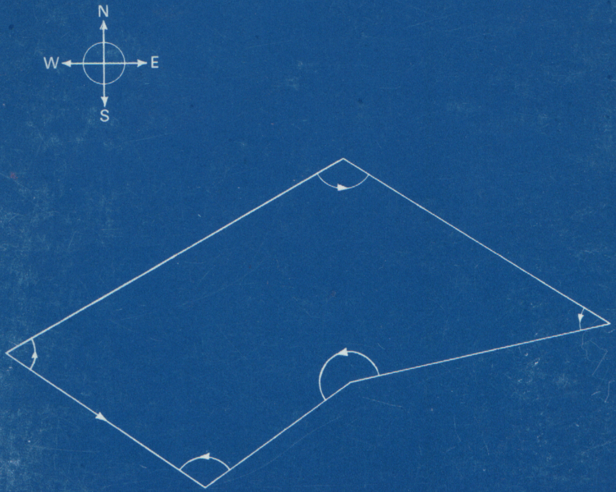
HEWLETT PACKARD

HP-35

SURVEYING



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INTRODUCTION

This booklet shows how programs written originally for the 9100A desk calculator can be turned into sequences of key operations for the model 35 hand calculator.
The versatility of this small machine is such that one can use a "programming" form of the following simple design to turn quite complicated expressions into continuous sequences with the minimum of paper and pencil recording.

For example, the beginning of the first sequence is:

STORE														Δ_E
T						E_A		E_A	E_B	E_B	E_B	Δ_N	Δ_N	Δ_N
Z				E_A		N_B		N_A	E_A	E_A	E_B	E_B	Δ_N	Δ_N
Y		E_A		N_A		E_B		N_B	N_A	N_B	E_A	E_B	E_B	E_B
X	E_A	E_A	N_A	N_A	E_B	E_B	N_B	E_B	N_B	N_A	Δ_N	E_A	Δ_E	Δ_E
KEY		↑		↑		↑		$x \rightleftarrows y$	R↓	$x \rightleftarrows y$	−	R↓	−	STO

It is not suggested that the examples are necessarily the shortest way to do each particular problem but they do illustrate how small an amount of recording is required with such a calculator, – a facility which reduces one of the major sources of error in survey calculations – that of copying numbers down incorrectly. One of the most used sequences for the surveyor will be the conversion of degrees, minutes and seconds to decimal degrees and this can be most conveniently achieved thus:

Deg, ENTER↑, Min, ENTER↑, Secs, ENTER↑, 60, ÷, +, 60, ÷, +.

Bearing and distance from coords.

$$\text{Tan Brg.}_{AB} = \frac{E_B - E_A}{N_B - N_A} = \frac{\Delta E}{\Delta N}$$

$$\text{Length}_{AB} = \frac{\Delta E}{\sin\ \text{Brg.}}$$

EXAMPLE

E_A 4768.23
N_A 2194.53

E_B / N_B	5419.08 / 3244.66	+	+	1235.47 / 31° 47′ 23.4″
E_C / N_C	5419.08 / 1144.40	–	+	1235.47 / 148° 12′ 36.6″
E_D / N_D	4117.38 / 1144.40	–	–	1235.47 / 211° 47′ 23.4″
E_E / N_E	4117.38 / 3244.66	+	–	1235.47 / 328° 12′ 36.6″

Note: Will not accept 90°, 180°, 270° or 360°

i.e. when $E_A = E_\rho$; or $N_A = N_\rho$

Bearing and distance from coords.

Enter	Key	Record
E_A	ENTER↑	
N_A	ENTER↑	
E_B	ENTER↑	
N_B	x⇄y	
	R↓	
	x⇄y	
	−	Sign of display + or − = (a)
	R↓	
	−	Sign of display + or − = (b)
	STO	
	R↓	
	R↓	
	RCL	
	x⇄y	
	÷	
	arc	
	tan	
0, 180, 360*	+	Brg°
	ENTER↑	
	sin	
	RCL	
	x⇄y	
	÷	L
	CL x	
β°	−	
60	×	β′°
β′	−	
60	×	β″°

* Enter 0, 180 or 360 according to (a) and (b) above

(a)	(b)	Enter
+	+	0
−	+	180
−	−	180
+	−	360

Coords. from bearing and distance

$E_B = E_A + L \cdot \sin Brg.$

$N_B = N_A + L \cdot \cos Brg.$

EXAMPLE

E_A	4768.23		
N_A	2194.53		
β	31° 47′ 23″	E_B	5419.08
L	1235.47	N_B	3244.66
β	148° 12′ 37″	E_C	5419.08
L	1235.47	N_C	1144.40
β	211° 47′ 23″	E_D	4117.38
L	1235.47	N_D	1144.40
β	328° 12′ 37″	E_E	4117.38
L	1235.47	N_E	3244.66

Coords. from bearing and distance

Enter	Key	Record
β°	ENTER↑	
β'	ENTER↑	
β''	ENTER↑	
60	÷	
	+	
60	÷	
	+	
	ENTER↑	
	sin	
	$x \rightleftarrows y$	
	cos	
	$x \rightleftarrows y$	
L	ENTER↑	
	R↓	
	×	
	R↓	
	×	
	$x \rightleftarrows y$	
	CL x	
E_A	ENTER↑	
N_A	R↓	
	$x \rightleftarrows y$	
	R↓	
	+	E_B
	R↓	
	+	N_B

Traverse – anticlockwise, internal angles

$$E_n = E_{(n-1)} + L_{(n-1)} \sin Brg_{(n-1 \rightarrow n)}$$

$$N_n = N_{(n-1)} + L_{(n-1)} \cos Brg_{(n-1 \rightarrow n)}$$

$$Brg_{(n-1 \rightarrow n)} = Brg_{(n-2 \rightarrow n-1)} + 180 + \alpha_{n-1} \; (-360)$$

EXAMPLE

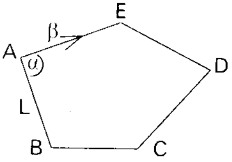
β 51° 32′ 24″

E_0 10000.0
N_0 10000.0

α_1	70° 46′ 48″	L_1	943.35
α_2	107° 12′ 01″	L_2	791.50
α_3	213° 24′ 50″	L_3	847.88
α_4	44° 18′ 49″	L_4	1345.94
α_5	104° 17′ 32″	L_5	1492.61

	E	N
1	10797.20	9495.64
2	11399.24	10009.46
3	12240.68	10113.76
4	11169.28	10928.41
0′	10000.50	10000.05

Traverse – anticlockwise, internal angles



Enter	Key	Record
β°	ENTER↑	
β'	ENTER↑	
β''	ENTER↑	
60	÷	
	+	
60	÷	
	+	
	STO	

Enter	Key	Record
α_n°	ENTER↑	
α_n'	ENTER↑	
α_n''	ENTER↑	
60	÷	
	+	
60	÷	
	+	
	RCL	
	+	
	* STO	
	ENTER↑	
	sin	
	$x \rightleftarrows y$	
	cos	
L_n	ENTER↑	
	R↓	

Enter	Key	Record
	×	
	R↓	
	×	
	$x \rightleftarrows y$	
	CL x	
E_n	+	E_{n+1}
N_n	$x \rightleftarrows y$	
	R↓	
	$x \rightleftarrows y$	
	+	N_{n+1}
	RCL	
180	+	
	* STO	

(After * STO, return to α_n°.)

* If display is > 360 enter 360 −

Traverse – clockwise, internal angles

$$E_n = E_{n-1} + L_{n-1} \sin Brg_{(n-1 \rightarrow n)}$$

$$N_n = N_{n-1} + L_{n-1} \cos Brg_{(n-1 \rightarrow n)}$$

$$Brg_{(n-1 \rightarrow n)} = Brg_{(n-2 \rightarrow n-1)} + 180 - \alpha_{n-1} \ (\pm 360)$$

EXAMPLE

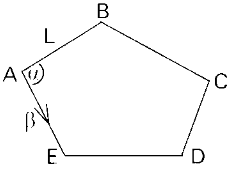
β = 122° 19′ 09″

E_0 10000.0
N_0 10000.0

α_1	70° 46′ 48″	L_1	1492.61
α_2	104° 17′ 32″	L_2	1345.94
α_3	44° 18′ 49″	L_3	847.88
α_4	213° 24′ 50″	L_4	791.50
α_5	107° 12′ 01″	L_5	943.35

	E	N
1	11168.76	10928.37
2	12240.17	10113.74
3	11398.73	10009.43
4	10796.69	9495.60
0′	9999.48	9999.95

Traverse – clockwise, internal angles



Enter	Key	Record
β°	ENTER↑	
β'	ENTER↑	
β''	ENTER↑	
60	÷	
	+	
60	÷	
	+	
	STO	
α_n°	ENTER↑	
α_n'	ENTER↑	
α_n''	ENTER↑	
60	÷	
	+	
60	÷	
	+	
	RCL	
	$x \rightleftarrows y$	
	−	
	*1 STO	
	ENTER↑	
	sin	
	$x \rightleftarrows y$	

Enter	Key	Record
	COS	
L_n	ENTER↑	
	R↓	
	×	
	R↓	
	×	
E_n	+	E_{n+1}
	R↓	
	R↓	
N_n	+	N_{n+1}
	RCL	
180	+	
	*2 STO (→ to α_n°)	

*1 If display is < 0 enter 360 +

*2 If display is > 360 enter 360 −

Traverse using bearings

$$E_n = E_{n-1} + L_{n-1} \sin Brg_{(n-1 \rightarrow n)}$$

$$N_n = N_{n-1} + L_{n-1} \cos Brg_{(n-1 \rightarrow n)}$$

EXAMPLE

E_o 10000.0
N_o 10000.0

β_1	122° 19′ 12″	943.35
β_2	49° 31′ 13″	791.50
	⋮	⋮

E_1	10797.20	N_1	9495.64
E_2	11399.24	N_2	10009.46
	⋮		⋮

Traverse using bearings

Enter	Key	Record
E_o	STO	
N_o	ENTER↑	
→ β°	ENTER↑	
β'	ENTER↑	
60	÷	
	+	
β''	ENTER↑	
3600	÷	
	+	
	ENTER↑	
	sin	
	x⇄y	
	cos	
L_n	x⇄y	
	R↓	
	×	
	RCL	
	+	E_{n+1}
	STO	
	R↓	
	x⇄y	
L_n	×	
	+	N_{n+1}

Bowditch adjustment

Corrn. to N(E) = closing error N(E) ×

$$\times \frac{\text{Length of traverse leg}}{\text{Length of traverse}}$$

EXAMPLE

δE −0.506
δN −0.055
ΣL 5421.28

		dE	dN
L_1	943.35	−0.088	−0.009
L_2	791.50	−0.162	−0.018
L_3	847.88	−0.241	−0.026
L_4	1345.94	−0.367	−0.040
L_5	1492.61	−0.506	−0.055

Bowditch adjustment (running totals)

Enter	Key	Record
	CLR	
δE	ENTER↑	
δN	ENTER↑	
ΣL	ENTER↑	
	R↓	
	÷	
	R↓	
	$x \rightleftarrows y$	
	÷	
	$x \rightleftarrows y$	
	CL x	
▶ L_n	RCL	
	+	
	STO	
	R↓	
	ENTER↑	
	ENTER↑	
	RCL	
	×	dE
	R↓	
	$x \rightleftarrows y$	
	ENTER↑	
	ENTER↑	
	RCL	
	×	dN
	R↓	
	$x \rightleftarrows y$	

Solution of a triangle – using angles

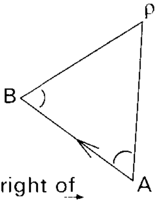
$$E_\rho = \frac{N_B - N_A + E_B \cot A + E_A \cot B}{\cot A + \cot B}$$

$$N_\rho = \frac{E_A - E_B + N_B \cot A + N_A \cot B}{\cot A + \cot B}$$

EXAMPLE

A	76° 39′ 43.9″
B	38° 21′ 19.7″
E_A	6134.82
N_A	5233.57
E_B	4239.11
N_B	3198.47
E_ρ	4479.32
N_ρ	6175.22

Solution of a triangle – using angles



ρ to right of direction $\vec{AB}$

Enter	Key	Record
A°	ENTER↑	
A′	ENTER↑	
A″	ENTER↑	
60	÷	
	+	
60	÷	
	+	
	tan	
	1/x	
	STO	
B°	ENTER↑	
B′	ENTER↑	
B″	ENTER↑	
60	÷	
	+	
60	÷	
	+	
	tan	
	1/x	

Enter	Key	Record
	ENTER↑	
	ENTER↑	
E_A	×	
N_A	−	
	RCL	
E_B	×	
	+	
N_B	+	
	x⇄y	
	ENTER↑	
	ENTER↑	
	RCL	
	+	
	x⇄y	
	R↓	
	÷	Eρ
	R↓	
	R↓	
	ENTER↑	
	ENTER↑	
E_A	x⇄y	
N_A	×	
	+	
E_B	−	
N_B	RCL	
	×	
	+	
	x⇄y	
	RCL	
	+	
	÷	Nρ

Solution of a triangle using bearings

$E_\rho = E_A + \Delta E_{A\rho}$
$N_\rho = N_A + \Delta N_{A\rho}$

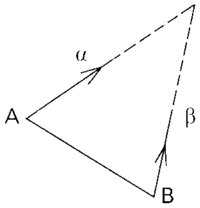
$$\Delta N_{A\rho} = \frac{\Delta E_{AB} - \Delta N_{AB} \tan \beta}{\tan \alpha - \tan \beta}$$

$$\Delta E_{A\rho} = \Delta N_{AB} \tan \alpha$$

EXAMPLE

α	39° 13′ 43″
β	107° 03′ 55″
E_A	380 907.86
N_A	433 483.44
E_B	381 018.09
N_B	436 590.08
E_ρ	382 957.98
N_ρ	435 994.58

Solution of a triangle using bearings



Enter	Key	Record
β°	ENTER↑	
β'	ENTER↑	
β''	ENTER↑	
60	÷	
	+	
60	÷	
	+	
	tan	
α°	ENTER↑	
α'	ENTER↑	
60	÷	
	+	
α''	ENTER↑	
3600	÷	
	+	
	tan	
E_B	ENTER↑	

Enter	Key	Record
E_A	−	
	STO	
N_B	ENTER↑	
N_A	−	
	R↓	
	R↓	
	R↓	
	×	
	RCL	
	−	
	R↓	
	STO	
	−	
	x⇄y	
	R↓	
	÷	
	ENTER↑	
	ENTER↑	
	RCL	
	×	
E_A	+	$E\rho$
	R↓	
N_A	+	$N\rho$

Solution of a triangle using bearings

$$E\rho = \frac{N_B - N_A - E_A \cot \alpha - E_B \cot \beta}{\cot \alpha - \cot \beta}$$

$$N\rho = \frac{E_B - E_A + N_A \tan \alpha - N_B \tan \beta}{\tan \alpha - \tan \beta}$$

EXAMPLE

α	39° 13′ 43″
β	107° 03′ 55″
E_A	380 907.86
N_A	433 483.44
E_B	381 018.09
N_B	436 590.08
Tan α	0.816 411 95
Tan β	−3.257 573 87
$E\rho$	382 957.98
$N\rho$	435 994.58

Solution of a triangle using bearings

Enter	Key	Record
α°	ENTER↑	
α'	ENTER↑	
α''	ENTER↑	
60	÷	
	+	
60	÷	
	+	
	tan	Tan α
	1/x	
	STO	
β°	ENTER↑	
β'	ENTER↑	
β''	ENTER↑	
60	÷	
	+	
60	÷	
	+	
	tan	Tan β
	1/x	
	ENTER↑	
	ENTER↑	
E_A	RCL	
	×	
N_A	x⇄y	
	−	
E_B	x⇄y	
	R↓	
	×	
	x⇄y	
	R↓	
	+	
N_B	−	
1	CHS	
	×	

Enter	Key	Record
	RCL	
	x⇄y	
	R↓	
	x⇄y	
	R↓	
	x⇄y	
	−	
	÷	$E\rho$
Tan α	STO	
	ENTER↑	
Tan β	ENTER↑	
E_A	ENTER↑	
N_A	ENTER↑	
	RCL	
	×	
	x⇄y	
	−	
E_B	+	
	x⇄y	
	ENTER↑	
	ENTER↑	
N_B	×	
	x⇄y	
	R↓	
	−	
	R↓	
	R↓	
	RCL	
	x⇄y	
	−	
	x⇄y	
	R↓	
	÷	$N\rho$

α = Bearing $A\rho$
β = Bearing $B\rho$

Stadia tacheometry

$H_B = H_A + h_i \pm dh - M$

where

$dh = 50 \times (U - L) \sin 2V$

$D = 100\,(U - L) \cos^2 V$

EXAMPLE

H_A	47.210
H_i	1.320

V	+4° 17′	−6° 38′	−7° 21′
U	3.144	3.055	2.817
L	1.761	2.278	0.731
M	2.452	2.667	1.774
D	137.53	76.66	205.19
H_B	56.378	36.948	20.289

Stadia tacheometry

Enter	Key	Record
H_A	ENTER↑	
h_i	+	
	STO	
→ $V°$	ENTER↑	
V'	ENTER↑	
60	÷	
	+	
	* CH S	
	ENTER↑	
	ENTER↑	
2	×	
	sin	
	$x \rightleftarrows y$	
	cos	
	ENTER↑	
	×	
U	ENTER↑	
L	−	
100	×	
	ENTER↑	
	R↓	
	×	D
	CL x	
2	÷	
	×	
M	−	
	RCL	
	+ (return to $V°$)	H_B

H_A = Reduced level of A
h_i = Ht of instrument
V = Vertical angle
* If −ive, use CH S where shown
U, L, M = Upper, Lower and Middle hair readings
D = Horizontal distance
H_B = Reduced level of B

Cut and fill (all cut or all fill)

$$\text{Area} = \frac{s^2(b - nh)^2}{n(s^2 - n^2)} - \frac{b^2}{n}$$

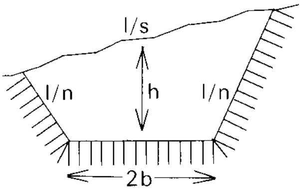
where h = depth of cut (fill) on the centre line

EXAMPLE

s	8
n	2
h	5
b	20

Area 280

Cut and fill (all cut or all fill)



Enter	Key	Record
s	ENTER↑	
	STO	
n	ENTER↑	
	ENTER↑	
	×	
	RCL	
	ENTER↑	
	×	
	x⇄y	
	−	
	x⇄y	
	ENTER↑	
	ENTER↑	
h	×	
	RCL	
	R↓	
	R↓	
	STO	
	×	
	x⇄y	
	ENTER↑	
	×	
	x⇄y	
	÷	

Enter	Key	Record
b	ENTER↑	
	R↓	
	x⇄y	
	R↓	
	+	
	ENTER↑	
	×	
	x⇄y	
	R↓	
	×	
	R↓	
	R↓	
	×	
	RCL	
	÷	
	−	Area

Cut and fill (part cut, part fill)

$$A_1 = \frac{(b + sh)^2}{2(s - n)}$$

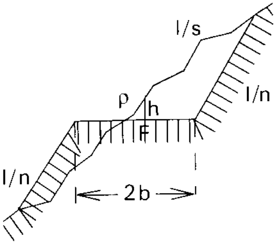
$$A_2 = \frac{(b - sh)^2}{2(s - n)}$$

EXAMPLE

s	8
n	3
h	2
b	20

$Area_1$	1.6
$Area_2$	129.6

Cut and fill (part cut, part fill)



Which of A_1 and A_2 is cut and which fill depends on whether ρ is to the right or left of centre line F

Enter	Key	Record
s	ENTER↑	
	ENTER↑	
n	−	
2	×	
	STO	
	x⇄y	
h	×	
	ENTER↑	
	ENTER↑	
b	ENTER↑	
	R↓	
	+	
	ENTER↑	
	×	
	R↓	
	−	
	ENTER↑	
	×	
	RCL	
	÷	A_1

Enter	Key	Record
	R↓	
	CL x	
	RCL	
	÷	A_2

Trigonometrical heights

$$dh = D \,.\, \tan\frac{(\beta \pm \alpha)}{2}\left[1 + \frac{(h_1 + h_2)}{2R} + \frac{D^2}{12R^2}\ \ldots\right]$$

EXAMPLE

α	$-0°\ 16'\ 54.3''$
β	$0°\ 02'\ 48.5''$
D	100 120 ft.
h_1	876.4 ft.
Δh	– ive
R	20 900 000 ft.

Δh -287.07 ft.

Trigonometric heights

Enter	Key	Record
α°	ENTER↑	
α'	ENTER↑	
α''	ENTER↑	
60	÷	
	+	
60	÷	
	+	
	STO	
β°	ENTER↑	
β'	ENTER↑	
β''	ENTER↑	
60	÷	
	+	
60	÷	
	+	
	RCL	
	$*_1$ + or −	
2	÷	
	tan	
D	STO	
	×	
	RCL	
	x⇄y	
	$*_2$ CH S	
	STO	
	ENTER↑	
h,	ENTER↑	
	+	
	+	
2	÷	
	x⇄y	

Enter	Key	Record
	ENTER↑	
	×	
12	÷	
R	RCL	
	x⇄y	
	STO	
	x⇄y	
	R↓	
	÷	
	RCL	
	÷	
	x⇄y	
	RCL	
	÷	
	+	
1	+	
	×	± dh

R = 6 370 000 m
= 20 900 000 ft.
$*_1$ = + if angles of opposite sign
− if same sign
$*_2$ = if dh is negative enter CH S

Area of a triangle – using 3 sides

$$A = \sqrt{s(s-a)(s-b)(s-c)}$$

EXAMPLE

a	143.28
b	207.69
c	138.71

Area 9901.501

Area of a triangle – using 3 sides

Enter	Key	Record
a	ENTER↑	
b	ENTER↑	
c	STO	
	x⇄y	
	ENTER↑	
	R↓	
	+	
	x⇄y	
	ENTER↑	
	R↓	
	+	
2	÷	
	RCL	
	x⇄y	
	STO	
	x⇄y	
	−	
	RCL	
	×	
	RCL	
	x⇄y	
	R↓	
	x⇄y	
	−	
	x⇄y	
	RCL	
	x⇄y	
	−	
	×	
	×	
	√x	Area

Area from coordinates

$$A = \frac{1}{2}\left[E_1(N_2 - N_n) + E_2(N_3 - N_1) + \ldots + E_n(N_1 - N_{n-1})\right]$$

EXAMPLE

	E	N
1	100.29	491.72
2	447.68	823.14
3	774.43	648.49
4	753.48	318.75
5	610.91	72.23
6	229.34	223.35

Area 328 277.19

Area from coordinates

Enter	Key	Record
	CLR	
E_1	ENTER↑	
N_1	ENTER↑	
→ E_n	ENTER↑	
	R↓	
	×	
	RCL	
	x⇄y	
	−	
	STO	
N_n	ENTER↑	
	R↓	
	×	
	RCL	
	+	
	STO	
	R↓	
	x⇄y ← (repeat from E_n)	
	* RCL	
	ENTER↑	
2	÷	Area

* Repeat entry of coords. for 1st. point at end then continue for area

Cosine formula – for angle

$$\cos A = \frac{b^2 + c^2 - a^2}{2bc}$$

EXAMPLE

a	143.2
b	184.7
c	122.4

A 50° 46′ 45″.3

Cosine formula – for angle

Enter	Key	Record
a	ENTER↑	
	×	
b	ENTER↑	
	STO	
	×	
	x⇄y	
	−	
c	ENTER↑	
	ENTER↑	
	R↓	
	×	
	+	
	RCL	
	x⇄y	
	R↓	
	×	
2	×	
	x⇄y	
	R↓	
	÷	
	arc	
	cos	A°.
A°	−	
60	×	A′.
A′	−	
60	×	A″.

Cosine formula – for side

$a^2 = b^2 + c^2 - 2bc \cdot \cos A$

EXAMPLE

A	50° 46′ 45″.3
b	184.7
c	122.4
a	143.2

Cosine formula – for side

Enter	Key	Record
A°	ENTER↑	
A′	ENTER↑	
A″	ENTER↑	
60	÷	
	+	
60	÷	
	+	
	COS	
b	ENTER↑	
	ENTER↑	
	×	
	STO	
	R↓	
	×	
c	ENTER↑	
	ENTER↑	
	×	
	RCL	
	+	
	STO	
	R↓	
	×	
2	×	
	RCL	
	$x \rightleftarrows y$	
	−	
	$\sqrt{x}$	a

Scale factor

$$F = F_o \, [1 + Q^2 \, . \, P + Q^4 \, . \, R]$$

where $F_o = 0.999601272$
$P \simeq 0.012289 - 24 \, . \, N \, 10^{-12}$
$Q = (E - 400000) \, 10^{-6}$
$R = 253 \times 10^{-7}$

EXAMPLE

E_A	626 238
N_A	302 646
E_{CM}	400 000
F	1.000 229 71

Scale factor

Enter	Key	Record
E_A	ENTER↑	
E_{CM}	−	
	E EX	
	CH S	
	6	
	×	
	ENTER↑	
	×	
	STO	
N_A	ENTER↑	
24	E EX	
	CH S	
	1	
	2	
	×	
0.012289	$x \rightleftarrows y$	
	−	
	RCL	
	×	
1	+	
253	E EX	
	CH S	
	7	
	RCL	
	ENTER↑	
	×	
	×	
	+	
0.999601272	×	F

Refractive index – radio waves

$$(n_r - 1)\,10^6 = N = \frac{103.49}{T}(\rho - e) + \frac{86.26}{T}\left(1 + \frac{5728}{T}\right)e$$

where

$e = e' - 0.00066\,\rho\,(t - t')$

$$\log_{10} e' = 0.660887 + 3.154882\left(\frac{t'}{100}\right) -$$

$$-1.274528\left(\frac{t'}{100}\right)^2 + 0.375114\left(\frac{t'}{100}\right)^3$$

EXAMPLE

t'	2.6° C
t	4.0° C
ρ	646.5 mm Hg
N	273.0

Refractive index – radio waves

Enter	Key	Record
t′	ENTER↑	
100	÷	
	STO	
	ENTER↑	
	ENTER↑	
	ENTER↑	
	×	
	ENTER↑	
	R↓	
	×	
0.375114	×	
	x⇄y	
3.154882	×	
	+	
	x⇄y	
1.274528	×	
	−	
0.660887	+	
0.434294	÷	
	e^x	
	ENTER↑	
	RCL	
100	×	
t	STO	
	x⇄y	
	−	
ρ	ENTER↑	
	R↓	
	×	
0.00066	×	
	−	

Enter	Key	Record
	ENTER↑	
	R↓	
	−	
	x⇄y	
	CL x	
273	RCL	
	+	
	STO	
	÷	
103.49	×	
	x⇄y	
86.26	×	
	RCL	
	÷	
5748	RCL	
	÷	
1	+	
	×	
	+	N

t′ = Wet bulb °C
t = Dry bulb °C
ρ = mm Hg
N = $(n-1)10^6$

Refractive index – light waves

$$(n_l - 1) = \frac{(n_g - 1)}{(1 + \alpha t)} \cdot \frac{p}{760} - \frac{55e}{(1 + \alpha t)\,10^9}$$

α = 0.00367
n_g = 1.000 3045
e = as for No. 19

EXAMPLE

t′ 2.6° C
t 4.0° C
p 646.5 mm Hg
n 1.000 2550

Refractive index – light waves

Enter	Key	Record
t′	ENTER↑	
100	÷	
	STO	
	ENTER↑	
	ENTER↑	
	ENTER↑	
	×	
	ENTER↑	
	R↓	
	×	
0.375114	×	
	$x \rightleftarrows y$	
3.154882	×	
	+	
	$x \rightleftarrows y$	
1.274528	×	
	−	
0.660887	+	
0.434294	÷	
	e^x	
	ENTER↑	
	RCL	
100	×	
t	STO	
	$x \rightleftarrows y$	
	−	
ρ	ENTER↑	
	R↓	
	×	
0.00066	×	
	−	

Enter	Key	Record
55	×	
	E EX	
	CH S	
	9	
	×	
	RCL	
0.00367	×	
1	+	
	STO	
	×	
	$x \rightleftarrows y$	
760	÷	
	RCL	
	÷	
3045	E EX	
	CH S	
	7	
	×	
	$x \rightleftarrows y$	
	−	
1	+	n

t′ = Wet bulb °C
t = Dry bulb °C
ρ = mm Hg

Reduction of EDM to spheroid

$$s = D - \frac{D^3}{24R^2} \cdot K - \frac{dh^2}{2D} - \frac{dh^4}{8D^3}$$

$$- \frac{D \, . \, dh}{2R} + \frac{s'}{24R^2}$$

where K = – · 44 for radio waves
= – · 23 for light waves

EXAMPLE

D	2582.063
h_1	1554.8
h_2	931.7
Radio	

s 2505.266

D = observed distance corrected for refractive index

Reduction of EDM to spheroid

Enter	Key	Record
D	ENTER↑	
	STO	
	×	
	RCL	
	×	
	7 (Radio) or 1 5 (Light)	
	×	
	3 8 4 (Radio) or 1 5 3 6 (Light)	
	÷	
6370000	ENTER↑	
	ENTER↑	
	R↓	
	×	
	÷	
	RCL	
	$x⇄y$	
	−	
	STO	
h_1	ENTER↑	
h_2	ENTER↑	
	R↓	
	+	
	RCL	
	×	
2	÷	
	$x⇄y$	
	ENTER↑	
	R↓	
	÷	
	RCL	
	$x⇄y$	
	−	
	STO	
h_1	−	
	ENTER↑	
	×	

Enter	Key	Record
	ENTER↑	
	ENTER↑	
	×	
	RCL	
	÷	
	RCL	
	÷	
	RCL	
	÷	
8	÷	
	RCL	
	$x⇄y$	
	R↓	
	÷	
2	÷	
	$x⇄y$	
	R↓	
	+	
	$x⇄y$	
	CL x	
	RCL	
	$x⇄y$	
	−	
	STO	
	ENTER↑	
	ENTER↑	
	×	
	×	
24	÷	
	$x⇄y$	
	ENTER↑	
	×	
	÷	
	RCL	
	+	s

Coefficient of refraction

$$K = \frac{1}{2}\left(1 - \frac{R \cdot \sin 1'' (\beta \pm \alpha)}{D}\right)$$

EXAMPLE

α $-0°\ 11'\ 17.8''$
β $-0°\ 08'\ 51.3''$
D 43 900.34

K = 0.0745

Coefficient of refraction

Enter	Key	Record
	CLR	
637	E EX	
	4	
	ENTER↑	
48.5	E EX	
	CH S	
	7	
	×	
	STO	
$\alpha°$	ENTER↑	
α'	ENTER↑	
α''	ENTER↑	
60	÷	
	+	
60	÷	
	+	
$\beta°$	ENTER↑	
β'	ENTER↑	
60	÷	
	+	
β''	ENTER↑	
3600	÷	
	+	
	* +	
3600	×	

Enter	Key	Record
D	÷	
	RCL	
	×	
1	$x \rightleftarrows y$	
	−	
2	÷	K

* If angles are of opposite signs, enter CH S
Vertical angles corrected for instrument and signal

Eccentric stn. correction

$$c'' = \frac{L_{op} \cdot \sin \beta}{L_{on} \cdot \sin 1''}$$

EXAMPLE

L_{op} 9.24 m

β_1	279° 55′ 10″	L_1	3040
β_2	57° 11′ 10″	L_2	4115

δ_1'' −617″
δ_2'' +389″

Eccentric stn. correction

Enter	Key	Record
L_{op}	STO	
β°	ENTER↑	
β'	ENTER↑	
β''	ENTER↑	
60	÷	
	+	
60	÷	
	+	
	sin	
	ENTER↑	
L_{on}	÷	
	RCL	
	×	
48.5	EEX	
	CHS	
	7	
	÷	$\pm\delta''_n$

L_{op} = Satellite distance
β = Bearings of rays reduced to OP as R.O.

(t − T) correction − approx.

$$\delta''_{AB} = (2E_A + E_B)\ (N_1 - N_2)\ /\ 6R^2 \sin 1''$$

$$\delta''_{BA} = (2E_B + E_A)\ (N_2 - N_1)\ /\ 6R^2 \sin 1''$$

EXAMPLE

E_A	626 238	(226 238)
E_B	651 410	(251 410)
N_A	302 646	
N_B	313 177	

δ''_{AB} $-6''.3$
δ''_{BA} $+6''.5$

(t−T) correction – approx.

Enter	Key	Record
E_A	* ENTER↑	
	ENTER↑	
	+	
	STO	
	x⇄y	
E_B*	ENTER↑	
	ENTER↑	
	+	
	x⇄y	
	R↓	
	+	
	R↓	
	CL x	
	RCL	
	+	
	x⇄y	
	CL x	
N_A	ENTER↑	
N_B	−	
	ENTER↑	
	CH S	
	R↓	
	×	
	R↓	
	×	
	x⇄y	
	CL x	
R	ENTER↑	
	×	
6	×	

Enter	Key	Record
48.5	E EX	
	CH S	
	7	
	×	
	ENTER↑	
	R↓	
	÷	
	R↓	
	x⇄y	
	÷	δ''_{AB}
	R↓	
	R↓	δ''_{BA}

R = 6,370,000 m
= 20,900,000 ft.
*E = Easting from central meridian
i.e. E_N − 400,000 m in UK

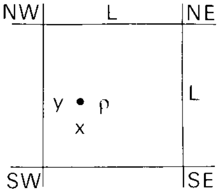
Interpolation of ht. in a square

$$H_P = \frac{y(SE-SW)}{L} + \frac{X}{L}\left[\frac{(NE-NW)y}{L} - \frac{(SE-SW)y}{L}\right]$$

EXAMPLE

L	50
y	23.62
X	7.14
SW	538.50
SE	540.00
NW	537.00
NE	538.50
H_P	538.99

Interpolation of HT in a square



Enter	Key	Record
x	ENTER↑	
y	ENTER↑	
L	ENTER↑	
	R↓	
	÷	
	STO	
	R↓	
	x⇄y	
	÷	
	x⇄y	
	R↓	
	ENTER↑	
	ENTER↑	
1	x⇄y	
	−	
	ENTER↑	
	ENTER↑	
1	RCL	
	−	
	STO	
	×	
SW	×	
	x⇄y	
	RCL	

Enter	Key	Record
1	−	
	CH S	
	x⇄y	
	ENTER↑	
	R↓	
	×	
SE	×	
	+	
	x⇄y	
1	−	
	CH S	
	ENTER↑	
	ENTER↑	
	RCL	
	×	
NW	×	
	x⇄y	
	R↓	
	+	
	x⇄y	
	CL x	
	RCL	
1	−	
	CH S	
NE	×	
	x⇄y	
	R↓	
	×	
	x⇄y	
	R↓	
	+	Hρ

Standard error

s. e of single observation $= \pm\sqrt{\frac{\lesssim r^2}{n-1}}$

s. e of mean value $= \pm\sqrt{\frac{\lesssim r^2}{n(n-1)}}$

EXAMPLE

10
14
12
8
11
12
7
10
11
15

$\bar{x}$	11.00
s. e_m	± 0.77
s. e_s	± 2.45

Standard error

Enter	Key	Record
	CLR	
x_1	ENTER↑	
	ENTER↑	
→ x_n	ENTER↑	
	R↓	
	+	
	$x \rightleftarrows y$	
	ENTER↑	
	R↓	
	$x \rightleftarrows y$	
	R↓	
	R↓	
	−	
	ENTER↑	
	×	
	RCL	
	+	
	STO (return to x_n)	
n	ENTER↑	
	R↓	
	÷	$\bar{x}$
	$x \rightleftarrows y$	
	−	
	ENTER↑	
	×	
	$x \rightleftarrows y$	
	ENTER↑	
	R↓	
	×	
	RCL	
	$x \rightleftarrows y$	

Enter	Key	Record
	−	
	STO	
	R↓	
	ENTER↑	
	ENTER↑	
1	−	
	ENTER↑	
	R↓	
	×	
	RCL	
	$x \rightleftarrows y$	
	÷	
	$\sqrt{x}$	$s.\,e_m$
	R↓	
	CL x	
	RCL	
	$x \rightleftarrows y$	
	÷	
	$\sqrt{x}$	$s.\,e_s$

$\bar{x}$ = Most probable value
$s.\,e_m$ = st. error of mean
$s.\,e_s$ = st. error of single observation

Azimuth by altitude of sun or stars

$$\tan \frac{z}{2} = \left[\sec s \,.\, \sin(s - H)\sin(s - \varnothing)\sec(s - \rho)\right]^{1/2}$$

where $s = \frac{1}{2}\left(H + \varnothing + \rho\right)$

EXAMPLE

H	22° 32′ 34″
∅	53° 29′ 19″
δ	−3° 21′ 56″

H°	22.°542 777 78
∅°	53.°488 611 11
δ°	−3.°365 555 56
ρ°	93.°365 555 56

Az. 131.°878 8928
= 131° 52′ 44.01″

Azimuth by altitude of sun or stars

Enter	Key	Record
H°	ENTER↑	
H′	ENTER↑	
H″	ENTER↑	
60	÷	
	+	
60	÷	
	+	H°.
	STO	
Ø°	ENTER↑	
Ø′	ENTER↑	
Ø″	ENTER↑	
60	÷	
	+	
60	÷	
	+	Ø°.
	RCL	
	+	
	STO	
δ°	ENTER↑	
δ′	ENTER↑	
δ″	ENTER↑	
60	÷	
	+	
60	÷	
	+	δ°.
	ENTER↑	
	* CH S	
*1	×	
90	x⇄y	

Enter	Key	Record
	−	ρ°.
	RCL	
	+	
2	÷	
	STO	
	cos	
	1/x	
	RCL	
H°.	−	
	sin	
	×	
	RCL	
Ø°.	−	
	sin	
	×	
	RCL	
ρ°.	−	
	cos	
	1/x	
	×	
	√x	
	arc	
	tan	
2	×	z°.

* = if δ is −ive, enter these two lines, otherwise omit

H = **corrected** altitude

Coords. round a circular curve

$Y = R(1 - \cos\psi)$
$X = R \cdot \sin\psi$

where ψ = angle subtended by

the arc $= \dfrac{\Sigma s}{R}$

EXAMPLE

R 286.4789

		Y	X
s_1	10	0.174	9.998
s_2	25	1.090	24.968
s_3	40	2.788	39.870
⋮	⋮	⋮	⋮

Coords. round a circular curve

Enter	Key	Record
R	ENTER↑	
	ENTER↑	
s	STO	
	$x \rightleftarrows y$	
	÷	
180	×	
π	÷	
	ENTER↑	
	sin	
	$x \rightleftarrows y$	
	cos	
1	$x \rightleftarrows y$	
	−	
	R↓	
	R↓	
	R↓	
	×	Y
	R↓	
	$x \rightleftarrows y$	
	×	X
	R↓	
	ENTER↑	
	ENTER↑	
S_n	RCL	
	+	

Y = "Easting"
X = "Northing"
s = chord lengths

Clothoid deflection angles

$$\tan\theta = \frac{l^2}{6RL} + \frac{l^6}{840(RL)^3} + \ldots$$

EXAMPLE

R	716.197		
L	100		
l_1	10	δ_1''	48″
l_2	20	δ_2''	192″
l_3	30	δ_3''	432″
⋮	⋮		⋮

Clothoid deflection angles

Enter	Key	Record
R	ENTER↑	
L	×	
	ENTER↑	
	ENTER↑	
	×	
	$x \rightleftarrows y$	
	ENTER↑	
	R↓	
	×	
840	×	
	STO	
	R↓	
	R↓	
6	×	
	R↓	
	R↓	
	CL x	
	RCL	
	÷	
	+	
	arc	
	tan	$\theta°$
3600	×	θ''
	CL x	
→ Σl_n	ENTER↑	
	×	
	ENTER↑	
	ENTER↑	
	×	
	$x \rightleftarrows y$	
	ENTER↑	
	R↓	
	×	
	$x \rightleftarrows y$	
	ENTER↑	
	R↓	
	$x \rightleftarrows y$	
	R↓	
	÷	

(After CL x, return to enter the next Σl_n.)

R = Radius at junction with circular arc

Σl_n = Running total of chord lengths

Vertical curve heights

$$h_x = b + g_1 x + \frac{(g_2 - g_1)x^2}{2L}$$

EXAMPLE

g_1	+ 3%
g_2	− 2%
L	385.24
b	389.26

x_1	4.76	h_1	389.40
x_2	24.76	h_2	389.96
⋮		⋮	

Vertical curve heights

Enter	Key	Record
g_1	ENTER↑	
	ENTER↑	
g_2	−	
200	÷	
L	÷	
	x⇄y	
100	÷	
	STO	
▶ x	ENTER↑	
	ENTER↑	
	×	
	x⇄y	
	RCL	
	×	
	R↓	
	×	
	x⇄y	
	R↓	
	−	
b	+	h_x
	R↓	
	CL x ◀ (return to x)	

g_1, g_2 = Percentage grades
L = Total length of curve
x = Distance along curve
b = Level at start of curve

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