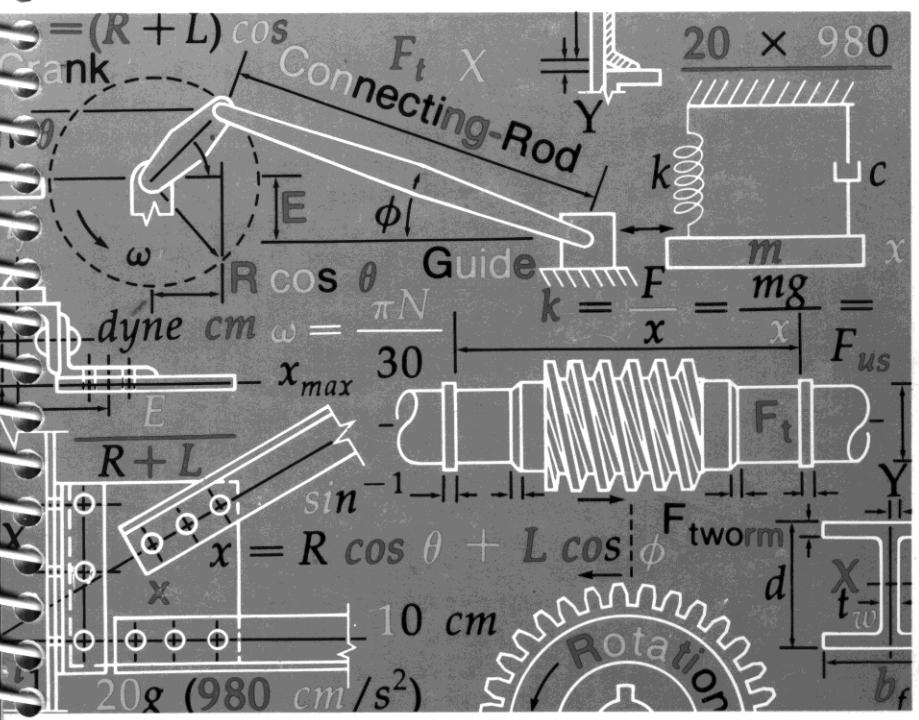


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Step-by-Step Solutions  
For Your HP Calculator

## Mechanical Engineering



HP-42S

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# **Mechanical Engineering**

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for Your HP-42S Calculator**



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# How To Use This Book

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Please take a moment to familiarize yourself with the formats used in this book.

**Organization.** Each chapter in this book covers a different area of mechanical engineering. Sections within each chapter highlight the use of each program. These sections are organized like this:

- Description of the program, including equations and variables used.
- Special remarks and limitations.
- General instructions.
- Keystroke examples.
- Program listings.

**About the Examples.** Unless otherwise stated, the keystrokes and displays shown in each section assume the following conditions:

- The required programs have been keyed into your calculator.
- The stack is clear and you're starting with the default display format (FIX 4). Generally this does not affect the results of the example, except that your displays may not exactly match the ones in this book.
- The SIZE is set to 25 registers (the default). The number of storage registers needed (if any) are listed under "Remarks."

As you work the examples, also remember that lowercase letters are displayed as uppercase letters when they appear in menu labels.

**If You Have a Printer.** Many of the programs in this book will produce printed output if printing is enabled. Press **PRINT** **▲** **PON** to enable printing.

If you are not using a printer, be sure to disable printing (**PRINT** **▲** **POFF**) to avoid losing results.

**About Program Listings.** It is assumed that you understand how to key programs into your calculator. If you're not sure, review part 2, "Programming," in the owner's manual.

If you print your programs, remember that the printer may print some characters differently than they are displayed. (For example, the  $\downarrow$  character is printed as  $\downarrow\downarrow$ .) Also note that some printers cannot print the angle character ( $\angle$ ).

**About the Subject Matter.** Discussions on the various topics included are beyond the scope of this book. Refer to basic texts on the subjects of interest. Many references are available in university libraries and in technical and college bookstores. The examples in this book demonstrate approaches to solving problems, but they do not cover the many ways to approach general problems in mechanical engineering.

*Our thanks to Dex Smith of TwentyEighth Street Publishing for developing this book.*

# Forces and Vectors

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## Vectors in the HP-42S

The HP-42S can represent a vector in two ways: as a complex number or a  $1 \times n$  matrix. Of course, you can use matrices for all your work with vectors. However, when you are working with coplanar vectors, there are advantages to using complex numbers:

- You can see both parts (coordinates) of each complex number. (The contents of a matrix can only be viewed while editing the matrix.)
- You can enter and display complex numbers using rectangular or polar coordinates. (Vectors stored as matrices are always in rectangular coordinates regardless of the current coordinate mode.)

# Using the “VEC” Program

The HP-42S provides most of the tools you will need for working with vectors. This program makes some of those tools easier to use by assigning them to the CUSTOM menu.

## Remarks.

- The “VEC” program sets flag 27 to display the CUSTOM menu.
- Registers  $R_{00}$ ,  $R_{01}$ , and  $R_{02}$  are used for temporary storage of the matrix elements. Therefore, the SIZE must be set to at least 3 storage registers (**MODES** **▼** **SIZE 3 ENTER**).

## Program Instructions.

1. Key the “VEC” program (listed on page 11) into your calculator.
2. Press **XEQ** **VEC** to execute the program.
3. Use the CUSTOM menu key assignments created by “VEC” for vector calculations.

**DOT** calculates the dot product of the vectors in the X- and Y-registers.

**CROSS** calculates the cross product of the vectors in the X- and Y-registers.

**UVEC** calculates the unit vector of the vector in the X-register.

**ST $\rightarrow$  [ ]** combines the coordinates in the X-, Y-, and Z-registers into a  $1 \times 3$  matrix in the X-register.

**[ ] $\div$  ST** returns the coordinates in a  $1 \times 3$  matrix to the X-, Y-, and Z-registers.

**POL** switches to Rectangular mode. (Press **REC** to return to Polar mode.)

**Example.** What is the unit vector of  $10\mathbf{i} - 3\mathbf{j} + 17\mathbf{k}$ ?

[XEQ] VEC

x: 0.0000  
DOT CROSS UVEC ST→0 0→ST POL

To enter the  $x$ -,  $y$ -, and  $z$ -coordinates into the X-, Y-, and Z-registers (respectively), enter the  $z$ -coordinate first.

17 [ENTER] 3 [+/-] [ENTER] 10

x: 10  
DOT CROSS UVEC ST→0 0→ST POL

Put the coordinates into vector (matrix) form.

ST+[]

x: [ 1x3 Matrix ]  
DOT CROSS UVEC ST→0 0→ST POL

Calculate the unit vector.

UVEC

x: [ 1x3 Matrix ]  
DOT CROSS UVEC ST→0 0→ST POL

Return the coordinates of the unit vector to the stack.

[]→ST

x: 0.5013  
DOT CROSS UVEC ST→0 0→ST POL

The  $x$ -coordinate of the unit vector is 0.5013 (to four decimal places).

R↓

x: -0.1504  
DOT CROSS UVEC ST→0 0→ST POL

The  $y$ -coordinate of the unit vector is -0.1504.

R↓

x: 0.8521  
DOT CROSS UVEC ST→0 0→ST POL

The  $z$ -coordinate of the unit vector is 0.8521.

## "VEC" Program Listing.

### Program:

```
00 C 136-Byte Program
01 LBL "VEC"
02 ASSIGN "DOT" TO 01
03 ASSIGN "CROSS" TO 02
04 ASSIGN "UVEC" TO 03
05 ASSIGN "ST+[]" TO 04
06 ASSIGN "[]+ST" TO 05
07 SF 27
08 LBL "REC■"
09 POLAR
10 ASSIGN "POL■" TO 06
11 RTN
12 LBL "POL■"
13 RECT
14 ASSIGN "REC■" TO 06
15 RTN

16 LBL "ST+[]"
17 STO 00
18 R+
19 STO 01
20 R+
21 STO 02
22 R+

23 3
24 ENTER
25 1
26 INDEX "REGS"
27 GETM
28 TRANS
29 RTN

30 LBL "[]+ST"
31 INDEX "REGS"
32 TRANS
33 PUTM
34 R+
```

### Comments:

Makes CUSTOM menu key assignments.

Stores the X-, Y-, and Z-register values into registers 00-02.

Gets a  $3 \times 1$  submatrix from the storage register matrix and transposes it to a  $1 \times 3$  matrix.

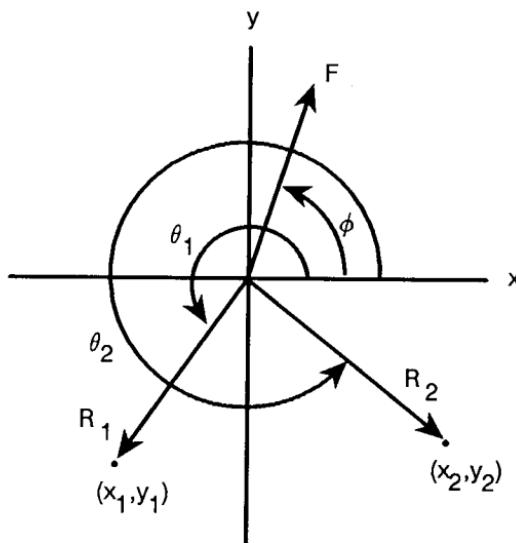
Transposes  $1 \times 3$  matrix and puts it into the storage register matrix. Recalls the vector elements from registers 00-02.

35 RCL 02  
36 RCL 01  
37 RCL 00  
38 END

---

## Static Equilibrium at a Point

This program calculates the two reaction forces necessary to balance two-dimensional resultant force vectors. The direction of the reaction forces must be specified as an angle relative to the arbitrary axis.



$$R_1 \cos \theta_1 + R_2 \cos \theta_2 = \sum F \cos \phi$$

$$R_1 \sin \theta_1 + R_2 \sin \theta_2 = \sum F \sin \phi$$

## Variables Used.

In Equations	Description	In Program
$\Sigma F$	Sum of forces.	$\Sigma F$
$\theta_1$	Angle of first reaction force.	$R1\angle$
$\theta_2$	Angle of second reaction force.	$R2\angle$

## Remarks.

- Angles are entered and displayed using the current angular mode of the calculator.
- Since complex numbers are used for output, angles are normalized to produce positive magnitudes.
- A positive value of force (tension) points away from the origin; a negative value (compression) points toward the origin.
- The program produces an error if  $R1\angle = R2\angle$ .
- This program sets Polar mode.
- Flags 21 and 55 are used to control printer output.

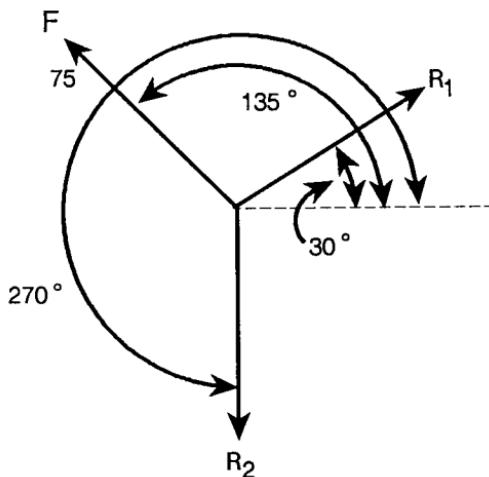
## Program Instructions.

1. Key the “ $\Sigma F$ ” program (listed on page 17) into your calculator.
2. Press **[ $\Sigma F$ ]** to execute the program.
3. Repeat these steps for each force:
  - a. Key in the magnitude of the force; press **[ENTER]**.
  - b. Key in the angle of the force (measured from the reference axis).
  - c. Optional: press **[COMPLEX]**. (If you skip this step, the program automatically converts your inputs into a complex number.)
  - d. Press **[ $\Sigma F+$ ]** to add the force. The current total force is displayed after each force is added.

If you enter a force incorrectly, you can delete it by adding an equal force in the opposite direction. If you notice the mistake immediately after entering it, press **[ $\pm/-$ ]** **[ $\Sigma F+$ ]**.

4. Store the angles of the reaction forces:
  - a. Key in  $R1\Delta$  and then press  $\boxed{R1\Delta}$ .
  - b. Key in  $R2\Delta$  and then press  $\boxed{R2\Delta}$ .
5. Press  $\boxed{R1R2}$  to calculate the reaction forces. (Press  $\boxed{\square}$  to clear the results from the display.)
6. To work another problem, press  $\boxed{CL\mathbb{EF}}$  to clear the accumulated forces and start over at step 3.

**Example 1: Balancing a Single Vector.** Find the reaction forces in the following diagram.



Set Degrees mode and run the “ $\Sigma F$ ” program.

**MODES**  $\boxed{\text{DEG}}$   
**XEQ**  $\boxed{\Sigma F}$

$\Sigma F = 0.0000 \angle 0.0000$   
 $\Sigma F + \boxed{\text{CL}\mathbb{EF}} \boxed{R1\Delta} \boxed{R2\Delta} \boxed{R1R2}$

Enter the force vector.

75 **ENTER** 135  $\boxed{\Sigma F +}$

$\Sigma F = 75.0000 \angle 135.0000$   
 $\Sigma F + \boxed{\text{CL}\mathbb{EF}} \boxed{R1\Delta} \boxed{R2\Delta} \boxed{R1R2}$

Enter the angles of the reaction forces.

30 R14

$R14=30.0000$
$\Sigma F+$ $\text{CLSF}$ $R14$ $R24$ $R1R2$

270 R24

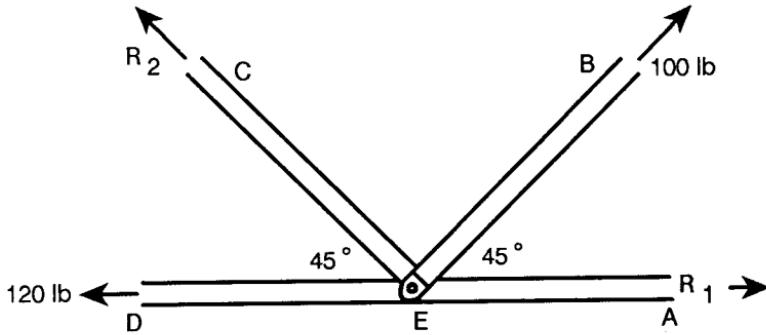
$R24=270.0000$
$\Sigma F+$ $\text{CLSF}$ $R14$ $R24$ $R1R2$

Now, calculate the reaction forces.

R1R2

$R1=61.2372 \angle 30.0000$
$R2=83.6516 \angle -90.0000$

**Example 2: Forces in a Bridge Truss.** Find the reaction forces in structural members A and C. Assume pin connections at the joint.



Set Degrees mode and then start the program. (If you just worked the previous example, you do not have to restart the program. Press  $\text{CLSF}$  to clear the message in the display and then press  $\text{CLSF}$  to clear the forces accumulated above.)

**MODES** DEG  
**XEQ**  $\Sigma F$

$\Sigma F=0.0000 \angle 0.0000$
$\Sigma F+$ $\text{CLSF}$ $R14$ $R24$ $R1R2$

Accumulate the forces.

100 **ENTER** 45  $\Sigma F+$

$\Sigma F=100.0000 \angle 45.0000$
$\Sigma F+$ $\text{CLSF}$ $R14$ $R24$ $R1R2$

120 [ENTER] 180  $\Sigma F +$

$\Sigma F = 86.1942$	$\angle 124.8787$
$\Sigma F +$	$\Sigma F$ $R1A$ $R2A$ $R1R2$

Enter the angles of the reaction forces.

0  $R1A$

$R1A = 0.0000$
$\Sigma F +$ $\Sigma F$ $R1A$ $R2A$ $R1R2$

180 [ENTER] 45  $\square$   $R2A$

$R2A = 135.0000$
$\Sigma F +$ $\Sigma F$ $R1A$ $R2A$ $R1R2$

Calculate the reaction forces.

$R1R2$

$R1 = 21.4214$	$\angle 180.0000$
$R2 = 100.0000$	$\angle -45.0000$

Note that for this problem, the reaction forces are displayed in the opposite direction of the angles entered for  $R_1$  and  $R_2$ . This indicates that the forces are *compressive*.

### **" $\Sigma F$ " Program Listing.**

#### **Program:**

```
00 C 245-Byte Prgm
01 LBL "ΣF"
02 CF 21
03 FS? 55
04 SF 21
05 CLMENU
06 POLAR
07 XEQ 02
08 "ΣF+"
09 KEY 1 XEQ 01
10 "CLEF"
11 KEY 2 XEQ 02
12 "R1A"
13 KEY 3 XEQ 03
```

#### **Comments:**

Sets or clears flag 21 to match flag 55. Clears the programmable menu and sets Polar mode.

Clears the stack and variables.

Defines the menu keys.

```
14 "R2Δ"  
15 KEY 4 XEQ 04  
16 "R1R2"  
17 KEY 6 XEQ 06  
18 KEY 9 GTO 09  
19 LBL 00  
20 MENU  
21 STOP  
22 GTO 00
```

Displays the menu and stops.  
Pressing **R/S** redisplays the menu.

```
23 LBL 01  
24 REAL?  
25 COMPLEX  
26 STO+ "ΣF"  
27 VIEW "ΣF"  
28 RTN
```

Adds the input to  $\Sigma F$ . If the input is not already complex, it's converted automatically.

```
29 LBL 02  
30 CLST  
31 STO "R1Δ"  
32 STO "R2Δ"  
33 COMPLEX  
34 STO "ΣF"  
35 VIEW "ΣF"  
36 RTN
```

Clears the stack and initializes the variables.

```
37 LBL 03  
38 CPX?  
39 COMPLEX  
40 STO "R1Δ"  
41 VIEW "R1Δ"  
42 RTN
```

Stores and displays  $R1\Delta$ . ( $R1\Delta$  cannot be complex.)

```
43 LBL 04  
44 CPX?  
45 COMPLEX  
46 STO "R2Δ"  
47 VIEW "R2Δ"  
48 RTN
```

Stores and displays  $R2\Delta$ . ( $R2\Delta$  cannot be complex.)

```
49 LBL 06
50 RCL "ΣF"
51 RECT
52 COMPLEX
53 POLAR
54 RCL "R2Δ"
55 SIN
56 STOX ST Z
57 LASTX
58 COS
59 STOX ST Z
60 R+
61 R+
62 -
63 RCL "R1Δ"
64 COS
65 STOX ST T
66 R+
67 LASTX
68 SIN
69 RCLX ST Z
70 R+
71 -
72 STO ST Z
73 ÷
74 RCL "R1Δ"
75 COMPLEX
76 "R1=""
77 ARCL ST X

78 X>Y
79 RCL "ΣF"
80 RECT
81 COMPLEX
82 POLAR
83 RCL "R1Δ"
84 SIN
85 STOX ST Z
86 R+
```

Calculates  $R_1$ .

Calculates  $R_2$ .

```
87 LASTX
88 COS
89 X
90 X<>Y
91 -
92 X<>Y
93 ÷
94 RCL "R24"
95 COMPLEX
96 F"4R2="
97 ARCL ST X
98 AVIEW          Displays the results.
99 RTN
100 LBL 09
101 EXITALL
102 END
```

# 2

## Equations of Motion

---

## Equations of Motion

This chapter contains three Solver programs for the following equations of motion for constant acceleration.

$$s = v_o t + 1/2at^2$$

$$v = v_o + at$$

$$v^2 = v_o^2 + 2as$$

### Variables Used.

In Equations	Description	In Programs
$t$	Time.	t
$a$	Acceleration.	a
$v_o$	Initial velocity.	v0
$v$	Final velocity.	v
$s$	Displacement.	s

**Remarks.** These Solver programs can also be used for angular motion. Use  $a$ ,  $v_o$ ,  $v$ , and  $s$  to represent  $\alpha$ ,  $\omega_o$ ,  $\omega$ , and  $\theta$ , respectively.

### Program Instructions.

1. Key the appropriate program (“MO1”, “MO2”, or “MO3”) into your calculator. (The programs are listed on pages 24 and 25.)
2. Press **[SOLVER]**.
3. Select “MO1”, “MO2”, or “MO3” by pressing the corresponding menu key.
4. Use the variable menu to store the known values. Key in each value and then press the corresponding menu key.

5. Optional: Store guesses into the unknown variable to direct the Solver to a particular solution (there might be more than one).
6. Press the menu key for the unknown value. The Solver immediately begins to search for a solution.

**Example.** If a rock dropped off a bridge hits the water 1.6 seconds later, how high is the bridge? What is the velocity of the rock when it strikes the water?

Since each of the equations only uses four of the five variables, many problems with two unknowns can be solved by carefully choosing the programs you use. In this case,  $s$  and  $v$  are unknown. First solve for  $s$  using the equation that does not require  $v$  ("MO1"). Then use one of the other two equations to find  $v$ . (Key "MO1" and "MO2" into your calculator before you begin this example.)

**SOLVER** M01

x: 0.0000				
T	A	v0	s	

Store the known values:  $t = 1.6$  seconds,  $a = -9.8 \text{ m/s}^2$  (for free falling objects), and  $v_0 = 0$ .

1.6 T

t=1.6000				
T	A	v0	s	

9.8 +/- A

a=-9.8000				
T	A	v0	s	

0 v0

v0=0.0000				
T	A	v0	s	

S

s=-12.5440				
T	A	v0	s	

The bridge is about 12.5 meters above the water. Now find  $v$ . Since  $s$  is now known, you can use "MO2" or "MO3".

**EXIT** **MO2**

**x: -12.5440**

T	a	v0	v	
---	---	----	---	--

When you first select a Solver program (as you just have), the first menu key you press executes a *store* to that variable, even if you don't key in a number first. Therefore, you'll have to press **V** twice to start the Solver.

**W**

**v=-12.5440**

T	a	v0	v	
---	---	----	---	--

**V**

**v=-15.6800**

T	a	v0	v	
---	---	----	---	--

The rock is traveling at almost 15.7 meters per second when it hits the water.

### "MO1" Program Listing.

00 C 40-Byte Prgm	09 RCLx "a"
01 LBL "MO1"	10 2
02 MVAR "t"	11 ÷
03 MVAR "a"	12 X<>Y
04 MVAR "v0"	13 RCLx "v0"
05 MVAR "s"	14 +
06 RCL "t"	15 RCL- "s"
07 ENTER	16 END
08 X <sup>2</sup>	

### **"MO2" Program Listing.**

00 C 33-Byte Prgm )	06 RCL "t"
01 LBL "MO2"	07 RCLX "a"
02 MVAR "t"	08 RCL+ "v0"
03 MVAR "a"	09 RCL- "v"
04 MVAR "v0"	10 END
05 MVAR "v"	

### **"MO3" Program Listing.**

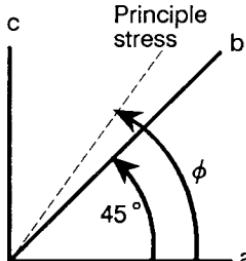
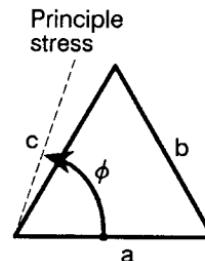
00 C 39-Byte Prgm )	08 RCL "v0"
01 LBL "MO3"	09 X+2
02 MVAR "a"	10 -
03 MVAR "v0"	11 2
04 MVAR "v"	12 RCLX "a"
05 MVAR "s"	13 RCLX "s"
06 RCL "v"	14 -
07 X+2	15 END

## Analysis Programs

---

## Mohr Circle Analysis

This program calculates the 2-D Mohr's circle for stress using strain gage data (equiangular or rectangular) or using known stresses.

Configuration Code	1	2
Type of Rosette	Rectangular	Delta (Equiangular)
		
Principal Strains $\epsilon_1, \epsilon_2$	$\frac{1}{2} [\epsilon_a + \epsilon_c]$ $\pm \sqrt{2(\epsilon_a - \epsilon_b)^2 + 2(\epsilon_b - \epsilon_c)^2 + 2(\epsilon_c - \epsilon_a)^2}$	$\frac{1}{3} [\epsilon_a + \epsilon_b + \epsilon_c]$ $\pm \sqrt{2(\epsilon_a - \epsilon_b)^2 + 2(\epsilon_b - \epsilon_c)^2 + 2(\epsilon_c - \epsilon_a)^2}$
Center of Mohr Circle $\frac{s_1 + s_2}{2}$	$\frac{E(\epsilon_a + \epsilon_c)}{2(1 - v)}$	$\frac{E(\epsilon_a + \epsilon_b + \epsilon_c)}{3(1 - v)}$
Maximum Shear Stress $\tau_{max}$	$\frac{E}{2(1 + v)}$ $\times \sqrt{2(\epsilon_a - \epsilon_b)^2 + 2(\epsilon_b - \epsilon_c)^2 + 2(\epsilon_c - \epsilon_a)^2}$	$\frac{E}{3(1 + v)}$ $\times \sqrt{2(\epsilon_a - \epsilon_b)^2 + 2(\epsilon_b - \epsilon_c)^2 + 2(\epsilon_c - \epsilon_a)^2}$
Orientation of Principal Stresses $\phi$	$\frac{1}{2} \tan^{-1} \left[ \frac{2\epsilon_b - \epsilon_a - \epsilon_c}{\epsilon_a - \epsilon_c} \right]$	$\frac{1}{2} \tan^{-1} \left[ \frac{\sqrt{3} (\epsilon_c - \epsilon_b)}{(2\epsilon_a - \epsilon_b - \epsilon_c)} \right]$

## Variables Used.

In Equations	Description	In Program
$E$	Young's modulus.	E
$\nu$	Poisson's ratio.	V
$\epsilon_a$	Strain $\epsilon_0$ .	e1
$\epsilon_b$	Strain $\epsilon_{45}$ or $\epsilon_{60}$ .	e2
$\epsilon_c$	Strain $\epsilon_{90}$ or $\epsilon_{120}$ .	e3
$\sigma_x$	Normal stress on the x-face.	X
$\sigma_y$	Normal stress on the y-face.	Y
$\sigma_1$	Minimum principal stress.	Smin
$\sigma_2$	Maximum principal stress.	Smax
$\tau_{xy}$	Shear stress.	TAUxy
$\tau_{\max}$	Maximum shear stress.	TAUmax
$\phi$	Counterclockwise angle from $\epsilon_a$ to the maximum principal stress.	$\angle$
$\theta$	Counterclockwise angle from the x-axis to the maximum principal axis.*	$\angle$
$\theta'$	Arbitrary angle counter-clockwise from the x-axis.*	ARB $\angle$
$S$	Normal stress.*	
$\tau$	Shear stress.*	

\*Refer to the equations on page 32.

## Remarks.

- Shearing stress on any element is positive if it tends to rotate the element clockwise. Tensile forces are considered positive; compressive forces are considered negative.
- Angles are entered and displayed using the current angular mode of the calculator.
- The program calculates the principal stresses for a two-dimensional stress state only. However, a knowledge of the stresses in the  $z$ -direction is necessary to determine the overall maximum and minimum stresses.
- This program uses storage register  $R_{00}$  to store intermediate results. Before running this program be sure the SIZE is set to at least 1 (■ MODES ▼ SIZE 1 ENTER).
- The program sets flag 21, which causes the program to stop each time a result is displayed if printing is disabled.

## Program Instructions.

1. Key the “MOHR” program (listed on page 34) into your calculator.
2. Press [XEQ] [MOHR] to execute the program.
3. When the program displays Type of Input?, press *one* of the following:
  - EQ if equiangular strain gage readings are known.
  - REC if rectangular strain gage readings are known.
  - STRES if stresses are known directly.
4. The program then displays Store Values: [R/S] and a variable menu containing the variables to be entered. Store each variable by keying in the value and then pressing the corresponding menu key. After all of the values have been stored, press [R/S]. The program then calculates and displays the results. If you are not using a printer, press [R/S] after each result.

5. Optional: To calculate the normal stress and the shear stress, do the following:

- When you see **ARE $\angle$ ?**, key in the arbitrary angle of rotation.
- Press **[R/S]**. If you are not using a printer, press **[R/S]** after each result.

**Example 1: Equiangular Strain Gage.** An equiangular rosette strain gage measures the following strains:

$$\epsilon_0 = 180 \mu$$

$$\epsilon_{60} = 200 \mu$$

$$\epsilon_{120} = -290 \mu$$

Find the principal stresses and their orientation. The material properties are  $E = 30 \times 10^6$  psi and  $\nu = 0.3$ .

**MODES** **DEG**  
**XEQ** **MOHR**

Type of Input?  
**EQ4** **REC** **STRES**

**EQ4**

Store Values; **[R/S]**  
**E** **V** **E1** **E2** **E3**

30 **E** 6 **E**

**E=30,000,000.0000**  
**E** **V** **E1** **E2** **E3**

.3 **V**

**V=0.3000**  
**E** **V** **E1** **E2** **E3**

180 **E** 6 **+/** **E1**

**e1=0.0002**  
**E** **V** **E1** **E2** **E3**

200 [E] 6 [+/-] E 2

e2=0.0002

E	V	E1	E2	E3	
---	---	----	----	----	--

290 [+/-] E 6 [+/-] E 3

e3=-0.0003

E	V	E1	E2	E3	
---	---	----	----	----	--

R/S

Smax=8,675.1358

x: 8,675.1358

R/S

Smin=-6,103.7072

x: -6,103.7072

R/S

TAUmax=7,389.4215

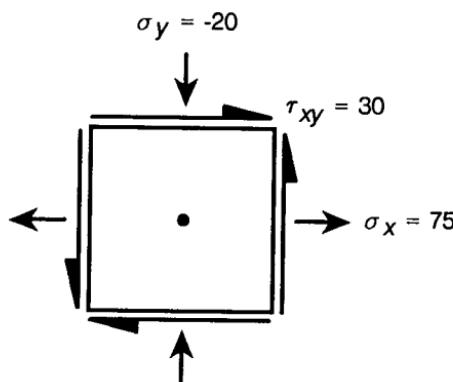
x: -6,103.7072

R/S

z=31.0333

x: -6,103.7072

**Example 2: Known Stresses.** The stresses acting on an element are shown below (all stresses are in MPa).



$$\tau_{\max} = \left[ \left( \frac{S_x - S_y}{2} \right)^2 + \tau_{xy}^2 \right]^{\frac{1}{2}}$$

$$S_1 = \frac{S_x + S_y}{2} + \tau_{\max}$$

$$S_2 = \frac{S_x + S_y}{2} - \tau_{\max}$$

$$\theta = \frac{1}{2} \tan^{-1} \left( \frac{-2\tau_{xy}}{S_x - S_y} \right)$$

$$S = \frac{S_1 + S_2}{2} + \tau_{\max} \cos 2(\theta' - \theta)$$

$$\tau = \tau_{\max} \sin 2(\theta' - \theta)$$

Find the principal stresses and their orientation, and the stresses on the face of the element oriented 45° counterclockwise from the  $x$ -axis.

**MODES** DEG  
**XEQ** MOHR

Type of Input?  
 ERA  REC  STRES

STRES

Store Values; [R/S]  
 $\tau_{xy}$

30  $\tau_{xy}$

$\tau_{xy}=30.0000$   
 $\tau_{xy}$

75  $x$

$x=75.0000$   
 $\tau_{xy}$

20 [+/-]  Y

Y=-20.0000

TAUxy

X

Y

R/S

Smax=83.6805

x: 83.6805

R/S

Smin=-28.6805

x: -28.6805

R/S

TAUmax=56.1805

x: -28.6805

R/S

z=-16.1378

x: -28.6805

R/S

y: -28.6805

ARBz?0.0000

45 R/S

Norm=-2.5000

x: -2.5000

R/S

Shear=47.5000

x: 47.5000

## “MOHR” Program Listing.

### Program:

```
00 < 412-Byte Prgm >
01 LBL "MOHR"
02 SF 21
03 CLMENU
04 "EQ4"
05 KEY 1 XEQ 01
06 "REC"
07 KEY 2 XEQ 02
08 "STRES"
09 KEY 3 XEQ 03
10 KEY 9 GTO 09

11 LBL A
12 "Type of Input?"
13 MENU
14 PROMPT
15 GTO A

16 LBL "M1"
17 MVAR "E"
18 MVAR "V"
19 MVAR "e1"
20 MVAR "e2"
21 MVAR "e3"

22 LBL "M2"
23 MVAR "TAUxy"
24 MVAR "X"
25 MVAR "Y"

26 LBL 00
27 VARMENU "M1"
28 XEQ 08

29 RCL "E"
30 1
31 RCL- "V"
```

### Comments:

Sets flag 21 to control output and defines the menu for selecting the type of analysis.

Displays the menu and prompts for the type of input. Pressing **R/S** redisplays the menu.

Declares the menu variables for the first variable menu.

Declares the menu variables for the second variable menu.

Selects the first variable menu for input.

Calculates  $\tau_{\max}$  for strain gage data.

```
32 ÷
33 STO 00
34 RCL "E"
35 1
36 RCL+ "V"
37 ÷
38 STO "TAUmax"
39 RCL "e1"
40 RCL "e2"
41 RCL "e3"
42 RTN

43 LBL 01
44 XEQ 00
45 -
46 3
47 SQRT
48 ÷
49 RCL "e2"
50 RCL+ "e3"
51 2
52 ×
53 RCL- ST Z
54 3
55 ÷
56 RCL ST Z
57 GTO 04

58 LBL 02
59 XEQ 00
60 RCL+ ST Z
61 2
62 ÷
63 RCL- ST Y
64 RCL "e3"
65 RT
66 GTO 04

67 LBL 03
68 VARMENU "M2"
69 XEQ 08
```

Calculates results using equiangular strain gage readings.

Calculates results using rectangular strain gage readings.

Selects the second variable menu for input.

```
70 1
71 STO 00
72 STO "TAUmax"
73 RCL "TAUxy"
74 +/-  
75 RCL "Y"
76 RCL "X"

77 LBL 04
78 STO "Smin"
79 +
80 2
81 ÷
82 STOx 00
83 RCL- "Smin"
84 ABS
85 →POL
86 STOx "TAUmax"
87 X<>Y
88 2
89 ÷
90 STO "z"

91 RCL "TAUmax"
92 RCL+ 00
93 STO "Smax"
94 VIEW "Smax"
95 RCL 00
96 RCL- "TAUmax"
97 STO "Smin"
98 VIEW "Smin"

99 VIEW "TAUmax"
100 VIEW "z"

101 INPUT "ARBz"
102 RCL- "z"
103 2
104 ×
105 SIN
```

Calculates results using known stresses.

Calculates  $\tau_{\max}$  and  $\theta$ .

Calculates  $S_{\max}$  and  $S_{\min}$ .

Displays  $\tau_{\max}$  and  $\theta$ .

Optional routine calculates normal and shear stress at an arbitrary angle.

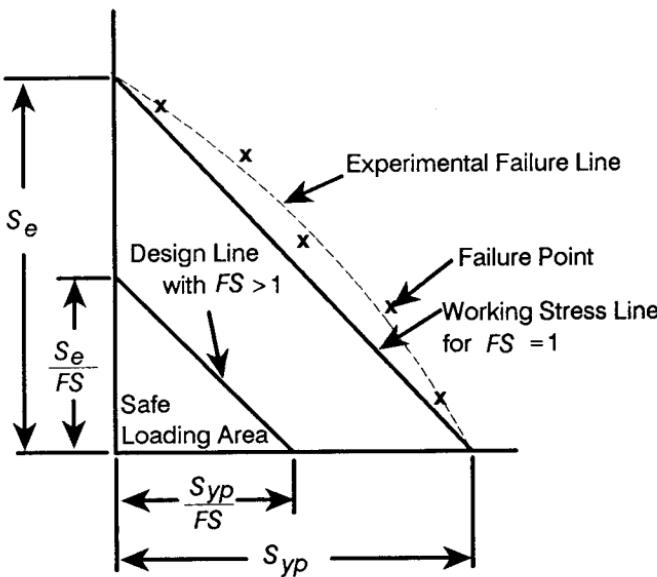
```
106 LASTX
107 COS
108 RCLX "TAUmax"
109 RCL+ 00
110 "Norm="
111 ARCL ST X
112 AVIEW
113 R+
114 RCLX "TAUmax"
115 "Shear="
116 ARCL ST X
117 AVIEW
118 RTN

119 LBL 08
120 "Store Values; "
121 F"[R/S]"
122 PROMPT
123 LBL 09
124 EXITALL
125 END
```

Prompts for input using the selected variable menu. Pressing **R/S** clears the menu and continues.

## Soderberg's Equation for Fatigue

This program is used with the Solver to calculate any one of the six variables in Soderberg's equation for fatigue when the other five are known. Soderberg's equation is shown graphically in the following figure.



$$\frac{S_{yp}}{FS} = \frac{1}{2} \left[ S_{max} + S_{min} + K \left( \frac{S_{yp}}{S_e} \right) \left( S_{max} - S_{min} \right) \right]$$

## Variables Used.

In Equation	Description	In Program
$s_{yp}$	Yield point stress.	SYP
$s_e$	Endurance stress.	SE
$s_{\max}$	Maximum applied stress.	SMAX
$s_{\min}$	Minimum applied stress.	SMIN
$K$	Stress concentration factor.	K
$FS$	Factor of safety.	FS

### Remarks.

- Soderberg's equation is valid for ductile materials only.
- Fatigue effects are magnified in corrosive environments.

### Program Instructions.

1. Key the "SODER" program (listed on page 41) into your calculator.
2. Press **SOLVER SODER** to select the Solver equation.
3. Store each of the known variables by keying in the value and then pressing the corresponding menu key.
4. Press the menu key for the unknown variable.

**Example.** Given the following values, what is the maximum allowable applied stress if the minimum applied stress is 15,000 psi?

$$s_{yp} = 80,000 \text{ psi}$$

$$s_e = 30,000 \text{ psi}$$

$$K = 1.5$$

$$FS = 2.0$$

■ [SOLVER] SODER

x: 0.0000  
SYP SE SMAX SMIN K FS

80000 SYP

Syp=80,000.0000  
SYP SE SMAX SMIN K FS

30000 SE

Se=30,000.0000  
SYP SE SMAX SMIN K FS

15000 SMIN

Smin=15,000.0000  
SYP SE SMAX SMIN K FS

1.5 K

K=1.5000  
SYP SE SMAX SMIN K FS

2 FS

FS=2.0000  
SYP SE SMAX SMIN K FS

SMAX

Smax=25,000.0000  
SYP SE SMAX SMIN K FS

### **"SODER" Program Listing.**

00 C 82-Byte Prgm )	11 RCL- "Smin"
01 LBL "SODER"	12 RCLX "K"
02 MVAR "Syp"	13 RCLX "Syp"
03 MVAR "Se"	14 RCL÷ "Se"
04 MVAR "Smax"	15 +
05 MVAR "Smin"	16 2
06 MVAR "K"	17 ÷
07 MVAR "FS"	18 RCL "Syp"
08 RCL "Smax"	19 RCL÷ "FS"
09 RCL+ "Smin"	20 -
10 LASTX	21 END

## Composite Section Properties

The mathematical properties of a cross section composed of a finite number of rectangular elements can be computed by adding the contribution of each rectangular region individually. This program uses this principle to calculate the area of a section, the moments of inertia about the specified set of axes, the moments of inertia about an axis translated to the centroid, the moments of inertia of the principal axes, and the angle of rotation between the translated axes and the principal axis.

$$A_{s_i} = \Delta x_i \Delta y_i$$

$$A = A_{s1} + A_{s2} + A_{s3} + \dots + A_m$$

$$\bar{x} = \frac{\sum_{i=1}^n x_{0i} A_{s_i}}{A}$$

$$\bar{y} = \frac{\sum_{i=1}^n y_{0i} A_{s_i}}{A}$$

$$I_{xy} = \sum_{i=1}^n x_{0i} y_{0i} A_{s_i} \quad I_{\bar{x} \bar{y}} = I_{xy} - A \bar{x} \bar{y}$$

$$I_x = \sum_{i=1}^n \left( y_{0i}^2 + \frac{\Delta y_i^2}{12} \right) A_{s_i} \quad I_{\bar{x}} = I_x - A \bar{y}^2$$

$$I_y = \sum_{i=1}^n \left( x_{0i}^2 + \frac{\Delta x_i^2}{12} \right) A_{s_i} \quad I_{\bar{y}} = I_y - A \bar{x}^2$$

$$J = I_x + I_y$$

$$\phi = \frac{1}{2} \tan^{-1} \left( \frac{2I_{\bar{x}\bar{y}}}{I_{\bar{x}} - I_{\bar{y}}} \right)$$

$$I_{\bar{x}\phi} = I_{\bar{x}} \cos^2 \phi + I_{\bar{y}} \sin^2 \phi + I_{\bar{x}\bar{y}} \sin 2\phi$$

$$I_{\bar{y}\phi} = I_{\bar{y}} \cos^2 \phi + I_{\bar{x}} \sin^2 \phi + I_{\bar{x}\bar{y}} \sin 2\phi$$

$$J_\phi = I_{\bar{x}\phi} + I_{\bar{y}\phi}$$

### Variables and Storage Registers Used.

In Equations	Description	In Program
$\Delta x_i$	Width of a rectangular element.	W
$\Delta y_i$	Height of a rectangular element.	H
$A_{si}$	Area of an element.	R <sub>02</sub>
$A$	Total area of the section.	R <sub>01</sub>
$\bar{x}$	$x$ -coordinate of the centroid (total).	R <sub>03</sub> $\div$ R <sub>01</sub>
$\bar{y}$	$y$ -coordinate of the centroid (total).	R <sub>04</sub> $\div$ R <sub>01</sub>
$x_{0i}$	$x$ -coordinate of the centroid of an element.	X <sub>C</sub>
$y_{0i}$	$y$ -coordinate of the centroid of an element.	Y <sub>C</sub>
$I_x$	Moment of inertia about the x-axis.	R <sub>06</sub>
$I_y$	Moment of inertia about the y-axis.	R <sub>07</sub>
$J$	Polar moment of inertia about the origin.	R <sub>08</sub>
$I_{xy}$	Product of inertia about the origin.	R <sub>09</sub>

In Equations	Description	In Program
$I_{\bar{x}}$	Moment of inertia about the x-axis translated to the centroid.	R <sub>06</sub>
$I_{\bar{y}}$	Moment of inertia about the y-axis translated to the centroid.	R <sub>07</sub>
$I_{\bar{x}\bar{y}}$	Product of inertia about the translated axis.	R <sub>09</sub>
$\phi$	Angle between the translated axis and the principal axis.	R <sub>05</sub>
$I_{\bar{x}\phi}$	Moment of inertia about the principal x-axis.	
$I_{\bar{y}\phi}$	Moment of inertia about the principal y-axis.	
$J_{\phi}$	Polar moment of inertia about the principal axis.	R <sub>08</sub>

### Remarks.

- Angles are entered and displayed using the current angular mode of the calculator.
- For a given origin, the polar moment of inertia is constant regardless of the angular rotation. Therefore,  $I_{\bar{x}\bar{y}}$  is equal to  $J_{\phi}$ .
- It is possible to obtain a negative value for the product of inertia.
- Before using “SECTION” be sure to set the SIZE to at least 11 registers ( **MODES** **▼** **SIZE** **11** **ENTER** ). The table above shows that some of the registers are used more than once. Storage registers not listed in the table are used for other intermediate results.
- This program clears *all* of the storage registers.
- Results are labeled and displayed in the same order as in the table above. The program uses variables only for the four section inputs.
- This program uses flags 21 and 55 to control printer output.

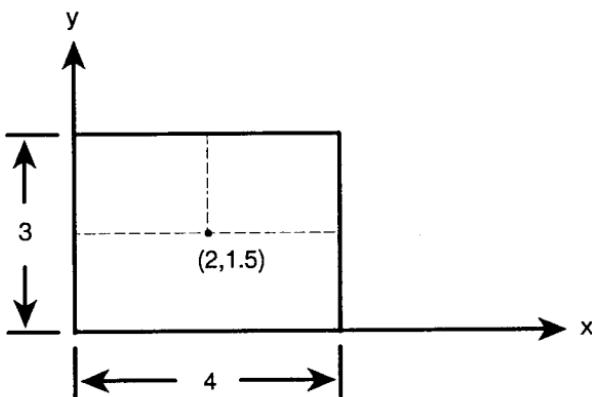
## Program Instructions.

1. Key the "SECTION" program (listed on page 53) into your calculator.
2. Press **[XEQ] SECT I** to execute the program.
3. When you see **Number of Sections?**, key in the number of composite sections and then press **[R/S]**.
4. Enter the data for each section:
  - a. Key in the *x*-coordinate of the centroid and then press **[X C]**.
  - b. Key in the *y*-coordinate of the centroid and then press **[Y C]**.
  - c. Key in the width of the section and then press **[W]**.
  - d. Key in the height of the section and then press **[H]**.
  - e. Press **[R/S]** to continue.

If you store an incorrect value, simply repeat the step to store the correct value. If you notice that you've made a mistake after pressing **[R/S]**, start over at step 2.

5. After the data for each section has been entered, the program calculates the results. If you are not using a printer, press **[R/S]** after each result is displayed.

**Example 1: Rectangular Section.** Calculate the section properties of the following cross section.



**Table of Inputs**

$x_c$	$y_c$	$\Delta x$	$\Delta y$
2	1.5	4	3

**MODES** DEG  
**XEQ** SECT I

Number of Sections?  
x: 0.0000

1 **R/S**

Input Section 1; [R/S]  

xc	yc	w	h		
----	----	---	---	--	--

2 **xc**

Xc=2.0000  

xc	yc	w	h		
----	----	---	---	--	--

1.5 **yc**

Yc=1.5000  

xc	yc	w	h		
----	----	---	---	--	--

4 W

W=4.0000			
xc	yc	W	H

3 H

H=3.0000			
xc	yc	W	H

R/S

Area=			
x: 12.0000			

R/S

Xc=			
x: 2.0000			

R/S

Yc=			
x: 1.5000			

R/S

Ix=			
x: 36.0000			

R/S

Iy=			
x: 64.0000			

R/S

J=			
x: 100.0000			

R/S

Ix y=			
x: 36.0000			

[R/S]

I<sub>xc</sub>=  
x: 9.0000

[R/S]

I<sub>yc</sub>=  
x: 16.0000

[R/S]

I<sub>xcyc</sub>=  
x: 0.0000

[R/S]

↳phi=  
x: 0.0000

[R/S]

I<sub>xc</sub> phi=  
x: 9.0000

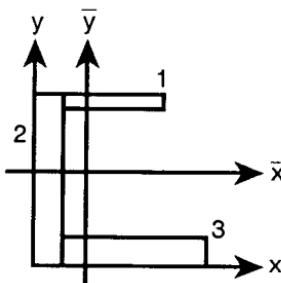
[R/S]

I<sub>yc</sub> phi=  
x: 16.0000

[R/S]

Jphi=  
x: 25.0000

**Example 2: Composite Section.** Calculate the section properties of the following section.



**Table of Inputs**

	$x_c$	$y_c$	$\Delta x$	$\Delta y$
1	5	11.5	6	1
2	1	6	2	12
3	7	1	10	2

■ MODES DEG  
[XEQ] SECTI

Number of Sections?  
x: 25.0000

3 [R/S]

Input Section 1; [R/S]  
xc yc w h

5 xc

xc=5.0000  
xc yc w h

11.5 yc

yc=11.5000  
xc yc w h

6  W

W=6.0000

XC	YC	W	H	

1  H

H=1.0000

XC	YC	W	H	

[R/S]

Input Section 2; [R/S]

XC	YC	W	H	

1  XC

XC=1.0000

XC	YC	W	H	

6  YC

YC=6.0000

XC	YC	W	H	

2  W

W=2.0000

XC	YC	W	H	

12  H

H=12.0000

XC	YC	W	H	

[R/S]

Input Section 3; [R/S]

XC	YC	W	H	

7  XC

XC=7.0000

XC	YC	W	H	

1 YC

Yc=1.0000

xc	yc	w	h		
----	----	---	---	--	--

10 W

W=10.0000

xc	yc	w	h		
----	----	---	---	--	--

2 H

H=2.0000

xc	yc	w	h		
----	----	---	---	--	--

R/S

Area=

x: 50.0000

R/S

Xc=

x: 3.8800

R/S

Yc=

x: 4.6600

R/S

Ix=

x: 1,972.6667

R/S

Iy=

x: 1,346.6667

R/S

J=

x: 3,319.3333

[R/S]

I<sub>x,y</sub>=  
x: 629.0000

[R/S]

I<sub>x,c</sub>=  
x: 886.8867

[R/S]

I<sub>y,c</sub>=  
x: 593.9467

[R/S]

I<sub>x,y,c</sub>=  
x: -275.0400

[R/S]

Δphi=  
x: 30.9814

[R/S]

I<sub>x,c</sub> phi=  
x: 1,052.0261

[R/S]

I<sub>y,c</sub> phi=  
x: 428.8072

[R/S]

Jphi=  
x: 1,480.8333

## **“SECTION” Program Listing.**

### **Program:**

```
00 C 395-Byte Program
01 LBL "SECTION"
02 MVAR "Xc"
03 MVAR "Yc"
04 MVAR "W"
05 MVAR "H"

06 LBL 00
07 "Number of "
08 F"Sections?""
09 PROMPT
10 ABS
11 IP
12 X=0?
13 GTO 00

14 CLRG
15 1E3
16 ÷
17 1
18 +
19 STO 00

20 LBL 01
21 VARMENU "SECTION"

22 "Input Section "
23 RCL 00
24 RIP
25 F";[R/S]""

26 CF 21
27 RVIEW
28 CLA
29 SF 21
30 STOP
31 ALENG
```

### **Comments:**

Defines the menu variables.

Prompts for the number of sections;  
rejects a zero input.

Clears the storage registers and  
stores a loop counter in R<sub>00</sub>.

Selects the variable menu.

Builds the prompt string using the  
loop counter.

Displays the prompt and stops.  
Pressing [R/S] continues the  
program.

```
32 X#0?
33 GTO 01

34 EXITALL
35 RCL "H"
36 RCLX "W"
37 STO 02
38 STO+ 01
39 RCLX "Yc"
40 STO+ 04
41 RCL "Xc"
42 RCLX 02
43 STO+ 03
44 RCL "Yc"
45 X#2
46 RCL "H"
47 X#2
48 12
49 ÷
50 +
51 RCLX 02
52 STO+ 06
53 RCL "Xc"
54 X#2
55 RCL "W"
56 X#2
57 12
58 ÷
59 +
60 RCLX 02
61 STO+ 07
62 +
63 STO+ 08
64 RCL "Xc"
65 RCLX "Yc"
66 RCLX 02
67 STO+ 09

68 ISG 00
69 GTO 01
```

Accumulates the inputs into the appropriate storage registers. (Refer to the table starting on page 43.)

Repeats loop for each section.

70 RCL 09	Calculates $I_{\bar{x}}$ .
71 RCL 03	
72 RCL $\times$ 04	
73 RCL $\div$ 01	
74 -	
75 STO 10	
76 RCL 03	
77 RCL 01	Displays the area.
78 "Area"	
79 XEQ 03	
80 $\div$	Calculates and displays $\bar{x}$ .
81 "Xc"	
82 XEQ 03	
83 X $\uparrow$ 2	Calculates and displays $\bar{x}$ .
84 RCL 04	
85 RCL $\div$ 01	
86 "Yc"	
87 XEQ 03	
88 X $\uparrow$ 2	Displays $I_x$ and calculates $I_{\bar{x}}$ .
89 RCL $\times$ 01	
90 +/-	
91 RCL 06	
92 "Ix"	
93 XEQ 03	
94 +	
95 STO 06	
96 R $\uparrow$	Displays $I_y$ .
97 RCL $\times$ 01	
98 +/-	
99 RCL 07	
100 "Iy"	
101 XEQ 03	
102 RCL 08	Displays $J$ .
103 "J"	
104 XEQ 03	

105 R+	Displays $I_{xy}$ .
106 RCL 09	
107 "Ix <sub>y</sub> "	
108 XEQ 08	
109 R+	Calculates $I_{\bar{y}}$ .
110 +	
111 STO 07	
112 RCL 06	Displays $I_{\bar{x}}$ .
113 "Ix <sub>c</sub> "	
114 XEQ 08	
115 STO 08	Displays $I_{\bar{y}}$ .
116 X<>Y	
117 "Iy <sub>c</sub> "	
118 XEQ 08	
119 STO+ 08	Displays $I_{\bar{y}}$ .
120 -	
121 STO 04	
122 RCL 10	
123 "Ix <sub>y</sub> c"	
124 XEQ 08	
125 X=0?	Calculates $\phi$ .
126 GTO 02	
127 ÷	
128 1/X	
129 2	
130 ×	
131 ATAN	
132 2	
133 ÷	
134 +/-	
135 LBL 02	
136 STO 05	
137 "4Phi"	
138 XEQ 08	

139 2	Calculates and displays $I_{\bar{x}\phi}$
140 x	
141 SIN	
142 RCLx 10	
143 +/-	
144 RCL 05	
145 SIN	
146 X†2	
147 RCLx 04	
148 -	
149 RCL+ 06	
150 "Ix <sub>c</sub> phi"	
151 XEQ 03	
152 RCL- 08	Calculates and displays $I_{\bar{y}\phi}$
153 +/-	
154 "Iy <sub>c</sub> phi"	
155 XEQ 03	
156 RCL 08	Displays $J_\phi$ .
157 "Jphi"	
158 XEQ 03	
159 GTO 00	Returns to the initial prompt.
160 LBL 03	
161 F"=	
162 FS? 55	
163 ARCL ST X	
164 AVIEW	
165 END	

## Spring Constant

This Solver program calculates the value of any of the five variables in the following spring equation, given the other four.

$$k = \frac{F_1 - F_2}{X_2 - X_1}$$

### Variables Used.

In Equations	Description	In Program
$X_1$	First spring length.	X1
$F_1$	Force required to retain spring at length $X_1$ .	F1
$X_2$	Second spring length.	X2
$F_2$	Force required to retain spring at length $X_2$ .	F2
$k$	Spring constant.	k

**Remarks.** The “SPRING” Solver program can also be used to solve any general linear equation of the form  $y - y_0 = m(x - x_0)$ .

### Program Instructions.

1. Key the “SPRING” program (listed on page 60) into your calculator.
2. Press **[SOLVER] SPRIN.**
3. Use the variable menu to store each of the known values by keying in the value and then pressing the corresponding menu key.
4. Press the menu key for the unknown.

**Example.** A compression spring is 4.0 cm long under no compressive forces. A force of 27 Newtons compresses the spring to a length of 2.8 cm. Find the spring constant,  $k$ , if the solid (fully compressed) height of the spring is 2.5 cm. Also find the force required to fully compress the spring.

**SOLVER** SPRIN

x: 0.0000				
x1	f1	x2	f2	k

4 x1

x1=4.0000				
x1	f1	x2	f2	k

0 f1

f1=0.0000				
x1	f1	x2	f2	k

2.8 x2

x2=2.8000				
x1	f1	x2	f2	k

27 f2

f2=27.0000				
x1	f1	x2	f2	k

k

k=22.5000				
x1	f1	x2	f2	k

The spring constant is 22.5.

2.5 x2

x2=2.5000				
x1	f1	x2	f2	k

f2

f2=33.7500				
x1	f1	x2	f2	k

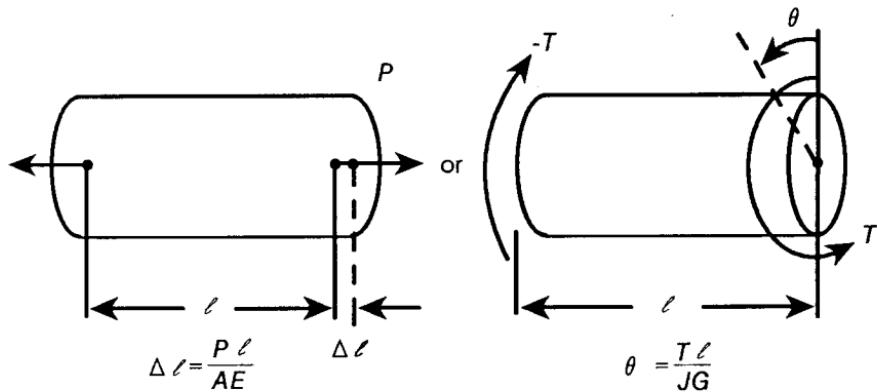
A force of 33.75 Newtons would completely compress the spring (to 2.5 cm).

### **“SPRING” Program Listing.**

00 C 49-Byte Prgm 3	07 RCL "F1"
01 LBL "SPRING"	08 RCL- "F2"
02 MVAR "X1"	09 RCL "X2"
03 MVAR "F1"	10 RCL- "X1"
04 MVAR "X2"	11 ÷
05 MVAR "F2"	12 RCL- "k"
06 MVAR "k"	13 END

## Linear or Angular Deformation

This program solves for linear deflection under tensile load, or the analogous angular deflection under torque. Given four of the five variables, the unknown is calculated.



**Variables Used.** Since the form of the two equations is identical, either type of deformation problem can be solved using this program. Use the following table to relate the variables used in the equations to the variables used in the program.

In Equations	Description	In Program
$\Delta l$	Change in length.	Delta
$P$	Applied load.	P
$l$	Length.	L
$A$	Cross-sectional area.	A
$E$	Modulus of elasticity.	E
$\theta$	Deflection angle (in radians).	Delta
$T$	Applied torque.	P
$J$	Polar moment of the section.	A
$G$	Modulus of elasticity in shear.	E

### Remarks.

- This program is not applicable for non-elastic media or elastic media where stress exceeds the elastic limit. Materials must be isotropic.
- The equation for angular deflection is not valid in the neighborhood of the applied torque.
- Even though the polar moment must be expressed in radians, it is not necessary to set Radians mode because no trigonometric functions are used in the program.

### Program Instruction.

1. Key the “DEFORM” program (listed on page 64) into your calculator.
2. Press **SOLVER** **DEFOR** to select the program.
3. Store each of the known values by keying in the value and then pressing the corresponding menu key.

4. Solve for the unknown value by pressing the corresponding menu key.

**Example.** Steel bars (each 10 meters long) affixed to a roof are to be used to support the end of a cantilever balcony. The load on each bar will be 50,000 N. If the maximum allowable deflection is 0.001 meters, what should the area of the bars be? The modulus of elasticity is given as  $2.068 \times 10^{11}$  N/m<sup>2</sup>.

■ [SOLVER] DEFOR

x: 0.0000

DELTA P L H E

.001 DELTA

Delta=0.0010

DELTA P L H E

50000 P

P=50,000.0000

DELTA P L H E

10 L

L=10.0000

DELTA P L H E

2.068 E 11 E

E=206,800,000,000.

DELTA P L H E

H

A=0.0024

DELTA P L H E

## **"DEFORM" Program Listing.**

00 C 48-Byte Prgm 0	07 RCL "P"
01 LBL "DEFORM"	08 RCLX "L"
02 MVAR "Delta"	09 RCL÷ "A"
03 MVAR "P"	10 RCL÷ "E"
04 MVAR "L"	11 RCL- "Delta"
05 MVAR "A"	12 END
06 MVAR "E"	

## Thermodynamics

---

---

## Equations of State

This section contains programs for both ideal gas and Redlich-Kwong equations of state.

The ideal gas equation is

$$PV = nRT$$

The Redlich-Kwong equation is

$$P = \frac{nRT}{(V - b)} - \frac{a}{T^{1/2} V (V + b)}$$

where:

$$a = 4.934 b nRT_c^{1.5}$$

$$b = 0.0867 \frac{nRT_c}{P_c}$$

### Variables Used.

In Equations	Description	In Program
$P$	Absolute pressure.	P
$V$	Volume.	V
$n$	Number of moles present.	n
$R$	Universal gas constant.	R
$T$	Absolute temperature.	T
$T_c$	Critical temperature.	Tc
$P_c$	Critical pressure.	Pc

### Values of the Universal Gas Constant

Value of $R$	Units of $R$	Units of $P$	Units of $V$	Units of $T$
8.314	N-m/g mole-K	N/m <sup>2</sup>	m <sup>3</sup> /g mole	K
83.14	cm <sup>3</sup> -bar/g mole-K	bar	cm <sup>3</sup> /g mole	K
82.05	cm <sup>3</sup> -atm/g mole-K	atm	cm <sup>3</sup> /g mole	K
0.7302	atm-ft <sup>3</sup> /lb mole-°R	atm	ft <sup>3</sup> /lb mole	°R
10.73	psi-ft <sup>3</sup> /lb mole-°R	psi	ft <sup>3</sup> /lb mole	°R
1545	psf-ft <sup>3</sup> /lb mole-°R	psf	ft <sup>3</sup> /lb mole	°R

### Critical Temperatures and Pressures

Substance	$T_c$ , K	$T_c$ , °R	$P_c$ , atm
Ammonia	405.6	730.1	112.5
Argon	151	272	48.0
Carbon dioxide	304.2	547.6	72.9
Carbon monoxide	133	239	34.5
Chlorine	417	751	76.1
Helium	5.3	9.5	2.26
Hydrogen	33.3	59.9	12.8
Nitrogen	126.2	227.2	33.5
Oxygen	154.8	278.6	50.1
Water	647.3	1165.1	218.2
Dichlorodifluoromethane	384.7	692.5	39.6
Dichlorofluoromethane	451.7	813.1	51.0
Ethane	305.5	549.9	48.2
Ethanol	516.3	929.3	63
Methanol	513.2	923.8	78.5
n-Butane	425.2	765.4	37.5
n-Hexane	507.9	914.2	29.9
n-Pentane	469.5	845.1	33.3
n-Octane	568.6	1023.5	24.6
Trichlorofluoromethane	471.2	848.1	43.2

## Remarks.

- $P$ ,  $V$ ,  $n$ , and  $T$  must have units compatible with  $R$ .
- At low temperatures or high pressures, the ideal gas law does not represent the behavior of real gases.
- No equation of state is valid for all substances over an infinite range of conditions. The Redlich-Kwong equation gives moderate to good accuracy for a variety of substances over a wide range of conditions. Results should be used with caution and tempered by experience.

## Program Instructions.

1. Key the “IDEAL” program (listed on page 70) or the “RK” program (listed on page 71) into your calculator.
2. Press **[SOLVER] IDEAL** (for an ideal gas) or **[SOLVER] RK** (for Redlich-Kwong).
3. Use the variable menu to store each of the known values: key in the value and then press the corresponding menu key. Notice that there are seven menu variables. Therefore, you must use **[▲]** or **[▼]** to enter or solve for  $P_c$ .
4. Solve for the unknown by pressing the corresponding menu key.

**Example 1: An Ideal Gas.** What is the pressure (in bars) when 0.63 g moles of air is enclosed in a 25,000 cm<sup>3</sup> space at 1200K? Assume an ideal gas. From the table on page 67,  $R$  is given as 83.14. (Key the “IDEAL” program into your calculator.)

**[SOLVER] IDEAL**

x: 0.0000	P	V	N	R	T
-----------	---	---	---	---	---

25000 **[V]**

V=25,000.0000	P	V	N	R	T
---------------	---	---	---	---	---

.63 **[N]**

n=0.6300	P	V	N	R	T
----------	---	---	---	---	---

83.14 

R=83.1400

P V N R T

1200 

T=1,200.0000

P V N R T



P=2.5142

P V N R T

**Example 2: Using Redlich-Kwong's Equation.** The specific volume of a gas in a container is  $800 \text{ cm}^3/\text{g mole}$ . The temperature will reach 400K. Given the following constants, what will the pressure be using the Redlich-Kwong relation?

$$T_c = 305.5\text{K}$$

$$P_c = 48.2 \text{ atm}$$

$$R = 82.05 \text{ cm}^3 \text{ atm/g mole K}$$

 RK

x: 2.5142

P V N R T Tc

800 

V=800.0000

P V N R T Tc

1 

n=1.0000

P V N R T Tc

82.05 

R=82.0500

P V N R T Tc

400  T

T=400.0000						
P	V	N	R	T	Tc	

305.5  TC

Tc=305.5000						
P	V	N	R	T	Tc	

48.2  PC

Pc=48.2000						
PC						

P

P=36.2669						
P	V	N	R	T	Tc	

### **"IDEAL" Program Listing.**

00 C 40-Byte Prgm 3	07 RCL "n"
01 LBL "IDEAL"	08 RCL $\times$ "R"
02 MVAR "P"	09 RCL $\times$ "T"
03 MVAR "V"	10 RCL "P"
04 MVAR "n"	11 RCL $\times$ "V"
05 MVAR "R"	12 -
06 MVAR "T"	13 END

### **"RK" Program Listing.**

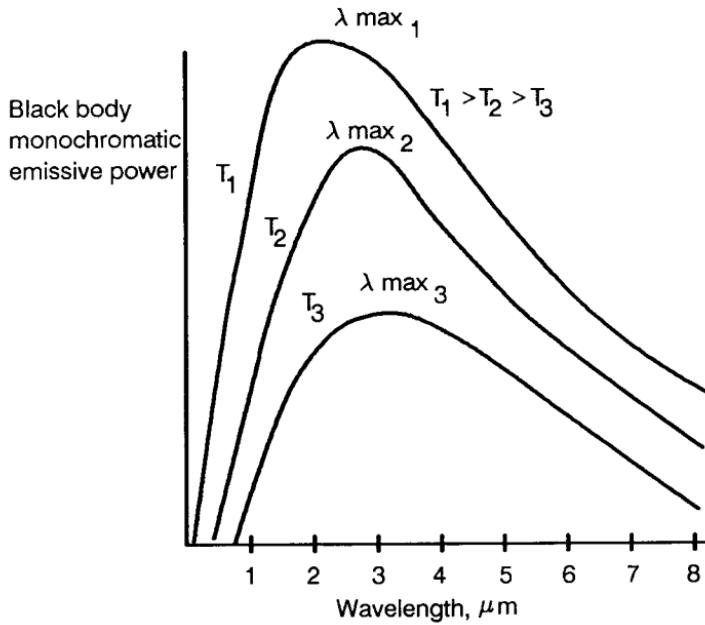
00 C 113-Byte Program	23 XEQ 01
01 LBL "RK"	24 RCL "V"
02 MVAR "P"	25 +
03 MVAR "V"	26 LASTX
04 MVAR "n"	27 ×
05 MVAR "R"	28 RCL "T"
06 MVAR "T"	29 SQRT
07 MVAR "Tc"	30 ×
08 MVAR "Pc"	31 ÷
09 RCL "T"	32 -
10 XEQ 00	33 RCL- "P"
11 RCL "V"	34 RTN
12 XEQ 01	35 LBL 00
13 -	36 RCL× "n"
14 ÷	37 RCL× "R"
15 XEQ 01	38 RTN
16 4.984	39 LBL 01
17 ×	40 0.0867
18 RCL "Tc"	41 RCL× "Tc"
19 1.5	42 XEQ 00
20 Y+X	43 RCL÷ "Pc"
21 XEQ 00	44 END
22 ×	

## Black Body Thermal Radiation

All bodies emit thermal radiation according to their temperature. The higher the temperature, the more thermal radiation emitted. A black body is one that emits the maximum possible amount of energy at every wavelength for a specified temperature. The figure below represents the black body thermal emission as a function of wavelength.

This program can be used to calculate the following:

- The wavelength of maximum emissive power for a given temperature.
- The temperature corresponding to a particular wavelength of maximum emissive power.
- The total emissive power for all wavelengths at a particular temperature.
- The emissive power at a particular wavelength and temperature.



$$\lambda_{\max} T = c_3$$

$$E_{b(0-x)} = \sigma T^4$$

$$E_{b\lambda} = \frac{2\pi c_1}{\lambda^5 (e^{c_2/\lambda T} - 1)}$$

### Variables Used.

In Equations	Description	In Program
$\lambda_{\max}$	Wavelength of maximum emissivity in microns.	W
$T$	Absolute temperature in °R or K.	T
$E_{b(0-x)}$	Total emissive power in Btu/hr-ft <sup>2</sup> or watts/m <sup>2</sup> .	E
$E_{b\lambda}$	Emissive power at $\lambda$ in Btu/hr-ft <sup>2</sup> -μm or watts/m <sup>2</sup> -μm.	P

### Remarks.

- This program uses flag 00 to determine which set of units to use for the following constants:

	SI Units (Flag 00 Clear)	English Units (Flag 00 Set)
$c_1$	$5.9544 \times 10^{-8} \text{ W-m}^2$	$1.8887982 \times 10^7 \text{ Btu-}\mu\text{m}^4/\text{hr-ft}^2$
$c_2$	$1.4388 \times 10^4 \mu\text{m-K}$	$2.58984 \times 10^4 \mu\text{m-}^\circ\text{R}$
$c_3$	$2.8978 \times 10^3 \mu\text{m-K}$	$5.216 \times 10^3 \mu\text{m-}^\circ\text{R}$
$\sigma$	$5.6697 \times 10^{-8} \text{ W/m}^2\text{-K}^4$	$1.713 \times 10^{-9} \text{ Btu/hr-ft}^2\text{-}^\circ\text{R}^4$

- This program uses flags 21 and 55 to control printer output.

## Program Instructions.

1. Key the “BBODY” program (listed on page 76) into your calculator.
2. Clear flag 00 to select SI units (**■FLAGS CF 00**) or set flag 00 to select English units (**■FLAGS SF 00**).
3. Press **[XEQ] BBODY** to execute the program.
4. Use the variable menu to store each of the known values (key in the value and then press the corresponding menu key). Then calculate the desired unknown by pressing its menu key. Be sure to use values with consistent units.

To Calculate	You Must Provide
$W$	$T$
$T$	$W$
$E$	$T$
$P$	$W$ and $T$

**Example.** If sunlight has a maximum wavelength of  $0.550 \mu\text{m}$ , what is the sun’s temperature in K? Assume the sun is a black body. What is the total emissive power and the emissive power at  $\lambda_{\text{max}}$ ? What is the emissive power at  $\lambda = 0.400 \mu\text{m}$  (ultraviolet limit) and  $0.700 \mu\text{m}$  (infrared limit)? (Clear flag 00 for SI units.)

**■FLAGS CF 00**  
**[XEQ] BBODY**

x: 0.0000  
W T E P

.55 W

W=0.5500  
W T E P

T

T-5, 268, 7273

W T E P

The sun's temperature is 5,269K.

E

E=43,690,091,4860

U. S. GOVERNMENT

The total emissive power is approximately 43,690,000 W/m<sup>2</sup>.

1

P=5.2229E-8

44 T E P

The power at  $0.550 \mu\text{m}$  is  $5.2229 \times 10^{-8} \text{ W/m}^2\cdot\mu\text{m}$ .

.4 11

W-8-4000

W. W. FISHER

F

P=3 9649E-8

W T F P

The power at  $0.400 \mu\text{m}$  is  $3.9649 \times 10^{-8} \text{ W/m}^2\cdot\mu\text{m}$ .

74

W-0 3000

W-8.1888

1

P=4 5934E-9

9 7 1 1 6 8 9 2 0

The power at  $0.700 \mu\text{m}$  is  $4.5934 \times 10^{-8} \text{ W/m}^2\cdot\mu\text{m}$ .

**“BBODY” Program Listing.** This program uses a variable menu for input. When you select a variable that you want to calculate, the program uses the character number (ASCII value) of the variable name to cause the program to branch to the appropriate subroutine (lines 13 through 15). For example, when you press **T** to calculate  $T$ , the program branches to LBL 84 because the character number of “T” is 84.

**Program:**

```
00 C 202-Byte Prgm
01 LBL "BBODY"
02 MVAR "W"
03 MVAR "T"
04 MVAR "E"
05 MVAR "P"
06 CF 21
07 FS? 55
08 SF 21

09 LBL 00
10 VARMENU "BBODY"
11 CLA
12 STOP
13 RTOX
14 X#0?
15 XEQ IND ST X
16 GTO 00

17 LBL 87
18 XEQ 01
19 RCL+ "T"
20 STO "W"
21 VIEW "W"
22 RTN

23 LBL 84
24 XEQ 01
25 RCL+ "W"
26 STO "T"
27 VIEW "T"
28 RTN

29 LBL 69
30 RCL "T"
31 X#2
32 X#2
33 FC? 00
34 5.6697E-8
```

**Comments:**

Declares the menu variables and sets or clears flag 21 to match flag 55.

Displays the variable menu and stops. Pressing **R/S** redisplays the menu. If a menu key is pressed to calculate an unknown, the character code of the variable name is used to branch to the appropriate routine.

Calculates *W*.

Calculates *T*.

Calculates *E*. Flag 00 is tested to determine which value to use for the constant,  $\sigma$ .

```
35 FS? 00
36 1.713E-9
37 x
38 STO "E"
39 VIEW "E"
40 RTN

41 LBL 00
42 2
43 PI
44 x
45 FC? 00
46 5.9544E-8
47 FS? 00
48 18887982
49 x
50 FC? 00
51 14388
52 FS? 00
53 25898.4
54 RCL÷ "W"
55 RCL÷ "T"
56 E+X
57 1
58 -
59 RCL "W"
60 5
61 Y+X
62 x
63 ÷
64 STO "P"
65 VIEW "P"
66 RTN

67 LBL 01
68 FC? 00
69 2897.8
70 FS? 00
71 5216
72 END
```

Calculates  $P$ . Flag 00 is tested to enter the appropriate values for the constants  $c_1$  and  $c_2$ .

Tests flag 00 and enters the appropriate value for the constant  $c_3$ .

## Fluid Dynamics

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## Conduit Flow

This program solves for either the average velocity or the pressure drop for viscous, incompressible flow in conduits.

$$V^2 = \frac{\Delta P / \rho}{2 \left[ f \frac{L}{D} + \frac{K_T}{4} \right]}$$

For laminar flow ( $Re \leq 2300$ )

$$f = 16/Re$$

For turbulent flow ( $Re > 2300$ )

$$f = \frac{0.0772}{\left\{ \log \left[ \frac{6.9}{Re} + \left( \frac{\epsilon}{3.7D} \right)^{1.111} \right] \right\}^2}$$

**Note**

Results calculated when  $2300 < Re < 4000$  are meaningless. To determine if results are valid, examine the calculated Reynolds number after the calculation (step 5 in the program instructions).

---

## Variables Used.

In Equations	Description	In Program
$V$	Average velocity.	V
$\Delta P$	Pressure drop.	P
$L$	Conduit length.	L
$D$	Conduit diameter. If the conduit is <i>not</i> circular, use an <i>equivalent</i> diameter defined by: $D_{eq} = 4 \times \frac{\text{Cross Sectional Area}}{\text{Wetted Perimeter}}$	D
$\epsilon$	Surface irregularity.	E
Re	Reynolds number; $Re = DV/\nu$ .	R
$\nu$	Fluid kinematic viscosity.	B
$\rho$	Fluid density.	S
$f$	Fanning friction factor.*	F
$K_T$	Sum of fitting coefficients.	K

\*The Fanning friction factor is one-fourth the Darcy friction factor. That is,  $f = f_D \div 4$ .

### Fitting Coefficients

Fitting	K
Globe valve, wide open	7.5 to 10
Angle valve, wide open	3.8
Gate valve, wide open	0.15 to 0.19
Gate valve, 3/4 open	0.85
Gate valve, 1/2 open	4.4
Gate valve, 1/4 open	20
90° elbow	0.4 to 0.9
Standard 45° elbow	0.35 to 0.42
Tee, through side outlet	1.5
Tee, straight through	0.4
180° bend	1.6
Entrance to circular pipe	0.25 to 0.50
Sudden expansion	$(1 - A_{up}/A_{dn})^2$ *
Acceleration from $V = 0$ to $V = V_{entrance}$	1.0

\* $A_{up}$  is the upstream area and  $A_{dn}$  is the downstream area.

## Surface Irregularities

Material	$\epsilon$ (Feet)	$\epsilon$ (Meters)
Drawn or smooth tubing	$5.0 \times 10^{-6}$	$1.5 \times 10^{-6}$
Commercial steel or wrought iron	$1.5 \times 10^{-4}$	$4.6 \times 10^{-5}$
Asphalted cast iron	$4.0 \times 10^{-4}$	$1.2 \times 10^{-4}$
Galvanized iron	$5.0 \times 10^{-4}$	$1.5 \times 10^{-4}$
Cast iron	$8.3 \times 10^{-4}$	$2.5 \times 10^{-4}$
Wood stave	$6.0 \times 10^{-4}$ to $3.0 \times 10^{-3}$	$1.8 \times 10^{-4}$ to $9.1 \times 10^{-4}$
Concrete	$1.0 \times 10^{-3}$ to $1.0 \times 10^{-2}$	$3.0 \times 10^{-4}$ to $3.0 \times 10^{-3}$
Riveted steel	$3.0 \times 10^{-3}$ to $3.0 \times 10^{-2}$	$9.1 \times 10^{-4}$ to $9.1 \times 10^{-3}$

## Program Instructions.

1. Key the “FLOW” program (listed on page 84) into your calculator.
2. Press **[SOLVER]** **FLOW** to select the program.
3. Use the variable menu to store the known values. Key in each value and then press the corresponding menu key. Since there are more than six variables, use the **[▼]** and **[▲]** keys to display the alternate rows of the variable menu.
4. Solve for the unknown value by pressing the corresponding menu key.
5. View the Reynolds number by pressing **[PGM.FCN]** **VIEW** **[ENTER]** **R** **[ENTER]**. If the Reynolds number is greater than 2300 and less than 4000, the results calculated are meaningless.
6. Optional: To view the Fanning friction factor, press **[PGM.FCN]** **VIEW** **[ENTER]** **F** **[ENTER]**.

**Example.** A 60-meter pipe has three  $180^\circ$  bends ( $K_T = 3 \times 1.6$ ). The fluid is water ( $\nu = 9.3 \times 10^{-7} \text{ m}^2/\text{s}$ ,  $\rho = 1000 \text{ kg/m}^3$ ). The pipe diameter is 0.030 m and the surface roughness is  $3 \times 10^{-4} \text{ m}$ . If the average velocity is 3.20 m/s, what is the pressure drop in Pascals? What is the Reynolds number? What is the Fanning friction factor?

■ [SOLVER] FLOW

x: 0.0000	E	D	V	B	L	K
-----------	---	---	---	---	---	---

3 [E] 4 [+/-] E

E=0.0003	E	D	V	B	L	K
----------	---	---	---	---	---	---

.03 D

D=0.0300	E	D	V	B	L	K
----------	---	---	---	---	---	---

3.2 V

V=3.2000	E	D	V	B	L	K
----------	---	---	---	---	---	---

9.3 [E] 7 [+/-] B

B=9.3000E-7	E	D	V	B	L	K
-------------	---	---	---	---	---	---

60 L

L=60.0000	E	D	V	B	L	K
-----------	---	---	---	---	---	---

3 [ENTER] 1.6 [X] K

K=4.8000	E	D	V	B	L	K
----------	---	---	---	---	---	---

E 3 [▼] S

S=1,000.0000	S	P				
--------------	---	---	--	--	--	--

... P 12

P=418,351.2590

S	P			
---	---	--	--	--

Check the Reynolds number and the Fanning friction factor.

■ PGM.FCN VIEW ENTER R ENTER R=103,225.8065

S	P			
---	---	--	--	--

■ PGM.FCN VIEW ENTER F ENTER F=0.0096

S	P			
---	---	--	--	--

### "FLOW" Program Listing.

00 C 128-Byte Prgm 3	28 LOG
01 LBL "FLOW"	29 3.6
02 MVAR "E"	30 x
03 MVAR "D"	31 1/X
04 MVAR "V"	32 X <sup>2</sup>
05 MVAR "B"	33 LBL 00
06 MVAR "L"	34 STO "F"
07 MVAR "K"	35 RCL <sup>x</sup> "L"
08 MVAR "S"	36 RCL <sup>÷</sup> "D"
09 MVAR "P"	37 RCL "K"
10 RCL "E"	38 4
11 RCL <sup>÷</sup> "D"	39 ÷
12 3.7	40 +
13 ÷	41 2
14 1.111	42 x
15 Y <sup>2</sup> X	43 RCL "V"
16 RCL "V"	44 X <sup>2</sup>
17 RCL <sup>x</sup> "D"	45 x
18 RCL <sup>÷</sup> "B"	46 RCL "P"
19 STO "R"	47 RCL <sup>÷</sup> "S"
20 2300	48 -
21 X>Y?	49 RTN
22 GTO 01	50 LBL 01
23 R <sup>4</sup>	51 16
24 1/X	52 RCL <sup>÷</sup> "R"
25 6.9	53 GTO 00
26 x	54 END
27 +	

## Flow With a Free Surface

This Solver program allows you to solve for any of the five variables in the Manning flow formula, provided the other four are known.

$$S = \frac{(nQ)^2}{2.2082 r^{4/3} \times a^2}$$

### Variables Used.

In Equation	Description	In Program
<i>S</i>	Slope of the bottom (dimensionless).	<i>S</i>
<i>n</i>	Roughness coefficient.	<i>n</i>
<i>r</i>	Hydraulic radius (in feet).	<i>r</i>
<i>Q</i>	Discharge flow rate (in $\text{ft}^3/\text{sec}$ ).	<i>Q</i>
<i>a</i>	Cross-sectional area (in $\text{ft}^2$ ).	<i>a</i>

### Program Instructions.

1. Key the “MANN” program (listed on page 87) into your calculator.
2. Press **[SOLVER] MANN** to select the Manning flow formula Solver program.
3. Use the variable menu to store the known values. Key in each value and then press the corresponding menu key.
4. Solve for the unknown value by pressing the corresponding menu key.

**Example.** Find  $Q$  for  $S = 0.001$ ,  $n = 0.013$ ,  $R = 5/12$  ft, and  $A = 5.0$   $\text{ft}^2$ .

**[SOLVER] MANN**

x: 0.0000	S	N	R	Q	A
-----------	---	---	---	---	---

.001 S

S=0.0010				
S	N	R	Q	H

.013 N

n=0.0130				
S	N	R	Q	H

5 [ENTER] 12 ÷ R

r=0.4167				
S	N	R	Q	H

5 A

a=5.0000				
S	N	R	Q	H

Q

Q=10.0826				
S	N	R	Q	H

## **“MANN” Program Listing.**

00 < 57-Byte Prgm >	12 RCL "r"
01 LBL "MANN"	13 4
02 MVAR "S"	14 ENTER
03 MVAR "n"	15 3
04 MVAR "r"	16 ÷
05 MVAR "Q"	17 Y↑X
06 MVAR "a"	18 ÷
07 RCL "n"	19 RCL "a"
08 RCLX "Q"	20 X↑2
09 X↑2	21 ÷
10 2.2082	22 RCL- "S"
11 ÷	23 END

## Unit Conversions

---

## Introduction

This chapter contains three programs for converting values from one system of units to another: "LENGTH," "FORCE," and "TEMP." Instructions for writing your own unit conversion programs and the conversion factors for 120 units of measure are also included.

**Variable Used.** *UNIT* contains the current value expressed in the base units.

### Remarks.

- The following "Program Instructions" can be used with any of the programs in this chapter.
- The program tests flag 22 to determine when a number has been keyed in.
- Flags 21 and 55 are used to control printer output.

### Program Instructions.

1. Key the appropriate program into your calculator. There are three sample programs listed in this chapter: "LENGTH" (page 91), "FORCE" (page 93), and "TEMP" (page 95).
2. Press **[XEQ]** followed by the menu key corresponding to the program (such as **[XEQ] FORCE**).
3. Key in the value you want to convert and then press the menu key corresponding to the *old* units.
4. Press the menu key corresponding to the *new* units. The new value is displayed. Repeat this step for as many different units as you wish.
5. To perform another conversion, go to step 3. Press **[EXIT]** to quit.

**Example 1: Length Conversions.** How many inches are in one kilometer? (Key the "LENGTH" program into your calculator.)

**[XEQ] LENG**

x: 0.0000
CM M KM IN FT MI

1 KM

1.0000	km				
CM	M	KM	IN	FT	MI

IN

39,370.0787	in				
CM	M	KM	IN	FT	MI

What is the same distance in feet?

FT

3,280.8399	ft				
CM	M	KM	IN	FT	MI

Now convert six miles to meters.

6 MI

6.0000	mi				
CM	M	KM	IN	FT	MI

M

9,656.0640	m				
CM	M	KM	IN	FT	MI

EXIT

**Example 2: Force Conversions.** Convert a 135 pound force to Newtons. (Key the “FORCE” program into your calculator.)

XEQ FORCE

x: 9,656.0640				
GF	KIP	N	LBF	PDL

135 LBF

135.0000 1bf				
GF	KIP	N	LBF	PDL

N

600.5099 N				
GF	KIP	N	LBF	PDL

EXIT

**“LENGTH” Program Listing.** This program performs unit conversions using centimeters, meters, kilometers, inches, feet, and miles. The base unit is the meter.

**Program:**

```
00 C 183-Byte Program
01 LBL "LENGTH"
02 CF 21
03 FS? 55
04 SF 21

05 CLMENU
06 STO "UNIT"
07 XEQ 01
08 KEY 1 XEQ 01
09 XEQ 02
10 KEY 2 XEQ 02
11 XEQ 03
12 KEY 3 XEQ 03
13 XEQ 04
14 KEY 4 XEQ 04
15 XEQ 05
16 KEY 5 XEQ 05
17 XEQ 06
18 KEY 6 XEQ 06
19 KEY 9 GTO 09
20 RCL "UNIT"
21 SF 22

22 LBL A
23 MENU
24 STOP

25 FC?C 22
26 GTO 00
27 X
28 STO "UNIT"
29 R+
30 LASTX
```

**Comments:**

Sets or clears flag 21 to match flag 55.

Defines the unit menu. The value in the X-register is temporarily saved in the variable *UNIT*.

Displays the menu and stops.

If flag 22 is not set (no data entry), converts the value into new units.

31 LBL 00	Displays the new value and the unit string.
32 1/X	
33 RCLX "UNIT"	
34 RSTO ST L	
35 CLA	
36 ARCL ST X	
37 F" "	
38 ARCL ST L	
39 AVIEW	
40 GTO R	
41 LBL 01	Subroutines for each menu key.
42 "cm"	Each routine enters a string into the Alpha register and a conversion factor into the X-register.
43 0.01	
44 RTN	
45 LBL 02	
46 "m"	
47 1	
48 RTN	
49 LBL 03	
50 "km"	
51 1000	
52 RTN	
53 LBL 04	
54 "in"	
55 0.0254	
56 RTN	
57 LBL 05	
58 "ft"	
59 0.3048	
60 RTN	
61 LBL 06	
62 "mi"	
63 1609.344	
64 RTN	
65 LBL 09	Ends the program (when <b>EXIT</b> is pressed).
66 END	

**“FORCE” Program Listing.** This program performs unit conversions using gram-force, kilopound-force, Newtons, pound-force, and poundals. The base unit is the Newton.

**Program:**

```
00 C 193-Byte Prgm
01 LBL "FORCE"
02 CF 21
03 FS? 55
04 SF 21

05 CLMENU
06 STO "UNIT"
07 XEQ 01
08 KEY 1 XEQ 01
09 XEQ 02
10 KEY 2 XEQ 02
11 XEQ 03
12 KEY 3 XEQ 03
13 XEQ 04
14 KEY 4 XEQ 04
15 XEQ 05
16 KEY 5 XEQ 05
17 KEY 9 GTO 09
18 RCL "UNIT"
19 SF 22

20 LBL A
21 MENU
22 STOP

23 FC?C 22
24 GTO 00
25 X
26 STO "UNIT"
27 R+ ►
28 LASTX

29 LBL 00
30 1/X
```

**Comments:**

Sets or clears flag 21 to match flag 55.

Defines the unit menu. The value in the X-register is temporarily saved in the variable *UNIT*.

Displays the menu and stops.

If flag 22 is not set (no data entry), converts the value into new units.

Displays the new value and the unit string.

```
31 RCLX "UNIT"
32 ASTO ST L
33 CLA
34 ARCL ST X
35 F" "
36 ARCL ST L
37 AVIEW
38 GTO A

39 LBL 01
40 "gf"
41 9.80665E-3
42 RTN
43 LBL 02
44 "kip"
45 4448.22161526
46 RTN
47 LBL 03
48 "N"
49 1
50 RTN
51 LBL 04
52 "1bf"
53 4.44822161526
54 RTN
55 LBL 05
56 "pd1"
57 0.13825495438
58 RTN

59 LBL 09
60 END
```

Subroutines for each menu key.  
Each routine enters a string into the  
Alpha register and a conversion  
factor into the X-register.

Ends the program (when **EXIT** is  
pressed).

**"TEMP" Program Listing.** Conversions between the four temperature scales (Kelvin, °Celcius, °Fahrenheit, and °Rankine) involve additive constants as well as multiplicative factors. Without these additive constants (on lines 47, 52, 57, and 62), only relative conversions would be possible. Therefore, the "TEMP" program takes on a slightly different form than the programs listed earlier.

**Note**

To key in lines 46 and 47 of the following program, press 1 **ENTER** **♦** 0. Use the same technique (pressing **ENTER** and **♦** after the first number and before the second) to key in lines 51 and 52, 56 and 57, and 61 and 62.

**Program:**

```
00 C 196-Byte Prgm
01 LBL "TEMP"
02 CF 21
03 FS? 55
04 SF 21

05 CLMENU
06 STO "UNIT"
07 XEQ 01
08 KEY 1 XEQ 01
09 XEQ 02
10 KEY 2 XEQ 02
11 XEQ 03
12 KEY 3 XEQ 03
13 XEQ 04
14 KEY 4 XEQ 04
15 KEY 9 GTO 09
16 RCL "UNIT"
17 SF 22

18 LBL A
19 MENU
20 STOP

21 STO "+"
22 R+
23 FC?C 22
24 GTO 00
25 X
26 STO "UNIT"
```

**Comments:**

Sets or clears flag 21 to match flag 55.

Defines the unit menu. The value in the X-register is temporarily saved in the variable *UNIT*.

Displays the menu and stops.

If flag 22 is not set (no data entry), converts the value into new units.

```
27 R+
28 STO+ "UNIT"
29 R+
30 R+
31 LASTX

32 LBL 00
33 1/X
34 RCL "UNIT"
35 RCL- "+"
36 X
37 ASTO ST L
38 CLA
39 ARCL ST X
40 F" "
41 ARCL ST L
42 AVIEW
43 GTO R

44 LBL 01
45 ""K"
46 1
47 0
48 RTN
49 LBL 02
50 ""C"
51 1
52 273.15
53 RTN
54 LBL 03
55 ""R"
56 0.555555555556
57 0
58 RTN
59 LBL 04
60 ""F"
61 0.555555555556
62 255.372222222
63 RTN

64 LBL 09
65 END
```

Displays the new value and the unit string.

Subroutines for each menu key. Each routine enters a string into the Alpha register, a conversion factor into the Y-register, and an additive constant into the X-register.

Ends the program (when **EXIT** is pressed).

---

## Writing Your Own Unit Conversion Programs

If the sample programs in this chapter do not contain the units that you work with regularly, you may want to write your own unit conversion programs.

1. Using the table at the end of this chapter (or from other reference material), select up to six units of measure.
2. Using the conversion program that follows, fill in the blank lines as follows:
  - a. Line 01 should be a global label that indicates the type of units included (such as LBL "MASS" or LBL "TIME").
  - b. The two lines immediately following each label, LBL 01 (line 41) through LBL 06 (line 61), should include the *unit name* and the *conversion factor*.

Each conversion factor you use should be expressed in relation to the same *base unit*. (For example, in the "LENGTH" program above, the base unit is the meter.)

- c. Optional: If you assign your unit conversion programs to the custom menu, you can make them appear to be submenus of CUSTOM by inserting SF 27 after LBL 09.

## The Blank Conversion Program.

```
00 C nnn -Byte Prgm 0      34 ASTO ST L
01 LBL "program name here" 35 CLA
02 CF 21                   36 ARCL ST X
03 FS? 55                  37 F" "
04 SF 21                   38 ARCL ST L
05 CLMENU                  39 AVIEW
06 STO "UNIT"               40 GTO A
07 XEQ 01                  41 LBL 01
08 KEY 1 XEQ 01             42 "unit name here"
09 XEQ 02                  43 conversion factor here
10 KEY 2 XEQ 02             44 RTN
11 XEQ 03                  45 LBL 02
12 KEY 3 XEQ 03             46 "unit name here"
13 XEQ 04                  47 conversion factor here
14 KEY 4 XEQ 04             48 RTN
15 XEQ 05                  49 LBL 03
16 KEY 5 XEQ 05             50 "unit name here"
17 XEQ 06                  51 conversion factor here
18 KEY 6 XEQ 06             52 RTN
19 KEY 9 GTO 09             53 LBL 04
20 RCL "UNIT"               54 "unit name here"
21 SF 22                   55 conversion factor here
22 LBL A                   56 RTN
23 MENU                     57 LBL 05
24 STOP                     58 "unit name here"
25 FC?C 22                  59 conversion factor here
26 GTO 00                  60 RTN
27 x                        61 LBL 06
28 STO "UNIT"               62 "unit name here"
29 R+                       63 conversion factor here
30 LASTX                    64 RTN
31 LBL 00                  65 LBL 09
32 1/X                      66 END
33 RCLx "UNIT"
```

---

## Dimensionless Units of Angle

Plane and solid angles are called *dimensionless* because they involve no physical dimensions. The following table relates these dimensionless units to their actual values.

Dimensionless Unit	Abbreviation	Value
Arcmin	arcmin	$\frac{1}{21600}$ unit circle
Arcsec	arcs	$\frac{1}{1296000}$ unit circle
Degree	°	$\frac{1}{360}$ unit circle
Grade	grad	$\frac{1}{400}$ unit circle
Radian	r	$\frac{1}{2\pi}$ unit circle
Steradian	sr	$\frac{1}{4\pi}$ unit sphere

## Conversion Factors

The conversion factors in the following table are based on the International System of Units (SI).

If you use a unit that is not in the table, be sure that the conversion factor correctly relates the unit to the base unit for your program.

Unit	Full Name	Description	Value
a	Are	Area	100 m <sup>2</sup>
A	Ampere	Electric current	1 A
acre	Acre	Area	4046.87260987 m <sup>2</sup>
arcmin	Minute of arc	Plane angle	4.62962962963E-5
arcs	Second of arc	Plane angle	7.71604938272E-7
atm	Atmosphere	Pressure	101325 N/m <sup>2</sup>
au	Astronomical unit	Length	149597900000 m
A°	Angstrom	Length	0.0000000001 m
b	Barn	Area	1.E-28 m <sup>2</sup>
bar	Bar	Pressure	100000 N/m <sup>2</sup>
bbl	Barrel, oil	Volume	0.158987294928 m <sup>3</sup>
Bq	Becquerel	Activity	1 1/s
Btu	International Table Btu	Energy	1055.05585262 Kg·m <sup>2</sup> /s <sup>2</sup>
bu	Bushel	Volume	0.03523907 m <sup>3</sup>
c	Speed of light	Velocity	299792458 m/s
C	Coulomb	Electric charge	1 A·s
cal	International Table calorie	Energy	4.1868 Kg·m <sup>2</sup> /s <sup>2</sup>
cd	Candela	Luminous intensity	1 cd
chain	Chain	Length	20.1168402337 m

Unit	Full Name	Description	Value
Ci	Curie	Activity	3.7E10 1/s
ct	Carat	Mass	0.0002 Kg
cu	US cup	Volume	2.365882365E-4 m <sup>3</sup>
d	Day	Time	86400 s
dyn	Dyne	Force	0.00001 Kg-m/s <sup>2</sup>
erg	Erg	Energy	0.000001 Kg-m <sup>2</sup> /s <sup>2</sup>
eV	Electron volt	Energy	1.60219E-19 Kg-m <sup>2</sup> /s <sup>2</sup>
F	Farad	Capacitance	1 A <sup>2</sup> -s <sup>4</sup> /Kg-m <sup>2</sup>
fath	Fathom	Length	1.82880365761 m
fbm	Board foot	Volume	0.002359737216 m <sup>3</sup>
fc	Footcandle	Luminance	0.856564774909
Fdy	Faraday	Electric charge	96487 A-s
fermi	Fermi	Length	1.E-15 m
flam	Footlambert	Luminance	3.42625909964 cd/m <sup>2</sup>
ft	International foot	Length	0.3048 m
ftUS	Survey foot	Length	0.304800609601 m
g	Gram	Mass	0.001 Kg
ga	Standard freefall	Acceleration	9.80665 m/s <sup>2</sup>
gal	US gallon	Volume	0.003785411784 m <sup>3</sup>
galC	Canadian gallon	Volume	0.00454609 m <sup>3</sup>
galUK	UK gallon	Volume	0.004546092 m <sup>3</sup>
gf	Gram-force	Force	0.00980665 Kg-m/s <sup>2</sup>
grad	Grade	Plane angle	0.0025
grain	Grain	Mass	0.00006479891 Kg
Gy	Gray	Absorbed dose	1 m <sup>2</sup> /s <sup>2</sup>
h	Hour	Time	3600 s
H	Henry	Inductance	1 Kg-m <sup>2</sup> /A <sup>2</sup> -s <sup>2</sup>

Unit	Full Name	Description	Value
hp	Horsepower	Power	745.699871582 Kg-m <sup>2</sup> /s <sup>3</sup>
Hz	Hertz	Frequency	1 1/s
in	Inch	Length	0.0254 m
inHg	Inches of mercury	Pressure	3386.38815789 N/m <sup>2</sup>
inH2O	Inches of water	Pressure	248.84 N/m <sup>2</sup>
J	Joule	Energy	1 Kg-m <sup>2</sup> /s <sup>2</sup>
kip	Kilopound-force	Force	4448.22161526 Kg-m/s <sup>2</sup>
knot	Knot	Speed	0.514444444444 m/s
kph	Kilometer per hour	Speed	0.277777777778 m/s
l	Liter	Volume	0.001 m <sup>3</sup>
lam	Lambert	Luminance	3183.09886184 cd/m <sup>2</sup>
lb	Avoirdupois pound	Mass	0.45359237 Kg
lbf	Pound-force	Force	4.44822161526 Kg-m/s <sup>2</sup>
lbt	Troy lb	Mass	0.3732417 Kg
lm	Lumen	Luminance flux	7.95774715459E-2 cd
lx	Lux	Illuminance	7.95774715459E-2 cd/m <sup>2</sup>
lyr	Light year	Length	9.46052840488E15 m
m	Meter	Length	1 m
mho	Mho	Electric conductance	1 A <sup>2</sup> -s <sup>3</sup> /Kg-m <sup>2</sup>
mi	International mile	Length	1609.344 m
mil	Mil	Length	0.0000254 m
min	Minute	Time	60 s
miUS	US statute mile	Length	1609.34721869 m
mmHg	Millimeter of mercury	Pressure	133.322368421 N/m <sup>2</sup>
mol	Mole	Amount of substance	1 mol
mph	Miles per hour	Speed	0.44704 m/s

Unit	Full Name	Description	Value
N	Newton	Force	1 Kg·m/s <sup>2</sup>
nmi	Nautical mile	Length	1852 m
ohm	Ohm	Electric resistance	1 Kg·m <sup>2</sup> /A <sup>2</sup> ·s <sup>3</sup>
oz	Ounce	Mass	0.028349523125 Kg
ozfl	US fluid oz	Volume	2.95735295625E-5 m <sup>3</sup>
ozt	Troy oz	Mass	0.031103475 Kg
ozUK	UK fluid oz	Volume	0.000028413075 m <sup>3</sup>
P	Poise	Dynamic viscosity	0.1 N/m
Pa	Pascal	Pressure	1 N/m <sup>2</sup>
pc	Parsec	Length	3.08567818585E16 m
pdl	Poundal	Force	0.138254954376 Kg·m/s <sup>2</sup>
ph	Phot	Luminance	795.774715459 cd/m <sup>2</sup>
pk	Peck	Volume	0.0088097675 m <sup>3</sup>
psi	Pounds per square inch	Pressure	6894.75729317 N/m <sup>2</sup>
pt	Pint	Volume	0.000473176473 m <sup>3</sup>
qt	Quart	Volume	0.000946352946 m <sup>3</sup>
r	Radian	Plane angle	0.159154943092
R	Roentgen	Radiation exposure	0.000258 A-s/Kg
rad	Rad	Absorbed dose	0.01 m <sup>2</sup> /s <sup>2</sup>
rd	Rod	Length	5.02921005842 m
rem	Rem	Dose equivalent	0.01 m <sup>2</sup> /s <sup>2</sup>
s	Second	Time	1 s
S	Siemens	Electric conductance	1 A <sup>2</sup> ·s <sup>3</sup> /Kg·m <sup>2</sup>
sb	Stilb	Luminance	10000 cd/m <sup>2</sup>
slug	Slug	Mass	14.5939029372 Kg
sr	Steradian	Solid angle	7.95774715459E-2

Unit	Full Name	Description	Value
st	Stere	Volume	1 m <sup>3</sup>
St	Stokes	Kinematic viscosity	0.0001 m <sup>2</sup> /s
Sv	Sievert	Dose equivalent	1 m <sup>2</sup> /s <sup>2</sup>
t	Metric ton	Mass	1000 Kg
T	Tesla	Magnetic flux	1 Kg/A·s <sup>2</sup>
tbsp	Tablespoon	Volume	1.47867647813E-5 m <sup>3</sup>
therm	EEC therm	Energy	105506000 Kg·m <sup>2</sup> /s <sup>2</sup>
ton	Short ton	Mass	907.18474 Kg
tonUK	Long ton	Mass	1016.0469088 Kg
torr	Torr	Pressure	133.322368421 N/m <sup>2</sup>
tsp	Teaspoon	Volume	4.92892159375E-6 m <sup>3</sup>
u	Unified atomic mass	Mass	1.66057E-27 Kg
V	Volt	Electric potential	1 Kg·m <sup>2</sup> /A·s <sup>3</sup>
W	Watt	Power	1 Kg·m <sup>2</sup> /s <sup>3</sup>
Wb	Weber	Magnetic flux	1 Kg·m <sup>2</sup> /A·s <sup>2</sup>
yd	International yard	Length	0.9144 m
yr	Year	Time	31556925.9747 s
°	Degree	Angle	2.77777777778E-3
°C	Degree Celsius	Temperature	1 K*
°F	Degree Fahrenheit	Temperature	0.555555555556 K*
K	Degree Kelvin	Temperature	1 K*
°R	Degree Rankine	Temperature	0.555555555556 K*
μ	Micron	Length	0.000001 m

\*Refer to the "TEMP" program listing starting on page 94.

# *Step-by-Step Solutions for Your HP-42S Calculator*

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*Mechanical Engineering* contains a variety of programs and examples to provide solutions for mechanical engineers and engineering students.

## **■ Forces and Vectors**

Vectors in the HP-42S • Static Equilibrium at a Point

## **■ Equations of Motion**

## **■ Analysis Programs**

Mohr Circle Analysis • Soderberg's Equation for Fatigue • Composite Section Properties • Spring Constant • Linear or Angular Deformation

## **■ Thermodynamics**

Equations of State • Black Body Thermal Radiation

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