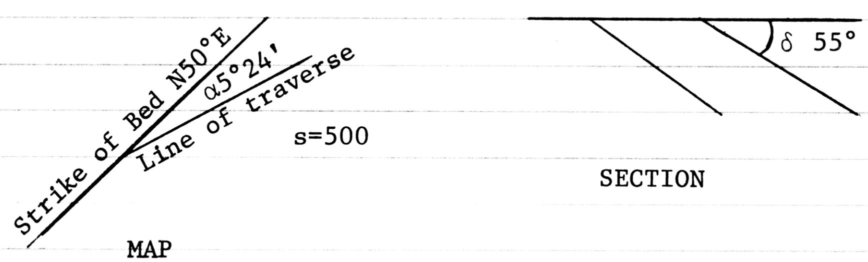
Angles are entered as DD.MMSS

Program Description II

Sketch(es)



Sample Problem(s) In a region of no relief a conglomerate strikes N50° E and dips 55°SE. Calculate the depth to the conglomerate 500 feet 5°24' E of its outcrop



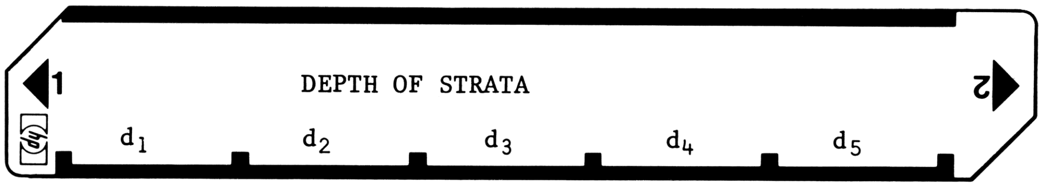
Solution(s) 500 [ENTER ↑] 55 [ENTER ↑] 0 [ENTER ↑] 5.24 [D] → 67.20 d_4

* NOTE: "ZERO" was entered because σ (ground slope) was "ZERO".

Reference(s) Billings, Marland P., Structural Geology, Third Edition, P. 510-519.

This program is a modification of the Users' Library Program No. 02889A, submitted by Michael Everts.

User Instructions



STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Load Side 1				
2	If d_1 desired				
	Input:				
	S	S	ENT ↑		
	δ	δ	A		d_1
	Calculate d_1				
3	If d_2 desired input:				
	S	S	ENT ↑		
	δ	δ	ENT ↑		
	σ	σ	B		d_2
	Calculate d_2				
4	If d_3 desired input:				
	S	S	ENT ↑		
	δ	δ	ENT ↑		
	σ	σ	C		d_3
	Calculate d_3				
5	If d_4 desired input				
	S	S	ENT ↑		
	δ	δ	ENT ↑		
	σ	σ	ENT ↑		
	α	α	D		d_4
	Calculate d_4				
6	If d_5 desired input				
	S	S	ENT ↑		
	δ	δ	ENT ↑		
	σ	σ	ENT ↑		
	α	α	E		d_5
	Calculate d_5				

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	d_1
002	CLRG	16-53	
003	STO2	35 02	
004	R↓	-31	
005	STO1	35 01	
006	GSB0	23 00	
007	PRTX	-14	
008	RTN	24	
009	*LBL0	21 00	Turn flag 1 on
010	SF1	16 21 01	
011	RCL2	36 02	
012	HMS→	16 36	
013	TAN	43	Tan δ
014	STO5	35 05	
015	RCL3	36 03	
016	HMS→	16 36	
017	ENT↑	-21	
018	SIN	41	Sin σ
019	STO6	35 06	
020	R↓	-31	
021	COS	42	Cos σ
022	STO7	35 07	
023	RCL4	36 04	
024	HMS→	16 36	
025	SIN	41	Sin α
026	STO8	35 08	
027	RCL1	36 01	
028	RCL5	36 05	
029	x	-35	
030	RTN	24	
031	*LBLB	21 12	d_2
032	CLRG	16-53	
033	STO3	35 03	
034	R↓	-31	
035	STO2	35 02	
036	R↓	-31	
037	STO1	35 01	
038	GSB0	23 00	
039	*LBL1	21 01	
040	RCL5	36 05	
041	RCL7	36 07	
042	x	-35	
043	RCL6	36 06	
044	F1?	16 23 01	Test Flag 1
045	CHS	-22	
046	+	-55	
047	RCL1	36 01	
048	x	-35	
049	PRTX	-14	
050	RTN	24	
051	*LBLC	21 13	d_3
052	CLRG	16-53	
053	STO3	35 03	
054	R↓	-31	
055	STO2	35 02	
056	R↓	-31	

STEP	KEY ENTRY	KEY CODE	COMMENTS
057	STO1	35 01	
058	GSB0	23 00	
059	CF1	16 22 01	Turn flag 1 off
060	GTO1	22 01	
061	*LBLD	21 14	d_4
062	STO4	35 04	
063	R↓	-31	
064	STO3	35 03	
065	R↓	-31	
066	STO2	35 02	
067	R↓	-31	
068	STO1	35 01	
069	GSB0	23 00	
070	*LBL2	21 02	
071	RCL5	36 05	
072	RCL7	36 07	
073	x	-35	
074	RCL8	36 08	
075	x	-35	
076	RCL6	36 06	
077	CHS	-22	
078	F1?	16 23 01	
079	CHS	-22	
080	+	-55	
081	RCL1	36 01	
082	x	-35	
083	PRTX	-14	
084	RTN	24	
085	*LBLE	21 15	d_5
086	STO4	35 04	
087	R↓	-31	
088	STO3	35 03	
089	R↓	-31	
090	STO2	35 02	
091	R↓	-31	
092	STO1	35 01	
093	GSB0	23 00	
094	CF1	16 22 01	
095	GTOD	22 14	
096	R/S	51	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	2

REGISTERS

0	1	2	3	4	5	6	7	8	9
	S	δ	σ	α	Tan δ	Sin σ	Cos σ	Sin α	
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title STRATA THICKNESS

Contributor's Name Hewlett-Packard

Address 1000 N.E. Circle Blvd.

City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables

1 - Thickness if ground surface is horizontal measured @ RT ∡'s

$t = S \sin \delta$ S = Breadth of outcrop

δ = Angle of dip of the bed

2 - Thickness if ground surface is sloping in opposite direction of beds measured ω RT ∡'s

$t = S \sin (\delta + \sigma)$ σ = ∡ of slope of ground

δ = Same as above

3 - Ground surface slopes in same direction @ RT ∡'s

$t = S \sin (\delta - \sigma)$ δ & σ = Same as above

4 - Ground surface slopes in opposite direction not @ RT ∡'s

$t = S (\sin \delta \cos \sigma \sin \alpha + \sin \sigma \cos \delta)$ S = Slope distance (not map)

α = Azimuth of traverse

5 - Ground surface slopes in same direction not @ RT ∡'s

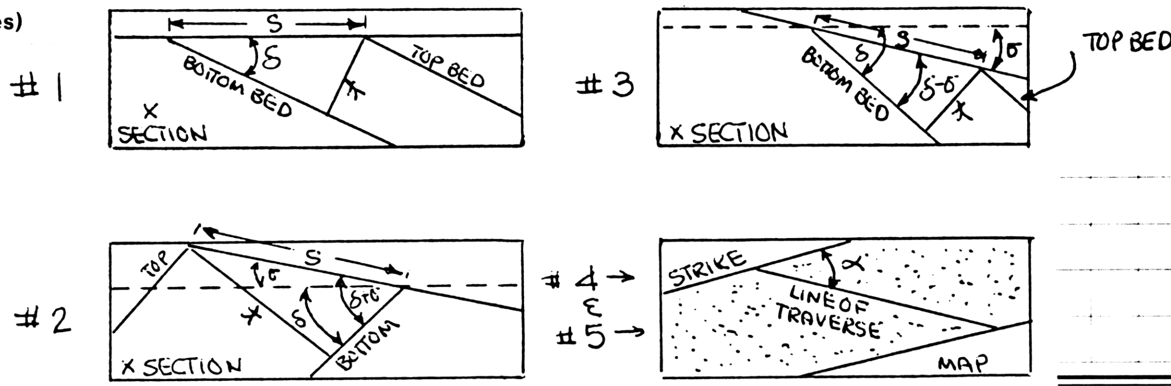
$t = S (\sin \delta \cos \sigma \sin \alpha - \sin \sigma \cos \delta)$

S = Slope Dist (not map dist) δ, σ, α Same as above.

Operating Limits and Warnings Angles are entered as D.M.S.

Program Description II

Sketch(es)



Sample Problem(s)

1 - A limestone bed was found on level ground to have a breadth of 200 meters and dipped at 5° 45'. What is the thickness of the bed?

2 - An outcrop of sandstone dips 23° 23' opposite the ground slope which is 13° 23' the breadth measured 450.61 meters. What is the thickness of the sandstone?

3 - A lava flow is mapped and found to strike due north. The bed dips 20° and the ground slopes in the same direction at 5° 15'. A traverse of 4281 ft is made across the flow in a direction of N 29° 56' E. How thick is the lava?

Solution(s)

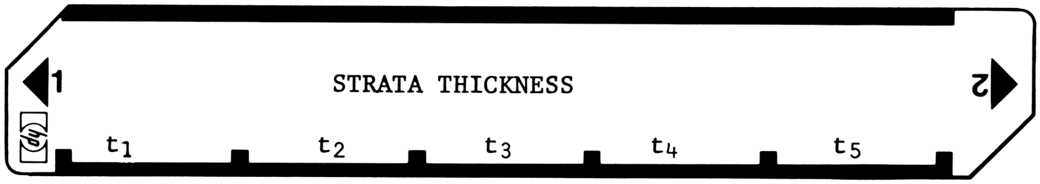
1. 20[ENTER↑] 5.45[A] --------------------------> 20.04 meters

2. 450.61[ENTER↑] 23.23[ENTER↑] 13.23[B]--------> 269.72 meters

3. 428[ENTER↑] 20[ENTER↑] 5.15[ENTER↑]29.56[E]--→ 359.46 ft.

Reference(s) Billings, M.P., Structural Geology., Prentice Hall, 1972, PP 508-510. This program is a modification of the Users' Library Program No. 02531A, submitted by Michael L. Everts.

User Instructions



STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load side 1			
2	For t, with hor.ground surface			
	Input:			
	Breadth of bed			
	measured @ RT. ∡'s	S	ENT ↑	
	Dip of bed	δ	A	t_1
	Compute thickness			
3	For t_2 with sloping ground surface			
	opposite dipping beds			
	Input:			
	Breadth of bed			
	measured @ RT ∡'s	S	ENT ↑	
	Dip of bed	δ	ENT ↑	
	Slope of surface	σ	B	t_2
	Compute t_2			
4	For t_3 with sloping ground surface in same			
	direction as beds			
	Input:			
	Breadth of bed			
	Measured @ RT ∡'s	S	ENT ↑	
	Dip of bed	δ	ENT ↑	
	Slope of surface	σ	C	t_3
	Compute t_3			
5	For t_4 with slope of ground surface opposite			
	dip of beds, and breadth of outcrop is not			
	measured at right ∡'s to the strike:			
	Input:			
	Slope distance	S	ENT ↑	
	Dip of bed	δ	ENT ↑	
	Slope of surface	σ	ENT ↑	
	Azimuth of traverse	α	D	t_4
	Compute t_4			
6	For t_5 with slope of ground surface in same			
	direction of beds and breadth of outcrop			
	(Continued on next page)			

User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
	is not @ RT ∡'s to strike.				
	Input:				
	Slope distance	S	ENT ↑		
	Dip of bed	δ	ENT ↑		
	Slope of surface	σ	ENT ↑		
	Azimuth of traverse	α	E		t_5
	Compute t_5				
6	For t_5 with slcpe of ground surface in				
	same direction of beds and breadth of				

FLAGS	
0	
1	
2	
3	

SET STATUS

FLAGS	ON	OFF
0	☐	☒
1	☐	☒
2	☐	☒
3	☐	☒

TRIG	
DEG	☒
GRAD	☐
RAD	☐

DISP	
FIX	☒
SCI	☐
ENG	☐
n	2

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	
002	STO2	35 02	t_2
003	R↓	-31	
004	STO1	35 01	
005	CLX	-51	
006	STO3	35 03	
007	GSB0	23 00	
008	PRTX	-14	
009	RTN	24	
010	*LBL0	21 00	
011	RCL2	36 02	
012	HMS→	16 36	
013	ENT↑	-21	
014	SIN	41	
015	STO5	35 05	Sin δ
016	R↓	-31	
017	COS	42	
018	STO6	35 06	Cos δ
019	RCL3	36 03	
020	HMS→	16 36	
021	ENT↑	-21	
022	SIN	41	
023	STO7	35 07	Sin σ
024	R↓	-31	
025	COS	42	
026	STO8	35 08	Cos σ
027	RCL1	36 01	
028	RCL5	36 05	
029	×	-35	
030	RTN	24	
031	*LBLB	21 12	
032	STO3	35 03	
033	R↓	-31	
034	STO2	35 02	
035	R↓	-31	
036	STO1	35 01	
037	RCL2	36 02	
038	RCL3	36 03	
039	HMS+	16-55	
040	HMS→	16 36	
041	SIN	41	
042	RCL1	36 01	
043	×	-35	
044	PRTX	-14	t_2
045	RTN	24	
046	*LBLC	21 13	
047	STO3	35 03	
048	R↓	-31	
049	STO2	35 02	
050	R↓	-31	
051	STO1	35 01	
052	RCL2	36 02	
053	RCL3	36 03	
054	CHS	-22	
055	HMS+	16-55	
056	HMS→	16 36	
057	SIN	41	
058	RCL1	36 01	
059	×	-35	
060	PRTX	-14	t_3
061	RTN	24	
062	*LBLD	21 14	
063	STO4	35 04	
064	R↓	-31	
065	STO3	35 03	
066	R↓	-31	
067	STO2	35 02	
068	R↓	-31	
069	STO1	35 01	
070	GSB0	23 00	
071	RCL5	36 05	
072	RCL8	36 08	
073	×	-35	
074	RCL4	36 04	
075	HMS→	16 36	
076	SIN	41	
077	×	-35	
078	RCL6	36 06	
079	RCL7	36 07	
080	×	-35	
081	+	-55	
082	RCL1	36 01	
083	×	-35	
084	PRTX	-14	t_4
085	RTN	24	
086	*LBLE	21 15	
087	STO4	35 04	
088	R↓	-31	
089	STO3	35 03	
090	R↓	-31	
091	STO2	35 02	
092	R↓	-31	
093	STO1	35 01	
094	GSB0	23 00	
095	RCL5	36 05	
096	RCL8	36 08	
097	×	-35	
098	RCL4	36 04	
099	HMS→	16 36	
100	SIN	41	
101	×	-35	
102	RCL6	36 06	
103	RCL7	36 07	
104	×	-35	
105	-	-45	
106	RCL1	36 01	
107	×	-35	
108	PRTX	-14	t_5
109	RTN	24	
110	R/S	51	

REGISTERS

0	1	2	3	4	5	6	7	8	9
	S	δ	σ	α	Sin δ	Cos δ	Sin σ	Cos σ	Used
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title TRUE AND APPARENT DIPS

Contributor's Name Hewlett-Packard
Address 1000 N.E. Circle Blvd.
City Corvallis **State** Oregon **Zip Code** 97330

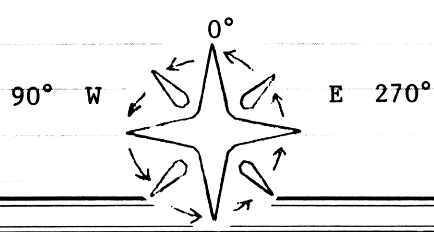
Program Description, Equations, Variables

Tan Apparent Dip Angle = (Tan True Dip Angle) (Cos Angle between True and Apparent Dip Directions)

$$\text{Tan True Dip Angle} = \frac{\text{Tan Apparent Dip Angle}}{\text{Cos Angle between True \& Apparent Dip Directions}}$$

Tan Angle between 1st Apparent Dip and True Dip Directions = (Csc Angle between two Apparent Dip Directions) [(Cot 1st Apparent Dip Angle) (Tan 2nd Apparent Dip Angle) - (Cos Angle between two Apparent Dip Directions)]

Operating Limits and Warnings Angles are entered and displayed in degrees and decimals of degrees. Directions are entered as Azimuths with North being 0° - West 90° - South 180° - East 270°



* Enter smallest apparent Dip Angle first. Angles must be greater than (0) zero.

Program Description II

Sketch(es)

Sample Problem(s)

1 - Two apparent dips on a sill are 15° S 27° E and 5° S 5° W.
What is the True Dip and True Dip Direction?

2 - The True Dip of a Bed is 27° S 42° W.
What is the Apparent Dip in a Direction N 65° W?

Solution(s)

1. 5 [ENTER ↑] 175 [ENTER ↑] 15 [ENTER ↑] 207 [A] → 20.60° (True Dip)
[RS]→251.54 (True Dip AZ)
2. 27 [ENTER ↑] 73 [B] → 25.98° (Apparent Dip)

Reference(s) Dennison, John M., <u>Analysis of Geologic Structures</u>, P. 7,8,12, 178, W.W. Norton, 1968.

This program is a modification of the User' Library Program No. 03603A, submitted by Michael L. Everts.

User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Load Side 1				
2	If True Dip is Desired,				
	Input:				
	Apparent Dip #1 (must be the				
	smallest of two Apparent Dips	A.D.#1	ENT ↑		
	Azimuth of Apparent Dip #1	A.Z.A.D.#1	ENT ↑		
	Apparent Dip #2	A.D.#2	ENT ↑		
	Azimuth of Apparent Dip #2	A.Z.A.D.#2	A		True Dip
	If Azimuth of True Dip is desired:		R/S		T.D. Az.
3	If Apparent Dip is desired,				
	Input:				
	True Dip		ENT ↑		
	Angle between True and Apparent				
	Dip Direction		B		App. Dip

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	True Dip
002	CLRG	16-53	
003	STO6	35 06	
004	R↓	-31	
005	STO5	35 05	
006	R↓	-31	Store Values
007	STO4	35 04	
008	R↓	-31	
009	STO3	35 03	
010	RCL4	36 04	
011	RCL6	36 06	
012	-	-45	
013	ABS	16 31	
014	STO7	35 07	
015	SIN	41	
016	1/X	52	
017	RCL3	36 03	
018	TAN	43	
019	1/X	52	
020	RCL5	36 05	
021	TAN	43	
022	×	-35	
023	RCL7	36 07	
024	COS	42	
025	-	-45	
026	×	-35	
027	TAN⁻¹	16 43	
028	STO8	35 08	
029	RCL6	36 06	
030	RCL4	36 04	
031	X>Y?	16-34	
032	GTO5	22 05	
033	RCL8	36 08	
034	+	-55	
035	STO2	35 02	
036	GTO1	22 01	
037	*LBL5	21 05	
038	RCL8	36 08	
039	-	-45	
040	STO2	35 02	
041	GTO1	22 01	
042	*LBLB	21 12	Apparent Dip
043	CLRG	16-53	
044	STO2	35 02	
045	X⇄Y	-41	Store Values
046	STO1	35 01	
047	X⇄Y	-41	
048	RCL1	36 01	
049	X=Y?	16-33	
050	GTO1	22 01	
051	RCL4	36 04	
052	RCL2	36 02	
053	-	-45	
054	SIN	41	
055	RCL1	36 01	
056	TAN	43	
057	×	-35	
058	TAN⁻¹	16 43	
059	ABS	16 31	
060	STO3	35 03	
061	*LBL4	21 04	
062	PRTX	-14	
063	R/S	51	
064	X⇄Y	-41	Answers
065	PRTX	-14	
066	RTN	24	
067	*LBL1	21 01	
068	RCL3	36 03	
069	TAN	43	
070	RCL4	36 04	
071	RCL2	36 02	
072	-	-45	
073	COS	42	
074	÷	-24	
075	TAN⁻¹	16 43	
076	STO1	35 01	
077	GTO4	22 04	
078	R/S	51	

SET STATUS

FLAGS	ON	OFF
0	☐	☒
1	☐	☒
2	☐	☒
3	☐	☒

TRIG: DEG ☒ GRAD ☐ RAD ☐

DISP: FIX ☒ SCI ☐ ENG ☐ n 2

REGISTERS

0	1	2	3	4	5	6	7	8	9
	True dip	Used	Ap-Dip#1	Az #1	Ap-Dip#2	Az #2	Used	Used	

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title BOUGUER ANOMOLY GRAVITY REDUCTION

Contributor's Name Hewlett-Packard

Address 1000 N.E. Circle Blvd.

City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables

Bouguer Anomoly = (Drift corrected dial division) x (Dial Constant) + Base gravity + (Elevation) x (Elevation factor) + Terrain correction - 978049 x (1 + .0052884 $\sin^2\phi$ - .0000059 $\sin^2 2\phi$)

This program is designed for use with the Worden Gravimeter, but is easily adaptable for use with other meters and variables.

Operating Limits and Warnings Program may be modified for other gravity meters and variables.

Program Description II

Sketch(es)

Sample Problem(s)

On a gravity survey a station measured the following:

Dial constant (dc) = .08770

Base gravity (BG) = 979539.86 milligals

Drift corrected dial division (dcdd) = -1166.6

Elevation = 6784 ft

Terrain correction = 2.99

Latitude of station = 38°36'13"

Solution(s)

.08770[A] 979539.86[B] 1166.6[CHS][C] 6784[R/S]

2.99[R/S] 38°.3613[R/S] ---------------------------→ -205.38 mg (Bouguer Anom.)

Reference(s)

This program is a modification of the Users' Library program #04828A submitted by Michael L. Everts.

User Instructions

B. A. GRAVITY REDUCTION

dc	BG	(ft) dcdd	(m) dcdd	

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Enter dial constant	dc	A		
3	Enter base gravity	BG	B		
4	If elevation is in feet:				
	Enter drift corrected dial division	dcdd	C		
	Enter elevation (ft)	Elev.	R/S		
	Enter terrain correction	TC	R/S		
	Enter Sta. latitude (DD.MM SS.) and				
	compute Bouguer Anomoly	LAT	R/S		B.A.
5	If elevation is in meters:				
	Enter drift corrected dial conversion	dcdd	D		
	Enter Elevation (m)	ELEV	R/S		
	Enter Terrain correction	TC	R/S		
	Enter STA. Lattitude (DD.MMSS)				
	and compute Bouguer Anomoly	LAT	R/S		B.A.

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	
002	STO1	35 01	Store dial constant
003	RTN	24	
004	*LBLB	21 12	
005	STO2	35 02	Store base gravity
006	RTN	24	
007	*LBLC	21 13	
008	ENT↑	-21	
009	RCL1	36 01	
010	×	-35	
011	RCL2	36 02	
012	+	-55	
013	R/S	51	
014	ENT↑	-21	
015	.	-62	
016	0	00	Elev. factor for feet
017	6	06	
018	0	00	
019	6	06	
020	*LBL1	21 01	
021	×	-35	
022	+	-55	
023	R/S	51	
024	+	-55	
025	R/S	51	
026	HMS→	16 36	
027	STO4	35 04	Store latitude
028	SIN	41	
029	ENT↑	-21	
030	×	-35	
031	.	-62	
032	0	00	
033	0	00	
034	5	05	
035	2	02	
036	8	08	
037	8	08	
038	4	04	
039	×	-35	
040	1	01	
041	+	-55	
042	RCL4	36 04	
043	2	02	
044	×	-35	
045	SIN	41	
046	ENT↑	-21	
047	×	-35	
048	.	-62	
049	0	00	
050	0	00	
051	0	00	
052	0	00	
053	0	00	
054	5	05	
055	9	09	
056	×	-35	
057	-	-45	
058	9	09	
059	7	07	
060	8	08	
061	0	00	
062	4	04	
063	9	09	
064	×	-35	
065	-	-45	
066	PRTX	-14	Bougner Anomoly
067	RTN	24	
068	*LBLD	21 14	
069	ENT↑	-21	
070	RCL1	36 01	
071	×	-35	
072	RCL2	36 02	
073	+	-55	
074	R/S	51	
075	ENT↑	-21	
076	.	-62	
077	1	01	Elevation factor for meters
078	9	09	
079	6	06	
080	6	06	
081	GTO1	22 01	
082	R/S	51	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	2

REGISTERS

0	1	2	3	4	5	6	7	8	9
	dc	BG		LAT					

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title GEOCENTRIC DISTANCE - AZIMUTH - BACK AZIMUTH

Contributor's Name Hewlett-Packard

Address 1000 N.E. Circle Blvd.

City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables The Geocentric Distance Δ and Azimuth Z_o from point (L_o, λ_o) to point (L,λ) are calculated from

$$\cos \Delta = \cos L'_o \cos L' \cos (\lambda-\lambda_o) + \sin L'_o \sin L'$$

$$\sin \Delta = (A^2 + B^2)^{1/2}$$

$$\tan Z_o = A/B$$

Where

$$A = \cos L' \sin (\lambda-\lambda_o)$$

$$B = \cos L'_o \sin L' - \sin L'_o \cos L'_o \cos (\lambda-\lambda_o)$$

L'_o, L' = Geocentric Latitudes of points

λ_o, λ = Longitudes of points

The Geocentric Latitude L' is gotten from the Geographic Latitude L by $\tan L' = (1-\alpha)^2 \tan L$, where α is the flattening of the Ellipsoid.

The back Azimuth is calculated by the same formulas with (L'_o,λ_o) and (L',λ) interchanged.

Operating Limits and Warnings Calculator must be in degree mode. North Latitude and East Longitude are positive. Azimuth is measured clockwise from North through East.

Program Description II

Sketch(es)

Sample Problem(s)

1. For a Spherical Earth, calculate the distance, Azimuths for L_o = 40° N, λ_o = 0° and L = 40.001° N, λ = 0°.

2. For the Real, Ellipsoidal Earth, calculate the distance and Azimuths from New York (L_o = 41° N, λ_o = 74° W) to Moscow (L = 56° N, λ = 37° E).

3. What is the Geocentric Latitude of New York?

Solution(s)

(1) [E] 40 [↑] 0 [A] 40.001 [↑] 0 [B] [DSP] [9] → .000999995
[R/S] [DSP] [2] → 360.00 (Z_o, deg) [R/S] → 180.00 (Z,deg)

(2) [D] 41 [↑] 74 [CHS] [A] 56 [↑] 37 [B]
→ 67.15 (△,deg) [R/S] → 34.69 (Z_o,deg) [R/S → 309.93 (Z.deg)

(3) 41 [C] → 40.81 (L',deg)

Reference(s) This program is a modification of the Users' Library Program No. 03629A, submitted by Bruce R. Julian.

User Instructions

GEOCENTRIC DIST. - AZ.

$L_o \uparrow \lambda$	$L \uparrow \lambda$	$L \rightarrow L'$	ELLIPTICAL	SPHERICAL

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter Program				
2	Store constant				
	$(1-\alpha)^2$				
	For Elliptical Earth		D		
	For Spherical Earth		E		
3	Enter Geographic	L_o,deg	↑		
	Coordinates of	λ_o,deg	A		
	First point				
4	Enter geographic	L,deg	↑		
	Coordinates of	λ,deg	B		Δ ,deg
	Second point and		R/S		Z_o,deg
	Calculate		R/S		Z, deg
	Distance, Azimuths				
	(Repeat as many times as desired.)				
5	To change first point, go to 3.				
6	To convert	L, deg	C		L',deg
	geographic to geocentric				
	latitude. (This is done automatically				
	in distance - Azimuth calculations.)				

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	
002	STO3	35 03	$\lambda_\circ \rightarrow R_3$
003	X⇄Y	-41	
004	GSBC	23 13	
005	1	01	
006	→R	44	
007	STO2	35 02	$\cos L_\circ' \rightarrow R_2$
008	R↓	-31	
009	STO1	35 01	$\sin L_\circ' \rightarrow R_1$
010	R/S	51	
011	*LBLB	21 12	
012	STO6	35 06	$\lambda \rightarrow R_6$
013	X⇄Y	-41	
014	GSBC	23 13	
015	1	01	
016	→R	44	
017	STO5	35 05	$\cos L' \rightarrow R_5$
018	X⇄Y	-41	
019	STO4	35 04	$\sin L' \rightarrow R_4$
020	RCL1	36 01	
021	×	-35	
022	X⇄Y	-41	
023	RCL2	36 02	
024	×	-35	
025	RCL6	36 06	
026	RCL3	36 03	
027	-	-45	
028	1	01	
029	→R	44	
030	STO6	35 06	$\cos(\lambda' - \lambda_\circ) \rightarrow R_6$
031	X⇄Y	-41	
032	STO7	35 07	$\sin(\lambda - \lambda_\circ) \rightarrow R_7$
033	R↓	-31	
034	×	-35	
035	+	-55	
036	RCL2	36 02	
037	RCL4	36 04	
038	×	-35	
039	STO4	35 04	$\cos L_\circ' \sin L' \rightarrow R_4$
040	RCL1	36 01	
041	RCL5	36 05	
042	×	-35	
043	RCL6	36 06	
044	×	-35	
045	-	-45	
046	RCL5	36 05	
047	RCL7	36 07	
048	×	-35	
049	X⇄Y	-41	
050	→P	34	
051	R↑	16-31	
052	→P	34	
053	R↓	-31	
054	R/S	51	Display $\triangle$
055	GSB0	23 00	
056	R/S	51	Display $Z_\circ$
057	RCL2	36 02	
058	RCL7	36 07	
059	CHS	-22	
060	×	-35	
061	RCL5	36 05	
062	RCL1	36 01	
063	×	-35	
064	RCL6	36 06	
065	RCL4	36 04	
066	×	-35	
067	-	-45	
068	→P	34	
069	*LBL0	21 00	
070	X⇄Y	-41	
071	0	00	
072	X⇄Y	-41	Make Azimuth Positive
073	X>Y?	16-34	
074	RTN	24	
075	3	03	
076	6	06	
077	0	00	
078	+	-55	
079	RTN	24	
080	*LBLC	21 13	Convert Geographic → Geocentric Latitude ($L \rightarrow L'$)
081	TAN	43	
082	RCL8	36 08	
083	×	-35	
084	TAN^{-1}	16 43	
085	RTN	24	
086	*LBLD	21 14	
087	.	-62	
088	9	09	
089	9	09	Elliptical constant
090	3	03	
091	3	03	
092	0	00	
093	5	05	
094	STO8	35 08	
095	RTN	24	
096	*LBLE	21 15	Spherical constant
097	1	01	
098	STO8	35 08	
099	RTN	24	
100	R/S	51	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	2

REGISTERS

0	1	2	3	4	5	6	7	8	9
	$\sin L_\circ'$	$\cos L_\circ'$	$\lambda_\circ$	Used	Used	Used	Used	$(1-\alpha)^2$	

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title HEAT FLOW - GEOPHYSICS

Contributor's Name Hewlett Packard

Address 1000 N.E. Circle Blvd.

City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables

Given:	Decay constant of radioactive element (years^{-1})	λ
	Atomic mass of radioactive element (grams)	MA
	Energy lost upon radioactive decay, mass def. (Mev)	MD
	Density of rock mass with earth (gm/cm^3)	σ
	Thickness of rock mass (km)	H

Calculate:

1) Heat generated (CAL/gram year)

HG = λ*(Calories/Mev)*(Atoms/Atomic Mass)*Mass Difference/Atomic Mass

HG = λ*A*B*MD/MA where A=3.82735**-14 CAL/Mev

B=6.02472** 12 Atoms/Atomic Mass

2) Heat generation Units (Cal/cm^3 sec ppm)

HGU = HG* Density/C

= HG* σ/C where C=3.1536**13 sec/year ppm

3) Heat flow (Cal/cm^2 sec ppm)

HF = H.G.U. *Thickness (Km) * 10^{+5} Mev = million electron volts

ppm = parts per million

Given: Heat generation units (Cal/cm^3 sec ppm) "A"

(Continued on next page)

Operating Limits and Warnings

Program Description I

Program Title

Contributor's Name

Address

City **State** **Zip Code**

Program Description, Equations, Variables

Given: Conductivity of radioactive layer (Cal/cm sec°C) "K"
Depth at which temperature desired (km) "Z"
Thickness of Radioactive layer (km) "H"

Calculate the temperature at "Z" due to radioactivity (°C)

$$T_z = \text{Tsurface} + \frac{AH\ Z}{K} - \frac{A\ Z^2}{2K} \quad (Z < H)$$

$$= \text{Tsurface} + \frac{AH^2}{2K} \quad (Z \geq H)$$

Calculate the temperature at the bottom of a layered section due to heat flow from below "Q" (Cal/ cm^2 sec) (°C)

$$T_\circ = Q \sum Zi/Ki,$$ Zi and Ki are the thickness and conductivity of each layer

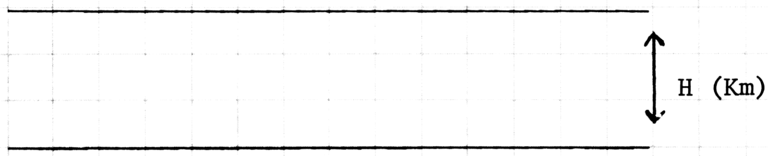
Compute the temperature at the bottom of the i-th layer

$$T = T_z + T_\circ \ (°C)$$

Operating Limits and Warnings

Program Description II

Sketch(es)



Sample Problem(s) 1. Calculate the heat generated, heat generation units, and heat flow due to the decay of 238 U.

$\lambda = 1.54 \times 10^{-10}$ years $^{-1}$

M_A = 238 grams

MD = 47.4 Mev

Density of layer = 3g/cc

Thickness = 1.5 Km

2. Given: Radioactive layer 1 Km thick

Conductivity of radioactive layer 5×10^{-3} Cal/cm sec °C

Heat Generator Unit. 50×10^{-13} Cal/cm^3 sec ppm

Four additional layers each 1 Km thick

Conductivity of each layer:

$K_1 = 5 \times 10^{-3}$

$K_2 = 10 \times 10^{-3}$

$K_3 = 2 \times 10^{-3}$

$K_4 = 4 \times 10^{-3}$

Heat flow from below of 9.0476×10^{-7}

a. Compute the temperature at 3 Km assuming no heat from below

b. Compute the temperature at the bottom of all layers (at 5 Km)

Solution(s)

1. [D] 1.54 [EEX] 10 [CHS] [ENTER ↑]

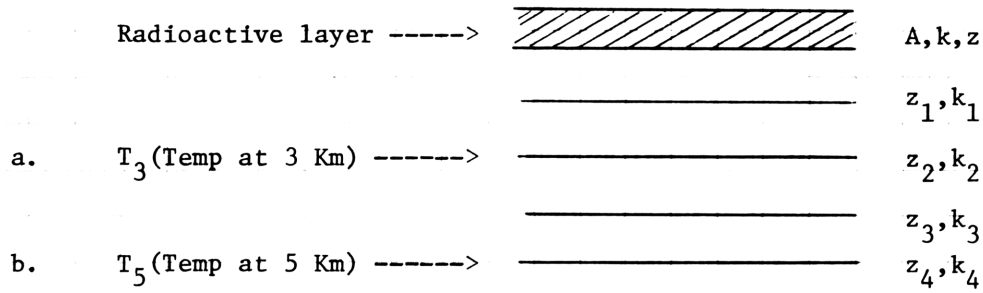
238 [ENTER ↑] 47.4 [A] → 7.072269600-01 ***
Cal/gm year

(Continued on next page)

Reference(s) This program is a modification of the Users' Library Program Nos. 03496A and 03628A, submitted by G. B. Young.

Program Description II

Sketch(es) 2.



Sample Problem(s)

Solution(s) (Continued)

3 [B] → 6.727805936-14 ***
Cal/cm^3 sec ppm

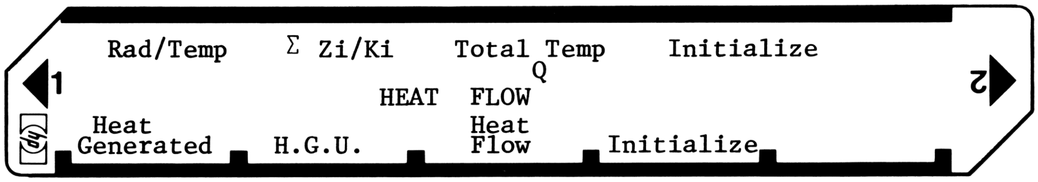
1.5 [C] → 1.009170890-08 ***
Cal/cm^2 sec ppm

a. [f] [D] 1 [ENTER ↑] 3 [ENTER ↑] 5 [EEX] 3 [CHS] [ENTER ↑]
50 [EEX] 13 [CHS] [f] [A] → 5.000000000+00 ***
°C

b. 1 [ENTER ↑] 5 [EEX] 3 [CHS] [f] [B]
1 [ENTER ↑] 10 [EEX] 3 [CHS] [f] [B]
1 [ENTER ↑] 2 [EEX] 3 [CHS] [f] [B]
1 [ENTER ↑] 4 [EEX] 3 [CHS] [f] [B]
9.0476 [EEX] 7 [CHS] [f[[C] → 9.999980000+01 ***
°C

Reference(s)

User Instructions



STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Load program				
2	To calculate temperature at any depth go				
	to Step 7.				
3	Initialize		D		
4	Enter decay constant - λ	$Years^{-1}$	ENT ↑		
	Enter atomic mass - M_A	gms	ENT ↑		
	Enter mass difference, M_D, and calculate				
	heat generated	Mev	A		Cal/gm yr.
5	Compute heat generation units,				
	H.G.U. Enter density	g/cm^3	B		Cal/Cm^3 sec ppm
6	Compute heat flow at surface.				
	Enter thickness of radioactive layer.	Km	C		Cal/Cm^2 sec ppm
7	To initialize for calculating				
	temperature and not using prior H.G.U.		f	D	
8	Compute temperature of depth due to radio-				
	activity				
	Enter thickness of radioactive layer	Km	ENT ↑		
	Enter depth at which temperature desired	Km	ENT ↑		
	Enter conductivity of radioactive layer	Cal/Cm sec° C	ENT ↑		
	If prior HGU is to be used from				
	Step 5.		f	A	°C
	or Enter HGU to be used.	Cal/Cm^3 sec ppm	f	A	°C
9	Compute Σ Zi/Ki				
	Enter Zi thickness	Km	ENT ↑		
	Enter Ki thickness	Cal/cm sec° C	f	B	
	Repeat Step 9 for each layer				
10	Compute temperature at bottom of ith layer				
	Enter heat flow (Q) due to				
	heat from below	Cal/Cm^2 sec	f	C	°C

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLD	21 14		057	SCI	-12	
002	SCI	-12	Initialize	058	DSP9	-63 09	Initialize and
003	DSP9	-63 09		059	CF1	16 22 01	clear flag 1
004	RTN	24		060	RTN	24	
005	*LBLA	21 11	Mass Difference	061	*LBLa	21 16 11	Compute temp due to
006	STO3	35 03	(Mev/atom)	062	F1?	16 23 01	Rad. Layer
007	R↓	-31		063	GTO1	22 01	Test for heat flow
008	STO2	35 02	Atomic Mass(gms)	064	STO6	35 06	I Program use
009	R↓	-31		065	R↓	-31	H.G.U.
010	STO1	35 01	Decay constant(yrs^{-1})	066	*LBL1	21 01	
011	2	02		067	RCL6	36 06	
012	.	-62		068	X⇄Y	-41	
013	3	03		069	÷	-24	
014	0	00		070	R↓	-31	
015	5	05		071	STO8	35 08	
016	8	08		072	X>Y?	16-34	Test for depth >
017	8	08	Cal * Atoms	073	GTO9	22 09	thickness
018	EEX	-23	Mev Atomic Mass	074	*LBL8	21 08	
019	1	01		075	STO7	35 07	
020	0	00		076	R↑	16-31	
021	x	-35		077	x	-35	
022	RCL2	36 02		078	X⇄Y	-41	
023	÷	-24		079	RCL7	36 07	
024	RCL3	36 03		080	2	02	
025	x	-35		081	÷	-24	
026	STO4	35 04	Heat generated	082	-	-45	
027	PRTX	-14	(Cal/gmyear)	083	x	-35	
028	RTN	24		084	EEX	-23	
029	*LBLB	21 12		085	1	01	
030	STO5	35 05	Density(gm/cc)	086	0	00	
031	RCL4	36 04		087	x	-35	
032	x	-35		088	RCL8	36 08	Depth at which temp
033	3	03		089	STO7	35 07	desired
034	.	-62		090	X⇄Y	-41	
035	1	01		091	STO8	35 08	Temp due to rad.
036	5	05	See/year ppm	092	PRTX	-14	(°C)
037	3	03		093	RTN	24	
038	6	06		094	*LBL9	21 09	
039	EEX	-23		095	CLX	-51	
040	1	01		096	R↓	-31	
041	3	03		097	ENT↑	-21	
042	÷	-24		098	GTO8	22 08	
043	STO6	35 06	Cal/cm^3 sec ppm	099	*LBLb	21 16 12	Compute $\Sigma\ ^{Zi}/Ki$
044	PRTX	-14	H.G.U.	100	÷	-24	
045	SF1	16 21 01		101	EEX	-23	
046	RTN	24		102	5	05	
047	*LBLC	21 13		103	x	-35	
048	RCL6	36 06		104	ST+9	35-55 09	$\Sigma\ ^{Zi}/Ki$
049	x	-35		105	RTN	24	
050	EEX	-23		106	*LBLc	21 16 13	Compute total temp.
051	5	05		107	STO1	35 01	
052	x	-35	Heat flow	108	RCL9	36 09	
053	STO7	35 07	(Cal/cm^2 sec ppm	109	STx1	35-35 01	
054	PRTX	-14		110	RCL8	36 08	
055	RTN	24		111	ST+1	35-55 01	
056	*LBLd	21 16 14		112	RCL1	36 01	

REGISTERS

0	1 Total Temp (°C)	2	3	4	5	6 H.G.U.	7 Depth at which Temp desired	8 Temp due to Rad. (°C)	9 Σ εi/Ki
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

97 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
113	FRTX	-14	Total temp (°C)
114	RTN	24	
115	R/S	51	

LABELS

A Heat Gen	B HGU	C Heat Flow	D Init.	E
a Used	b Used	c Used	d Init.	e
0	1	2	3	4
5	6	7	8	9

FLAGS

0	
1	Used
2	
3	

SET STATUS

FLAGS	ON	OFF
0	☐	☒
1	☐	☒
2	☐	☒
3	☐	☒

TRIG	
DEG	☒
GRAD	☐
RAD	☐

DISP	
FIX	☒
SCI	☐
ENG	☐
n	2

Program Description I

Program Title PHYSICAL PROPERTIES OF SEAWATER

Contributor's Name JAMES W. ELKINS

Address PIERCE HALL - CEPP; HARVARD UNIVERSITY

City CAMBRIDGE **State** MA **Zip Code** 02138

Program Description, Equations, Variables THE THERMAL CONDUCTIVITY OF SEA WATER (K) as a function of temperature and pressure (S = 34.994 ‰) is calculated from:

$$K = 5.5286 \times 10^{-3} + 3.4025 \times 10^{-7} P + 1.8364 \times 10^{-5} T - 3.3058 \times 10^{-9} T^3 \quad (\mathrm{W cm deg^{-1}})$$

where T = temperature °C and P = pressure in bars.

THE FREEZING POINT OF SEA WATER (T_f) as a function of salinity and depth (meters) is

$$T_f(°C) = -0.0137 - 0.051990 \, S‰ - 0.00007225 \, (S‰)^2 - 0.000758 \, z$$

where z is depth in meters and S‰ is the salinity.

THE SURFACE TENSION OF CLEAN SEA WATER as a function of temperature and salinity is

$$E = \text{Surface tension } (\mathrm{N m^{-1}}) = 10^3 \, (75.64 - 0.144 \, T + 0.0221 \, S‰)$$

where T is the temperature (°C) and S‰ is the salinity.

Operating Limits and Warnings Note K(T, P) is a function of temperature and pressure, T_f(S‰, z) is a function of salinity and depth, and Surface tension E(T, S‰) is a function of temperature and salinity. Sometimes seawater is given in chlorinity (Cl‰) instead of salinity (S‰). The conversion relation is S‰ = 1.80655 Cl‰.

Program Description II

Sketch(es)

Sample Problem(s) Calculate the thermal conductivity (K in $W cm deg^{-1}$), the Freezing point of sea water, and the surface tension of clean sea water (Nm^{-1}), if a given volume of seawater at the surface (z = 0 meters) is at 20°C, S = 34.994‰, and pressure = 100 bars.

Solution(s)

[f] [A]	→	0.0000
[f] [B]	→	1.0000
20 [A]	→	20.0000*** (°C)
34.994 [B]	→	34.9940*** (‰)
100 [C]	→	100.0000*** (bar)
[E]	→	-1.9215*** (°C)
[f] [C]	→	5.9035 -03*** ($W cm deg^{-1}$)
[f] [E]	→	7.3533 -02*** (Nm^{-1})

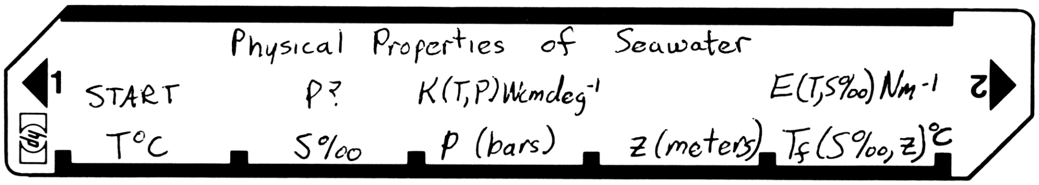
Reference(s)

Freezing point: Doherty, B.T. and Kester, D.R. (1974) J. Mar. Res., 17, 679

Surface tension: Fleming, R.H and Revelle, R.R., (1939), "Recent Marine Sediments" (N. Trask ed.) Amer. Soc. Petrol. Geol., Tulsa, Oklahoma.

Thermal conductivity: Castelli, V.J., Stanley, E.M. and Fischer, E.C. (1974). Deep-Sea Res., 21, 311.

User Instructions



STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Load both sides of card				
2	Initialize the program		f	A	0.0000
3	Print option		f	B	1.0000
4	Enter temperature (°C)	°C		A	°C
5	Enter salinity (‰)	S‰		B	S‰
6	Enter pressure (bars)	bars		C	bars
7	Enter depth (meters)	meters		D	meters
8	Calculate freezing point				
	Tf (S‰, z) °C			E	°C
9	Calculate thermal conductivity				
	K(T,P) Wcmdeg⁻¹		f	C	Wcmdeg⁻¹
10	Calculate surface tension				
	E(T,S‰) Nm⁻¹				Nm⁻¹

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLa	21 16 11	Initialize
002	CLRG	16-53	
003	P⇄S	16-51	
004	CLRG	16-53	
005	5	05	
006	.	-62	
007	5	05	
008	2	02	
009	8	08	
010	6	06	
011	EEX	-23	
012	3	03	
013	CHS	-22	
014	STO0	35 00	
015	3	03	
016	.	-62	
017	4	04	
018	0	00	
019	2	02	
020	5	05	
021	EEX	-23	
022	7	07	
023	CHS	-22	
024	STO1	35 01	
025	1	01	
026	.	-62	
027	8	08	
028	3	03	
029	6	06	
030	4	04	
031	EEX	-23	
032	5	05	
033	CHS	-22	
034	STO2	35 02	
035	3	03	
036	.	-62	
037	3	03	
038	0	00	
039	5	05	
040	8	08	
041	CHS	-22	
042	EEX	-23	
043	9	09	
044	CHS	-22	
045	STO3	35 03	
046	0	00	
047	.	-62	
048	0	00	
049	1	01	
050	3	03	
051	7	07	
052	CHS	-22	
053	STO4	35 04	
054	.	-62	
055	0	00	
056	5	05	
057	1	01	
058	9	09	
059	9	09	
060	CHS	-22	
061	STO5	35 05	
062	7	07	
063	.	-62	
064	2	02	
065	2	02	
066	5	05	
067	CHS	-22	
068	EEX	-23	
069	5	05	
070	CHS	-22	
071	STO6	35 06	
072	7	07	
073	.	-62	
074	5	05	
075	8	08	
076	CHS	-22	
077	EEX	-23	
078	4	04	
079	CHS	-22	
080	STO7	35 07	
081	7	07	
082	5	05	
083	.	-62	
084	6	06	
085	4	04	
086	STO8	35 08	
087	.	-62	
088	1	01	
089	4	04	
090	4	04	
091	CHS	-22	
092	STO9	35 09	
093	.	-62	
094	0	00	
095	2	02	
096	2	02	
097	1	01	
098	STOI	35 46	
099	0	00	
100	R/S	51	
101	*LBLb	21 16 12	Print?
102	F0?	16 23 00	
103	GTO0	22 00	
104	SF0	16 21 00	
105	1	01	
106	RTN	24	
107	*LBL0	21 00	
108	CF0	16 22 00	
109	0	00	
110	RTN	24	
111	R/S	51	
112	*LBLA	21 11	

REGISTERS

0	1	2	3	4	5	6	7	8	9
5.5286-03	3.4025-07	1.8364-05	-3.3058-09	-1.3700-02	-5.1990-02	-7.2250-05	-7.5800-04	7.5640+01	-1.4400-01
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I
T°C	S‰	P (bars)	z		2.2100-02

97 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
113	FIX	-11	STORE Temperature in A
114	F0?	16 23 00	
115	PRTX	-14	
116	STOA	35 11	
117	R/S	51	
118	*LBLB	21 12	STORE Salinity in B
119	FIX	-11	
120	F0?	16 23 00	
121	PRTX	-14	
122	STOB	35 12	
123	R/S	51	
124	*LBLC	21 13	STORE Pressure in C
125	FIX	-11	
126	F0?	16 23 00	
127	PRTX	-14	
128	STOC	35 13	
129	R/S	51	
130	*LBLD	21 14	STORE DEPTH in D
131	FIX	-11	
132	F0?	16 23 00	
133	PRTX	-14	
134	STOD	35 14	
135	R/S	51	
136	*LBLE	21 15	Calculate freezing point
137	RCLB	36 12	
138	ENT↑	-21	
139	X²	53	
140	RCL6	36 06	
141	×	-35	
142	X⇄Y	-41	
143	RCL5	36 05	
144	×	-35	
145	+	-55	
146	RCL4	36 04	
147	+	-55	
148	RCL7	36 07	
149	RCLD	36 14	
150	×	-35	
151	+	-55	
152	FIX	-11	
153	F0?	16 23 00	
154	PRTX	-14	
155	R/S	51	
156	*LBLc	21 16 13	Calculate thermal conductivity
157	RCLA	36 11	
158	ENT↑	-21	
159	ENT↑	-21	
160	3	03	
161	Yˣ	31	
162	RCL3	36 03	
163	×	-35	
164	X⇄Y	-41	
165	RCL2	36 02	
166	×	-35	
167	+	-55	
168	RCL1	36 01	

STEP	KEY ENTRY	KEY CODE	COMMENTS
169	RCLC	36 13	
170	×	-35	
171	+	-55	
172	RCL0	36 00	
173	+	-55	
174	SCI	-12	
175	F0?	16 23 00	
176	PRTX	-14	
177	R/S	51	
178	*LBLe	21 16 15	Calculate Surface Tension
179	RCL8	36 08	
180	RCL9	36 09	
181	RCLA	36 11	
182	×	-35	
183	+	-55	
184	RCLI	36 46	
185	RCLB	36 12	
186	×	-35	
187	+	-55	
188	EEX	-23	
189	3	03	
190	÷	-24	
191	SCI	-12	
192	F0?	16 23 00	
193	PRTX	-14	
194	R/S	51	
200			
210			
220			

LABELS

A T	B S‰	C P(bars)	D Z	E Tf
a START	b P?	c K(T,P)	d	e E(T,S‰)
0 No Print	1 Print	2	3	4
5	6	7	8	9

FLAGS

0	Print?
1	
2	
3	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	4

Program Description I

Program Title SIGMA-T AND AOU

Contributor's Name JAMES W. ELKINS

Address PIERCE HALL – CEPP; HARVARD UNIVERSITY

City CAMBRIDGE **State** MA **Zip Code** 02138

Program Description, Equations, Variables The first part of this program calculates sigma-t (σ_t), specific gravity (σ_ρ) for reference density ρ_4 of pure water at 4°C, and density of seawater (ρ) at atmospheric pressure. The formulas are

Sigma-t: $\sigma_t = \sum_i \sum_j b_{ij} T_{68}^i S^j$ where $T_{68} = T - 4.4 \times 10^{-6} (T)(100-T)$

T = temperature °C S = Salinity ‰

values of b_{ij} are given in Program Listing

Specific gravity: $\sigma_\rho = 0.999975\, \sigma_t - 0.025$

Density of seawater: $\rho = \sigma_\rho / 1000 + 1$ (grams/milliliter)

The second part calculates the apparent oxygen utilization (AOU) from the temperature, salinity, and dissolved oxygen (DO). DO can also be calculated from AOU. According to Weiss (1970), the solubility in ml(STP)/liter from water saturated air at a total pressure of one atmosphere is

$$\ln C^* = A_1 + A_2(100/T) + A_3 \ln(T/100) + A_4(T/100) + S‰(B_1 + B_2(T/100) + B_3(T/100)^2)$$

where T is the absolute temperature °K, A's and B's are constants given in Program Listing and S‰ is salinity. AOU is given by $AOU = C^* - C$ where C is the observed oxygen concentration.

Conversion constants used are 1 ml/l = 89.31 micro gram-atoms of O/liter ≈ 43.5 μmole/kg

Operating Limits and Warnings SIGMA-T part of program can not be used for pure water. Sometimes seawater is given in chlorinity (Cl‰) instead of salinity (S‰). The conversion relation is S‰ = 1.80655 Cl‰

Program Description II

Sketch(es)

Sample Problem(s) Calculate sigma-t (σ_t), specific density (σ_ρ), density (ρ), & AOU for a given volume of seawater at temperature, 27.65°C, salinity 34.055‰ (Cl = 18.851‰), and dissolved oxygen content (DO) of 2ml/liter.

Solution(s) KEYSTROKES.

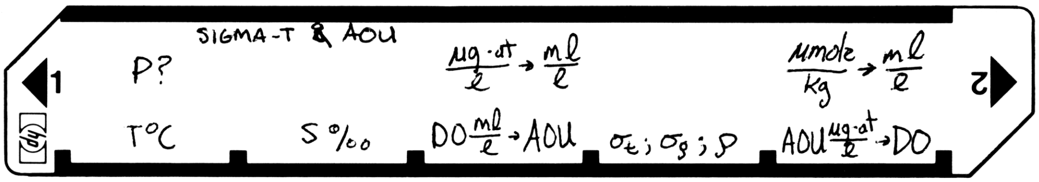
Keystrokes		Display
[f] [A]	→	1.0000
27.65 [A]	→	27.6500*** (T°C)
34.055 [B]	→	34.0550*** (‰S)
[D]	→	21.8305*** (σ_t)
[R/S]	→	21.8049*** (σ_ρ)
[R/S]	→	1.0218*** (ρ) g/ml
2 [C]	→	2.0000*** (DO ml/l)
	→	227.3250*** (AOU µg-at/l)

Reference(s) SIGMA-T: Fofonoff, N.P. and H. Bryden, 1975, Specific gravity and density of seawater at atmospheric pressure, Journal of Marine Science, Supplement, 33, 69-82.

AOU: Kester, D.A (1975), Dissolved Gases other than CO_2, p497, in Chemical Oceanography ed. J.P. Riley and G. Skirrow, 2nd edition, Academic Press.

Weiss, R.F. (1970), Deep-Sea Reasearch, 17, 721-735.

User Instructions



STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	LOAD CONSTANTS INTO STORAGE REGISTERS			
	$b_{40} = -2.04742 \times 10^{-6}$	b_{40}	STO 0	b_{40}
	IF STEP #1 — $b_{30} = 2.06066 \times 10^{-4}$	b_{30}	STO 1	b_{30}
	HAS BEEN — $b_{20} = -1.23382 \times 10^{-2}$	b_{20}	STO 2	b_{20}
	DONE, GTO #2. — $b_{10} = 9.92488 \times 10^{-2}$	b_{10}	STO 3	b_{10}
	$b_{41} = 5.60566 \times 10^{-8}$	b_{41}	STO 4	b_{41}
	$b_{31} = -6.63300 \times 10^{-6}$	b_{31}	STO 5	b_{31}
	$b_{32} = 5.40236 \times 10^{-8}$	b_{32}	STO 6	b_{32}
	$b_{22} = -2.88542 \times 10^{-6}$	b_{22}	STO 7	b_{22}
	$b_{21} = 2.71588 \times 10^{-4}$	b_{21}	STO 8	b_{21}
	$b_{11} = -5.92851 \times 10^{-3}$	b_{11}	STO 9	b_{11}
	$\frac{\mu g at/\ell}{m\ell/\ell} = 89.31$	89.31 μgat/mℓ	STO I	89.31 μgat/mℓ
	LOAD SECONDARY REGISTERS		f P⇄S	
	$b_{12} = 4.31145 \times 10^{-5}$	b_{12}	STO 0	b_{12}
	$b_{01} = 8.04296 \times 10^{-1}$	b_{01}	STO 1	b_{01}
	$b_{00} = -1.14000 \times 10^{-2}$	b_{00}	STO 2	b_{00}
	$A_1 = -1.734292 \times 10^{+2}$	A_1	STO 3	A_1
	$A_2 = 2.496339 \times 10^{+2}$	A_2	STO 4	A_2
	$A_3 = 1.433483 \times 10^{+2}$	A_3	STO 5	A_3
	$A_4 = -2.1849200 \times 10^{+1}$	A_4	STO 6	A_4
	$B_1 = -3.309600 \times 10^{-2}$	B_1	STO 7	B_1
	$B_2 = 1.425900 \times 10^{-2}$	B_2	STO 8	B_2
	$B_3 = -1.700000 \times 10^{-3}$	B_3	STO 9	B_3
	SWITCH BACK TO NORMAL MODE		f P⇄S	
	WRITE REGISTERS ON BOTH SIDES		f W/DATA	
	OF A CARD			
2	LOAD BOTH SIDES OF PROGRAM CARD			
3	PRINT MODE ?		f A	1.0000
4	ENTER TEMPERATURE °C	T °C	A	T °C
5	ENTER SALINITY S‰	S‰	B	S‰
6	CALCULATE σ_t	—	D	σ_t
	CALCULATE σ_θ	—	R/S	σ_θ
	CALCULATE ρ		R/S	ρ
7	CALCULATE AOU FROM DO	DO mℓ/ℓ	C	AOU μg-at/ℓ
8	CONVERT μg-at/liter to mℓ/liter	μg-at/liter	f C	mℓ/liter
9	CONVERT μmole/kg to mℓ/liter	μmole/kg	f E	mℓ/liter
10	CALCULATE DO FROM AOU	AOU μg-at/liter	E	DO mℓ/ℓ

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STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	STORE TEMPERATURE IN A
002	GSB9	23 09	
003	STOA	35 11	
004	R/S	51	
005	*LBLB	21 12	STORE SALINITY IN B
006	GSB9	23 09	
007	STOB	35 12	
008	R/S	51	
009	*LBLD	21 14	CALCULATE σ_t
010	RCLA	36 11	
011	ENT↑	-21	
012	ENT↑	-21	
013	ENT↑	-21	
014	1	01	
015	0	00	
016	0	00	
017	-	-45	
018	×	-35	
019	4	04	
020	.	-62	
021	4	04	
022	EEX	-23	
023	6	06	
024	CHS	-22	
025	×	-35	
026	+	-55	
027	STOC	35 13	
028	ENT↑	-21	
029	ENT↑	-21	
030	ENT↑	-21	
031	RCL0	36 00	
032	×	-35	
033	RCL1	36 01	
034	+	-55	
035	×	-35	
036	RCL2	36 02	
037	+	-55	
038	×	-35	
039	RCL3	36 03	
040	+	-55	
041	×	-35	
042	ENT↑	-21	
043	RCL4	36 04	
044	RCLC	36 13	
045	×	-35	
046	RCLB	36 12	
047	RCL6	36 06	
048	×	-35	
049	+	-55	
050	RCL5	36 05	
051	+	-55	
052	RCLC	36 13	
053	×	-35	
054	RCLB	36 12	
055	RCL7	36 07	
056	×	-35	
057	+	-55	
058	RCL8	36 08	
059	+	-55	
060	RCLC	36 13	
061	×	-35	
062	RCL9	36 09	
063	+	-55	
064	P⇄S	16-51	
065	RCL0	36 00	
066	RCLB	36 12	
067	×	-35	
068	+	-55	
069	RCLC	36 13	
070	×	-35	
071	RCL1	36 01	
072	+	-55	
073	RCLB	36 12	
074	×	-35	
075	+	-55	
076	RCL2	36 02	
077	+	-55	
078	P⇄S	16-51	
079	STOD	35 14	
080	GSB9	23 09	
081	R/S	51	
082	.	-62	Calculate σ_ρ
083	9	09	
084	9	09	
085	9	09	
086	9	09	
087	7	07	
088	5	05	
089	RCLD	36 14	
090	×	-35	
091	.	-62	
092	0	00	
093	2	02	
094	5	05	
095	-	-45	
096	STOC	35 13	
097	GSB9	23 09	
098	R/S	51	
099	RCLC	36 13	Calculate ρ
100	EEX	-23	
101	3	03	
102	÷	-24	
103	1	01	
104	+	-55	
105	GSB9	23 09	
106	R/S	51	
107	*LBL1	21 01	Calculate C*
108	P⇄S	16-51	
109	RCLA	36 11	
110	2	02	
111	7	07	
112	3	03	

REGISTERS

0	1	2	3	4	5	6	7	8	9
b_{40}	b_{30}	b_{20}	b_{10}	b_{41}	b_{31}	b_{32}	b_{22}	b_{21}	b_{11}
S0	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**
b_{12}	b_{01}	b_{00}	A_1	A_2	A_3	A_4	B_1	B_2	B_3

A	B	C	D	E	I
T °C	S ‰	USED	σ_t	C*	89.31

97 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
113	.	-62	
114	1	01	
115	5	05	
116	+	-55	
117	STOA	35 11	
118	RCL3	36 03	
119	RCL4	36 04	
120	RCLA	36 11	
121	÷	-24	
122	1	01	
123	0	00	
124	0	00	
125	x	-35	
126	+	-55	
127	RCLA	36 11	
128	1	01	
129	0	00	
130	0	00	
131	÷	-24	
132	LN	32	
133	RCL5	36 05	
134	x	-35	
135	+	-55	
136	RCL6	36 06	
137	RCLA	36 11	
138	x	-35	
139	1	01	
140	0	00	
141	0	00	
142	÷	-24	
143	+	-55	
144	RCL7	36 07	
145	RCL8	36 08	
146	RCLA	36 11	
147	x	-35	
148	1	01	
149	0	00	
150	0	00	
151	÷	-24	
152	+	-55	
153	RCLA	36 11	
154	1	01	
155	0	00	
156	0	00	
157	÷	-24	
158	X^2	53	
159	RCL9	36 09	
160	x	-35	
161	+	-55	
162	RCLB	36 12	
163	x	-35	
164	+	-55	
165	e^x	33	
166	STOE	35 15	
167	P⇄S	16-51	
168	RCLA	36 11	

STEP	KEY ENTRY	KEY CODE	COMMENTS
169	2	02	
170	7	07	
171	3	03	
172	.	-62	
173	1	01	
174	5	05	
175	-	-45	
176	STOA	35 11	
177	RCLE	36 15	
178	RTN	24	
179	*LBLC	21 13	Calculate AOU from DO
180	GSB9	23 09	
181	STOC	35 13	
182	GSB1	23 01	
183	RCLC	36 13	
184	-	-45	
185	RCLI	36 46	
186	x	-35	
187	GSB9	23 09	
188	R/S	51	
189	*LBLE	21 15	Calculate DO from AOU
190	ENT↑	-21	
191	RCLI	36 46	
192	÷	-24	
193	STOC	35 13	
194	GSB1	23 01	
195	RCLC	36 13	
196	-	-45	
197	R/S	51	
198	*LBLc	21 16 13	μg-at of O / l to ml of O_2 / l
199	RCLI	36 46	
200	÷	-24	
201	R/S	51	
202	*LBLe	21 16 15	μmole of O_2 / Kg to ml / l of O_2
203	4	04	
204	3	03	
205	.	-62	
206	5	05	
207	÷	-24	
208	R/S	51	
209	*LBLa	21 16 11	PRINT OPTIONAL
210	F0?	16 23 00	
211	GTO0	22 00	
212	SF0	16 21 00	
213	1	01	
214	RTN	24	
215	*LBL0	21 00	
216	CF0	16 22 00	
217	0	00	
218	RTN	24	
219	*LBL9	21 09	
220	F0?	16 23 00	
221	PRTX	-14	
222	RTN	24	
223	R/S	51	

LABELS

A T	B S‰	C ml/l → AOU	D σ_t; σ_θ; ρ	E AOU μg-at/l → DO ml/l
a P?	b	c μg-at/l → ml/l	d	e μmole/Kg → ml/l
0	1 C*	2	3	4
5	6	7	8	9 P?

FLAGS

0	PRINT?
1	
2	
3	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	4

Program Description I

Program Title ATMOSPHERIC THERMODYNAMICS

Contributor's Name Dick Jenssen

Address Meteorology Department/University of Melbourne

City Parkville AUSTRALIA **State** Victoria **Zip Code** 3052

Program Description, Equations, Variables General Description

The program computes variables usually determined from a thermodynamic diagram such as the skew-T/log p.

1. Given temperature (T) the saturation vapour pressure, e_s, may be found.
2. Given T and pressure (p) then the moist adiabatic lapse rate (Γ_m), the potential temperature (θ) and the saturation mixing ratio may be found.
3. Given T, p and relative humidity (u), then the lifting condensation level temperature (T_{LCL}) and pressure (p_{LCL}), and/or the wet-bulb temperature (T_w), and/or the equivalent temperature (T_e) may be found.
4. Given T, p, and T_w, the dew-point temperature (T_d) may be found.
5. Given T, p, and T_d the relative humidity may be found.

Thus given T, p, and <u>one</u> of u, T_w, T_d, the other two of the triad may be found, and hence all variables listed above may be determined.

Note that equivalent potential temperature may be found once T_e is known.

Note that actual mixing ratio (q) may be found from q_s and u

EQUATIONS - See attached sheet.

Operating Limits and Warnings

Data in registers 0 through 8, and secondary registers 0 through 9 must be preset before program use: this data is best stored on a magnetic card.

Program Description II

Sketch(es)

Sample Problem(s) DATA: p = 900 mb; T = 10°C; U = 0.6 (relative humidity 60%)

Find all other variables

KEYSTROKES	OUTPUT		
(LOAD DATA INTO STORAGE REGISTERS 0.7 and S0-S9 USING TABLE ON P.9 of 9 OR DATA CARD SIDES 1 and 2)			
10 (ENTER) 900 (f) (D)	10.000	°C	= T
(f) (E)	12.261	mb	= e_s
(C)	0.507	°C/100m	= Γ_m
(RCL) (D)[1], (D)	18.662	°C	= θ
(RCL) (D)[1] (E)	8.625	gm/Kgm	= q_s
.6(f)(A)(R/S)	6.255	°C	= T_w (also stores U)
(f)(B)(R/S)	2.668	°C	= T_d (also stores T_w)
(f)(C)	2.668		(to store T_d)
(B)	23.766	°C	= T_e
(D)	32.850	°C	= θ_e
(RCL)(B)[2](f)(E)	7.397	mb	= e(T) (vapour pressure)
(A)	1.381	°C	= T_{LCL}
(R/S)	807.802	mb	= p_{LCL}
(RCL)(B)[2](E)	5.175	gm/Kgm	= q
or (RCL)(D)[1](E) (RCL)(C)[3](X)	5.175	gm/Kgm	= q

NOTES: 1. T is stores in Register D

2. Td is stored in Register B

3. U is stored in Register C

Reference(s) See attached sheets: "Summary of Equations" (Jenssen)

User Instructions

$U \rightarrow T_w$ | $Tw \rightarrow Td$ | $Td \rightarrow U$ | Set T, p: $\rightarrow es$

1 ATMOSPHERIC THERMODYNAMICS 2

$\rightarrow T_{LCL}$ & p_{LCL} | $\rightarrow Te$ | $\rightarrow \Gamma m$ | $T \rightarrow \theta$ | qs

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	LOAD DATA IN R0-R7, RS0-RS9 FROM TABLE P.9 of 9				
	OR FROM DATA CARD (SIDES 1 and 2)				
2	LOAD SIDE 1, SIDE 2 OF PROGRAM CARD				
3	FOR SATURATION VAPOUR PRESSURE ONLY:				
	Set temperature T	T °C	f	E	e_s mb
4	FOR MOIST ADIABATIC LAPSE RATE, POTENTIAL				
	TEMPERATURE, SATURATION MIXING RATIO				
4a	Set temperature T	T °C	enter		
	Set pressure p	p mb	f	D	T °C
4b	For moist adiabatic lapse rate, Γm		C		Γm°C/100m
4c	For potential temperature, θ				
	Set temperature (this may be any temperature)	T' °C	D		θ(T')°C
4d	For saturation mixing ratio,				
	Set temperature (any value)	T' °C	E		q_s(p,T')
5	FOR LIFTING CONDENSATION LEVEL TEMPERATURE				gm/kgm
	AND PRESSURE, EQUIVALENT TEMPERATURE, WET-				
	BULB TEMPERATURE				
5a	Set relative humidity U ($0 \leq U \leq 1$).	U	f	A	
	If U is not known go to step 6 or 7 first				
	For wet-bulb temperature, T_w		R/S		Tw °C
5b	Then, for lifting condensation level data		A		T_{LCL} °C
			R/S		P_{LCL} °C
5c	And/or, for equivalent temperature, T_e		B		Te °C
	For equivalent potential temperature, θ_e		D		θ_e °C
6	TO FIND DEW POINT TEMPERATURE				
	Set wet-bulb temperature, Tw	T_w °C	f	B	
	Then		R/S		T_d °C
	If w not known, go to step 5a or 7				
7	TO FIND RELATIVE HUMIDITY				
	Set dew-point temperature, Td	T_d °C	f	C	
	Then		R/S		U
	If Td not known, go to step 5a or 6				
8	FOR MIXING RATIO (U known)				
	Do steps 4a, 4d. Then set U	U	X		q(T,p)mb
	(Td unknown)				
	Do step 4a. Set Td (or compute it)	Td °C	E		q(T,p)mb

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STEP	KEY ENTRY	KEY CODE	COMMENTS
001	g LBLf e	32 25 15	
	RCL 0	34 00	
	+	61	
	h 1/x	35 62	
	RCL 1	34 01	
	x	71	
	g e^x	32 52	
	RCL 2	34 02	
	x	71	
010	h RTN	25 22	
	f LBL E	31 25 15	
	RCL E	34 15	
	h x⇄y	36 52	
	g GSBf e	32 22 15	
	÷	81	
	1	01	
	−	51	
	h 1/x	35 62	
	RCL 3	34 03	
020	x	71	
	h RTN	35 22	
	g LBLf d	32 25 14	
	STO E	33 15	
	h x⇄y	35 52	
	STO D	33 14	
	h RTN	35 22	
	g LBLf b	32 25 12	
	STO A	33 11	
	h RTN	35 22	
030	f GSB E	31 22 15	
	RCL D	34 14	
	RCL 6	34 06	
	x	71	
	RCL 7	34 07	
	+	61	
	RCL D	34 14	
	RCL A	34 11	
	−	51	
	x	71	
040	h STI	35 33	
	RCL 4	34 04	
	x	71	
	−	51	
	1	01	
	RCL 5	34 05	
	h RCI	36 34	
	x	71	
	+	61	
	÷	81	
050	h STI	35 33	
	RCL E	34 15	
	x	71	
	h RCI	36 34	
	RCL 3	34 03	
	+	61	
	÷	81	
	RCL 2	34 02	
	÷	81	
	f LN	31 52	
060	h 1/x	35 62	
	RCL 1	34 01	
	x	71	
	RCL 0	34 00	
	−	51	
	h RTN	35 22	
	g LBLf c	32 25 13	
	STO B	33 12	
	h RTN	25 22	
	RCL B	34 12	
070	f GSB E	31 22 15	
	RCL D	34 14	
	f GSB E	31 22 15	
	÷	81	
	h RTN	35 22	
	g LBLf a	32 25 11	
	STO C	33 13	
	h RTN	35 22	
	RCL D	34 14	
	f GSB E	31 22 15	
080	x	71	
	STO 8	33 08	
	RCL 5	34 05	
	x	71	
	RCL 4	34 04	
	+	61	
	RCL 6	34 06	
	RCL D	34 14	
	x	71	
	RCL 7	34 07	
090	+	61	
	x	71	
	STO 9	33 09	
	RCL D	34 14	
	x	71	
	STO + 8	33 61 08	
	RCL D	34 14	
	3	03	
	1	01	
	CHS	42	
100	h STI	35 33	
	h R↓	35 53	
	ENTER	41	
	ENTER	41	
	f GSB E	31 22 15	
	STO A	33 11	
	h x⇄y	35 52	
	RCL 9	34 09	
	x	71	
	+	61	
110	RCL 8	34 08	
	−	51	
	RCL 0	34 00	

REGISTERS

0	1	2	3	4	5	6	7	8	9
			CONSTANTS: SEE SHEET LABELED "DATA"					Used	Used

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
			CONSTANTS: SEE SHEET LABELED "DATA"						

A	B	C	D	E	I
T_w	T_d	U	T	p	Used

STEP	KEY ENTRY	KEY CODE	COMMENTS
	h R↑	35 54	
	+	61	
	g x^2	32 54	
	RCL 1	34 01	
	h x≷y	35 52	
	÷	81	
	RCL A	34 11	
120	x	71	
	RCL 9	34 09	
	−	51	
	÷	81	
	+	61	
	h LSTx	35 82	
	h ABS	35 64	
	.	83	
	0	00	
	1	01	
130	−	51	
	f x>0	31 81	
	GTO (i)	22 24	
	h R↓	35 53	
	h RTN	35 22	
	g LBL A	31 25 11	
	RCL D	34 14	
	g GSBf e	32 22 15	
	RCL C	34 13	
	x	71	
140	RCL D	34 14	
	f GSB 0	31 22 00	
	÷	81	
	f PS	31 42	
	RCL 4	34 04	
	h y^x	35 63	
	RCL 5	34 06	
	x	71	
	RCL 6	34 06	
	f PS	31 42	
150	−	51	
	R/S	84	
	f GSB 0	31 22 00	
	RCL D	34 14	
	f GSB 0	31 22 00	
	÷	81	
	RCL E	34 15	
	x	71	
	h RTN	35 22	
	f LBL B	31 25 12	
160	RCL D	34 14	
	f GSB E	31 22 15	
	RCL C	34 13	
	x	71	
	f PS	31 42	
	RCL 2	34 02	
	h y^x	35 63	
	RCL 3	34 03	
	x	71	

STEP	KEY ENTRY	KEY CODE	COMMENTS
	f PS	31 42	
170	RCL D	34 14	
	+	61	
	h RTN	35 22	
	f LBL D	31 25 14	
	f PS	31 42	
	RCL 0	34 00	
	+	61	
	EEX	43	
	3	03	
	RCL E	34 15	
180	÷	81	
	RCL 1	34 01	
	h 1/x	35 62	
	h y^x	35 63	
	x	71	
	RCL 0	34 00	
	−	51	
	f PS	31 42	
	h RTN	35 22	
	f LBL C	31 25 13	
190	RCL D	34 14	
	g GSBf e	32 22 15	
	RCL E	34 15	
	÷	81	
	RCL D	34 14	
	f PS	31 42	
	RCL 0	34 00	
	+	61	
	÷	81	
	h STI	35 33	
200	RCL 7	34 07	
	x	71	
	RCL 9	34 09	
	+	61	
	h RCI	35 34	
	RCL D	34 14	
	RCL 0	34 00	
	+	61	
	÷	81	
	RCL 8	34 08	
210	x	71	
	1	01	
	+	61	
	÷	81	
	f PS	31 42	
	h RTN	35 22	
	f LBL 0	21 25 00	
	f PS	31 42	
	RCL 0	34 00	
	+	61	
220	RCL 1	34 01	
	f PS	31 42	
	h y^x	35 63	
	h RTN	35 22	

LABELS

A $U \to T_w$	B $T_w \to T_d$	C $T_d \to U$	D Input T,p	E $E \to e_s$
a Get T_{LCL} P_{LCL}	b Get T_e	c Get Γ_m	d $T \to \theta$	e Get q_s
0 Used by A	1	2	3	4
5	6	7	8	9

FLAGS

0
1
2
3

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	3

SUMMARY OF EQUATIONS: ATMOSPHERIC THERMODYNAMICS

T is temperature (°C): U is relative humidity $(0 \leq U \leq 1)$:

T_d is dewpoint temperature (°C): and T_w is wet bulb temperature (°C).

Note that U is defined to be

$U = q_s(T_d)/q_s(T)$ where q_s is saturation mixing ratio.

1. Saturation Vapor Pressure

$$e_s(T) = 269782133.1 \exp\left[\frac{-4271.071252}{T + 242.6254453}\right] \text{ mb}$$

2. Saturation Mixing Ratio

$$q_s(T) = 624.46846\, e_s(T)/\{p - e_s(T)\} \quad \text{gm/Kgm}$$

3. Relation between T, T_d, T_w and U

3a. T and U give T_w from the solution of

$$q_s(T_w) + XT_w - q_s(T_d) - XT = 0$$

where

$$X = (a + bT)(c + dq_s(T_d))$$

$a = 1.041185084$ $\quad$ $b = -1.029627108 \times 10^{-3}$

$c = 0.36664504$ $\quad$ $d = 3.823128854 \times 10^{-3}$

3b. T and T_w give T_d from

$$q_s(T_d) = \frac{q_s(T_w) - c(a + bT)(T - T_w)}{1 + b(a + bT)(T - T_w)} \quad \text{gm/Kgm}$$

Then

$$T_d = \frac{-4271.071252}{\ln\left[\{pq_s(T_d)/\left(624.46846 + q_s(T_d)\right)\} \quad /269782133.1\right]}$$

$$-242.6254453 \qquad {}^\circ C$$

3c. T and T_d give U from

$$U = q_s(T_d)/q_s(T)$$

Given any one of U, T_w, T_d then the other two can be found by scanning 3(a), (b), (c) cyclically. If <u>two</u> of U, T_w, T_d are given, then the third can be found from the appropriate routine.

4. <u>Lifting Condensation Level Temperature</u>

$$T_{LCL} = 1670.312578 \left[\frac{Ue_s(T)}{(T + 273.26)^{3.496503497}} \right]^{.151978365} - 111.2137286°C$$

5. <u>Lifting Condensation Level Pressure</u>

$$P_{LCL} = p \left[(T_{LCL} + 273.16)/(T + 273.16) \right]^{3.496503497} \text{ mb}$$

6. <u>Equivalent Temperature</u>

$$T_e = T + 2.40073851 \left[Uq_s(T) \right]^{1.062445218} \quad °C$$

7. <u>Potential Temperature</u>

$$\theta = (T + 273.16)(1000/p)^{2/7} - 273.16 \quad °C$$

T in °C

8. <u>Moist Adiabatic Lapse Rate</u>

$$\Gamma_m = \frac{.9754738016 + 5284.246205\ e_s(T)/pt}{1 + 8384300.279\ e_s(T)/pt^2} \quad °C/100m$$

NOTE: t = T + 273.16 °K

DATA:

Register	0	242.6254453
	1	-4271.071252
	2	269782133.1
	3	624.46846
	4	0.36664504
	5	$3.823128854 \times 10^{-3}$
	6	$-1.029627108 \times 10^{-3}$
	7	1.041185084

SECONDARY REGISTER

0	273.16
1	3.496503497
2	1.062445218
3	2.400738510
4	0.151978365
5	1670.312578
6	111.2137286
7	5284.246205
8	8384300.279
9	0.975473802

NOTES

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