Step-by-Step Solutions
For Your HP Calculator

Mechanical Engineering

\[ F_t = \frac{X}{20 \times 980} \]

\[ k = \frac{mg}{x} = \frac{F_{us}}{x} \]

\[ \omega = \frac{R \cos \theta}{\pi N} \]

\[ x_{max} = 30 \]

\[ x = R \cos \theta + L \cos \phi \]

\[ 20 \times (980 \text{ cm/s}^2) \]

\[ d \]

HP-42S
Help Us Help You!

Please take a moment to complete this postage-paid card, tear it out and put it in the mail. Your responses and comments will help us better understand your needs and provide you with the best procedures to solve your problems. Thank you!

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1. What calculator will you use this book with?  
   009 ☐ HP-42S  ☐ 006 ☐ Other

2. How many other HP solution books have you bought for this calculator?  

3. What is your occupation?  
   101 ☐ Student  103 ☐ Professional  109 ☐ Other

4. Where did you purchase this book?  
   403 ☐ Bookstore  404 ☐ Discount or Catalog Store  
   407 ☐ Mail Order  410 ☐ HP Direct  411 ☐ Other

5. How did you first hear about this book?  
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   507 ☐ Brochure  508 ☐ Other

6. To what degree did this book influence your calculator purchase decision?  
   601 ☐ Major Influence  602 ☐ Minor Influence  603 ☐ No Influence

7. How well does this book cover the material you expected?  
   701 ☐ Good  702 ☐ Moderate  703 ☐ Low

8. What level of knowledge is required to make use of the topics in this book?  
   801 ☐ High  802 ☐ Medium  803 ☐ Low

9. How clearly was the material in this book presented?  
   901 ☐ Good  902 ☐ Moderate  903 ☐ Low

10. How would you rate the value of this book for your money?  
    111 ☐ High  112 ☐ Medium  113 ☐ Low

Comments: (Please comment on improvements and additional applications or subjects you would like HP to cover in this or another solution book.)  

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Mechanical Engineering

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

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<td>100</td>
<td>Conversion Factors</td>
</tr>
</tbody>
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How To Use This Book

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 \texttt{PRINT} \texttt{~FON} to enable printing.

If you are not using a printer, be sure to disable printing (\texttt{PRINT} \texttt{~OFF}) 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 \texttt{+} character is printed as \texttt{v}.) Also note that some printers cannot print the angle character (\texttt{\&}).

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
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] [V] 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→1** combines the coordinates in the X-, Y-, and Z-registers into a $1 \times 3$ matrix in the X-register.
- **1→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 $10\mathbf{i} - 3\mathbf{j} + 17\mathbf{k}$?

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

$17 \text{ ENTER } 3 \div \text{ ENTER } 10$

Put the coordinates into vector (matrix) form.

Put the coordinates into vector (matrix) form.

Calculate the unit vector.

Return the coordinates of the unit vector to the stack.

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

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

The $z$-coordinate of the unit vector is 0.8521.
"VEC" Program Listing.

Program:

Comments:

00 ( 136-Byte Prgm )
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→

Makes CUSTOM menu key assignments.

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

Gets a 3 × 1 submatrix from the storage register matrix and transposes it to a 1 × 3 matrix.

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

1: Using the VEC Program
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.

<table>
<thead>
<tr>
<th>In Equations</th>
<th>Description</th>
<th>In Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Sigma F$</td>
<td>Sum of forces.</td>
<td>$\Sigma F$</td>
</tr>
<tr>
<td>$\theta_1$</td>
<td>Angle of first reaction force.</td>
<td>$R 1 \angle$</td>
</tr>
<tr>
<td>$\theta_2$</td>
<td>Angle of second reaction force.</td>
<td>$R 2 \angle$</td>
</tr>
</tbody>
</table>

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 $R 1 \angle = R 2 \angle$.
- 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 $\Sigma F \rightarrow$ to execute the program.
3. Repeat these steps for each force:
   a. Key in the magnitude of the force; press $\text{[ENTER]}$.
   b. Key in the angle of the force (measured from the reference axis).
   c. Optional: press $\text{[COMPLEX]}$. (If you skip this step, the program automatically converts your inputs into a complex number.)
   d. Press $\Sigma F \rightarrow$ 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 $\text{[+] } \Sigma F \rightarrow$. 

14 1: Static Equilibrium at a Point
4. Store the angles of the reaction forces:
   a. Key in \( R1 \times \) and then press \( \mathbb{R}1 \bigtriangleup \).
   b. Key in \( R2 \times \) and then press \( \mathbb{R}2 \bigtriangleup \).

5. Press \( \mathbb{R}1 \mathbb{R}2 \) to calculate the reaction forces. (Press \( \mathbb{C} \) to clear the results from the display.)

6. To work another problem, press \( \mathbb{C} \mathbb{L} \mathbb{X} \mathbb{F} \) 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.

Enter the force vector.

75 ENTER 135 \( \Sigma F + \)
Enter the angles of the reaction forces.

30 \theta R1\zeta

270 \theta R2\zeta

Now, calculate the reaction forces.

R1R2

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 \* to clear the message in the display and then press \(C\) to clear the forces accumulated above.)

Accumulate the forces.

100 [ENTER] 45 \Sigma F+
120 ENTER 180 ZF+

Enter the angles of the reaction forces.

0 R1Z

180 ENTER 45 - R2Z

Calculate the reaction forces.

R1R2

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.

"ΣF" Program Listing.

Program:

Program:
00 ( 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 "CLΣF"
11 KEY 2 XEQ 02
12 "R1Z"
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 "R2x"
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

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

29 LBL 02
30 CLST
31 STO "R1x"
32 STO "R2x"
33 COMPLEX
34 STO "ΣF"
35 VIEW "ΣF"
36 RTN

37 LBL 03
38 CPX?
39 COMPLEX
40 STO "R1x"
41 VIEW "R1x"
42 RTN

43 LBL 04
44 CPX?
45 COMPLEX
46 STO "R2x"
47 VIEW "R2x"
48 RTN

Displays the menu and stops. Pressing [R/S] redisplaysthe menu.

Adds the input to ΣF. If the input is not already complex, it's converted automatically.

Clears the stack and initializes the variables.

Stores and displays R1x. (R1x cannot be complex.)

Stores and displays R2x. (R2x cannot be complex.)
Calculates $R_1$.

Calculates $R_2$. 

1: Static Equilibrium at a Point
87 LASTX
88 COS
89 \times
90 \times Y
91 -
92 \times Y
93 \div
94 \text{RCL } "R2\times"
95 \text{COMPLEX}
96 \text{"R2="
97 \text{ARCL ST X}
98 \text{AVIEW}
99 \text{RTN}
100 \text{LBL 09}
101 \text{EXITALL}
102 \text{END}

Displays the results.

Exits all menus and ends.
Equations of Motion
Equations of Motion

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

\[ s = v_o t + \frac{1}{2}at^2 \]

\[ v = v_o + at \]

\[ v^2 = v_o^2 + 2as \]

**Variables Used.**

<table>
<thead>
<tr>
<th>In Equations</th>
<th>Description</th>
<th>In Programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t )</td>
<td>Time.</td>
<td>( t )</td>
</tr>
<tr>
<td>( a )</td>
<td>Acceleration.</td>
<td>( a )</td>
</tr>
<tr>
<td>( v_o )</td>
<td>Initial velocity.</td>
<td>( v_o )</td>
</tr>
<tr>
<td>( v )</td>
<td>Final velocity.</td>
<td>( v )</td>
</tr>
<tr>
<td>( s )</td>
<td>Displacement.</td>
<td>( s )</td>
</tr>
</tbody>
</table>

**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 \[\text{SOLVER}\].

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] [MO1]

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]
```

```
9.8 [/] [+/-] [A]
```

```
0 [V0]
```

```
S
```

```
2: Equations of Motion 23
```
The bridge is about 12.5 meters above the water. Now find $v$. Since $s$ is now known, you can use “MO2” or “MO3”.

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.

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

“MO1” Program Listing.

```
00 ( 40-Byte Prgm ) 09 RCL× "a"
01 LBL "MO1" 10 2
02 MVAR "t" 11 ÷
03 MVAR "a" 12 X<>Y
04 MVAR "v0" 13 RCL× "v0"
05 MVAR "s" 14 +
06 RCL "t" 15 RCL- "s"
07 ENTER 16 END
08 X+2
```
"MO2" Program Listing.

00 ( 33-Byte Prgm ) 06 RCL "t"
01 LBL "MO2" 07 RCL× "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 ( 39-Byte Prgm ) 08 RCL "v0"
01 LBL "MO3" 09 ×+2
02 MVAR "a" 10 -
03 MVAR "v0" 11 2
04 MVAR "v" 12 RCL× "a"
05 MVAR "s" 13 RCL× "s"
06 RCL "v" 14 -
07 ×+2 15 END
3

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.

<table>
<thead>
<tr>
<th>Configuration Code</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of Rosette</strong></td>
<td>Rectangular</td>
<td>Delta (Equiangular)</td>
</tr>
<tr>
<td><strong>Principal Strains</strong></td>
<td>$\frac{1}{2} \left[ \varepsilon_a + \varepsilon_c \right]$</td>
<td>$\frac{1}{3} \left[ \varepsilon_a + \varepsilon_b + \varepsilon_c \right]$</td>
</tr>
<tr>
<td></td>
<td>$\pm \sqrt{2(\varepsilon_a - \varepsilon_b)^2 + 2(\varepsilon_b - \varepsilon_c)^2}$</td>
<td>$\pm \sqrt{2(\varepsilon_a - \varepsilon_b)^2 + 2(\varepsilon_b - \varepsilon_c)^2 + 2(\varepsilon_c - \varepsilon_a)^2}$</td>
</tr>
<tr>
<td><strong>Center of Mohr Circle</strong></td>
<td>$\frac{E(\varepsilon_a + \varepsilon_c)}{2(1 - v)}$</td>
<td>$\frac{E(\varepsilon_a + \varepsilon_b + \varepsilon_c)}{3(1 - v)}$</td>
</tr>
<tr>
<td></td>
<td>$\frac{E}{2(1 + v)} \times \sqrt{2(\varepsilon_a - \varepsilon_b)^2 + 2(\varepsilon_b - \varepsilon_c)^2}$</td>
<td>$\frac{E}{3(1 + v)} \times \sqrt{2(\varepsilon_a - \varepsilon_b)^2 + 2(\varepsilon_b - \varepsilon_c)^2 + 2(\varepsilon_c - \varepsilon_a)^2}$</td>
</tr>
<tr>
<td><strong>Maximum Shear Stress</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Orientation of Principal Stresses</strong></td>
<td>$\frac{1}{2} \tan^{-1} \left[ \frac{2\varepsilon_b - \varepsilon_a - \varepsilon_c}{\varepsilon_a - \varepsilon_c} \right]$</td>
<td>$\frac{1}{2} \tan^{-1} \left[ \frac{\sqrt{3} (\varepsilon_c - \varepsilon_b)}{2\varepsilon_a - \varepsilon_b - \varepsilon_c} \right]$</td>
</tr>
</tbody>
</table>
### Variables Used.

<table>
<thead>
<tr>
<th>In Equations</th>
<th>Description</th>
<th>In Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E$</td>
<td>Young's modulus.</td>
<td>$E$</td>
</tr>
<tr>
<td>$\nu$</td>
<td>Poisson's ratio.</td>
<td>$\nu$</td>
</tr>
<tr>
<td>$\varepsilon_a$</td>
<td>Strain $\varepsilon_0$.</td>
<td>$\varepsilon_1$</td>
</tr>
<tr>
<td>$\varepsilon_b$</td>
<td>Strain $\varepsilon_{45}$ or $\varepsilon_{60}$.</td>
<td>$\varepsilon_2$</td>
</tr>
<tr>
<td>$\varepsilon_c$</td>
<td>Strain $\varepsilon_{90}$ or $\varepsilon_{120}$.</td>
<td>$\varepsilon_3$</td>
</tr>
<tr>
<td>$\sigma_x$</td>
<td>Normal stress on the x-face.</td>
<td>$\sigma_x$</td>
</tr>
<tr>
<td>$\sigma_y$</td>
<td>Normal stress on the y-face.</td>
<td>$\sigma_y$</td>
</tr>
<tr>
<td>$\sigma_1$</td>
<td>Minimum principal stress.</td>
<td>$\sigma_{\text{min}}$</td>
</tr>
<tr>
<td>$\sigma_2$</td>
<td>Maximum principal stress.</td>
<td>$\sigma_{\text{max}}$</td>
</tr>
<tr>
<td>$\tau_{xy}$</td>
<td>Shear stress.</td>
<td>$\tau_{\text{xy}}$</td>
</tr>
<tr>
<td>$\tau_{\text{max}}$</td>
<td>Maximum shear stress.</td>
<td>$\tau_{\text{max}}$</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Counterclockwise angle from $\varepsilon_a$ to the maximum principal stress.</td>
<td>$\phi$</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Counterclockwise angle from the x-axis to the maximum principal axis.*</td>
<td>$\theta$</td>
</tr>
<tr>
<td>$\theta'$</td>
<td>Arbitrary angle counter-clockwise from the x-axis.*</td>
<td>$\theta'$</td>
</tr>
<tr>
<td>$S$</td>
<td>Normal stress.*</td>
<td>$S$</td>
</tr>
<tr>
<td>$\tau$</td>
<td>Shear stress.*</td>
<td>$\tau$</td>
</tr>
</tbody>
</table>

*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] [V] [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:
   - EQU 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:
   a. When you see \( \text{ARE}\alpha\), key in the arbitrary angle of rotation.
   b. 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:

\[
\begin{align*}
\varepsilon_0 &= 180 \mu \\
\varepsilon_{60} &= 200 \mu \\
\varepsilon_{120} &= -290 \mu
\end{align*}
\]

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

- \([\text{MODES}]\) \(\text{DEG}\)  \(\text{EQ} \) \(\text{MOHR}\)
- \(\text{EQX}\)
- \(30 \ [\text{E} \ 6 \ [\text{E}\) \(E=30,000,000.0000\)
- \(.3 \ [\text{V}\) \(V=0.3000\)
- \(180 \ [\text{E} \ 6 \ [\text{E} \ 1\) \(\varepsilon_1=0.0002\)
Example 2: Known Stresses. The stresses acting on an element are shown below (all stresses are in MPa).

\[ \sigma_y = -20 \]
\[ \tau_{xy} = 30 \]
\[ \sigma_x = 75 \]
\[
\tau_{\text{max}} = \left( \frac{S_z - S_y}{2} \right)^2 + \tau_{xy}^2 \right)^{1/2}
\]

\[
S_1 = \frac{S_z + S_y}{2} + \tau_{\text{max}}
\]

\[
S_2 = \frac{S_z + S_y}{2} - \tau_{\text{max}}
\]

\[
\theta = \frac{1}{2} \tan^{-1} \left( \frac{-2\tau_{xy}}{S_z - S_y} \right)
\]

\[
S = \frac{S_1 + S_2}{2} + \tau_{\text{max}} \cos 2\left( \theta' - \theta \right)
\]

\[
\tau = \tau_{\text{max}} \sin 2\left( \theta' - \theta \right)
\]

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

Program:

00 { 412-Byte Prm }  
01 LBL "MOHR"  
02 SF 21  
03 CLMENU  
04 "EQ\angle"  
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 "TUXy"  
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 $r_{\text{max}}$ for strain gage data.
32 ÷
33 STO 00
34 RCL "E"
35 1
36 RCL+ "y"
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 R+ 
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.
Calculates results using known stresses.

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

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

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

Optional routine calculates normal and shear stress at an arbitrary angle.
3: Mohr Circle Analysis

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.

\[
\frac{s_{yp}}{FS} = \frac{1}{2} \left( s_{max} + s_{min} + K \left( \frac{s_{yp}}{s_e} \right) (s_{max} - s_{min}) \right)
\]
**Variables Used.**

<table>
<thead>
<tr>
<th>In Equation</th>
<th>Description</th>
<th>In Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>$s_{yp}$</td>
<td>Yield point stress.</td>
<td>Syp</td>
</tr>
<tr>
<td>$s_e$</td>
<td>Endurance stress.</td>
<td>Se</td>
</tr>
<tr>
<td>$s_{max}$</td>
<td>Maximum applied stress.</td>
<td>Smax</td>
</tr>
<tr>
<td>$s_{min}$</td>
<td>Minimum applied stress.</td>
<td>Smin</td>
</tr>
<tr>
<td>$K$</td>
<td>Stress concentration factor.</td>
<td>K</td>
</tr>
<tr>
<td>$FS$</td>
<td>Factor of safety.</td>
<td>FS</td>
</tr>
</tbody>
</table>

**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 $\mathbf{SOLVER}$ $\mathbf{SODER}$ 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?

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

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

$K = 1.5$

$FS = 2.0$
<table>
<thead>
<tr>
<th>SOLVER</th>
<th>SODER</th>
</tr>
</thead>
<tbody>
<tr>
<td>80000</td>
<td>SYP</td>
</tr>
<tr>
<td>30000</td>
<td>SE</td>
</tr>
<tr>
<td>15000</td>
<td>SMIN</td>
</tr>
<tr>
<td>1.5</td>
<td>K</td>
</tr>
<tr>
<td>2</td>
<td>FS</td>
</tr>
<tr>
<td>SMAX</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$S_y = 80,000$</th>
<th>$S_e = 30,000$</th>
<th>$S_{\text{min}} = 15,000$</th>
<th>$K = 1.5000$</th>
<th>$F_S = 2.0000$</th>
<th>$S_{\text{max}} = 25,000$</th>
</tr>
</thead>
<tbody>
<tr>
<td>${S_y, S_e, S_{\text{min}}, K, F_S}$</td>
<td>${S_y, S_e, S_{\text{min}}, K, F_S}$</td>
<td>${S_y, S_e, S_{\text{min}}, K, F_S}$</td>
<td>${S_y, S_e, S_{\text{min}}, K, F_S}$</td>
<td>${S_y, S_e, S_{\text{min}}, K, F_S}$</td>
<td>${S_y, S_e, S_{\text{min}}, K, F_S}$</td>
</tr>
</tbody>
</table>

3: Soderberg's Equation for Fatigue
"SODER" Program Listing.

00 ( 82-Byte Prgm )
01 LBL "SODER"
02 MVAR "Sy"n"
03 MVAR "Se"
04 MVAR "Sm"ax"
05 MVAR "Smin"
06 MVAR "K"
07 MVAR "FS"
08 RCL "Smax"
09 RCL+ "Smin"
10 LASTX

11 RCL- "Smin"
12 RCL× "K"
13 RCL× "Sy"n"
14 RCL÷ "Se"
15 +
16 2
17 ÷
18 RCL "Sy"n"
19 RCL÷ "FS"
20 -
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.

\[ A_{s_i} = \Delta x_i \Delta y_i \]

\[ A = A_{s_1} + A_{s_2} + A_{s_3} + \cdots + A_{s_m} \]

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

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

\[ I_{xy} = \sum_{i=1}^{n} x_{0i} y_{0i} A_{s_i} \]

\[ I_x = \sum_{i=1}^{n} \left( y_{0i}^2 + \frac{\Delta y_i^2}{12} \right) A_{s_i} \]

\[ I_y = \sum_{i=1}^{n} \left( x_{0i}^2 + \frac{\Delta x_i^2}{12} \right) A_{s_i} \]

\[ J = I_x + I_y \]
\[ \phi = \frac{1}{2} \tan^{-1} \left( \frac{2I_x y}{I_x - I_y} \right) \]

\[ I_{x\phi} = I_x \cos^2 \phi + I_y \sin^2 \phi + I_x I_y \sin 2\phi \]

\[ I_{y\phi} = I_y \cos^2 \phi + I_x \sin^2 \phi + I_x I_y \sin 2\phi \]

\[ J_\phi = I_{x\phi} + I_{y\phi} \]

Variables and Storage Registers Used.

<table>
<thead>
<tr>
<th>In Equations</th>
<th>Description</th>
<th>In Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta x_i )</td>
<td>Width of a rectangular element.</td>
<td>( W )</td>
</tr>
<tr>
<td>( \Delta y_i )</td>
<td>Height of a rectangular element.</td>
<td>( H )</td>
</tr>
<tr>
<td>( A_{xi} )</td>
<td>Area of an element.</td>
<td>( R_{02} )</td>
</tr>
<tr>
<td>( A )</td>
<td>Total area of the section.</td>
<td>( R_{01} )</td>
</tr>
<tr>
<td>( x )</td>
<td>( x )-coordinate of the centroid (total).</td>
<td>( R_{03} \div R_{01} )</td>
</tr>
<tr>
<td>( y )</td>
<td>( y )-coordinate of the centroid (total).</td>
<td>( R_{04} \div R_{01} )</td>
</tr>
<tr>
<td>( x_0 )</td>
<td>( x )-coordinate of the centroid of an element.</td>
<td>( x_c )</td>
</tr>
<tr>
<td>( y_0 )</td>
<td>( y )-coordinate of the centroid of an element.</td>
<td>( y_c )</td>
</tr>
<tr>
<td>( I_x )</td>
<td>Moment of inertia about the ( x )-axis.</td>
<td>( R_{06} )</td>
</tr>
<tr>
<td>( I_y )</td>
<td>Moment of inertia about the ( y )-axis.</td>
<td>( R_{07} )</td>
</tr>
<tr>
<td>( J )</td>
<td>Polar moment of inertia about the origin.</td>
<td>( R_{08} )</td>
</tr>
<tr>
<td>( I_{xy} )</td>
<td>Product of inertia about the origin.</td>
<td>( R_{09} )</td>
</tr>
<tr>
<td>In Equations</td>
<td>Description</td>
<td>In Program</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
<td>------------</td>
</tr>
<tr>
<td>$I_{x}$</td>
<td>Moment of inertia about the x-axis translated to the centroid.</td>
<td>R_{06}</td>
</tr>
<tr>
<td>$I_{y}$</td>
<td>Moment of inertia about the y-axis translated to the centroid.</td>
<td>R_{07}</td>
</tr>
<tr>
<td>$I_{xy}$</td>
<td>Product of inertia about the translated axis.</td>
<td>R_{09}</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Angle between the translated axis and the principal axis.</td>
<td>R_{05}</td>
</tr>
<tr>
<td>$I_{x\phi}$</td>
<td>Moment of inertia about the principal x-axis.</td>
<td></td>
</tr>
<tr>
<td>$I_{y\phi}$</td>
<td>Moment of inertia about the principal y-axis.</td>
<td></td>
</tr>
<tr>
<td>$J_{\phi}$</td>
<td>Polar moment of inertia about the principal axis.</td>
<td>R_{08}</td>
</tr>
</tbody>
</table>

**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, $I_{xy}$ 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] [V] [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 \textbf{XEQ SECT I} to execute the program.

3. When you see \textbf{Number of Sections?}, key in the number of composite sections and then press \textbf{R/S}.

4. Enter the data for each section:
   a. Key in the x-coordinate of the centroid and then press \textbf{X CO}. 
   b. Key in the y-coordinate of the centroid and then press \textbf{Y CO}.
   c. Key in the width of the section and then press \textbf{W}.
   d. Key in the height of the section and then press \textbf{H}.
   e. Press \textbf{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 \textbf{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 \textbf{R/S} after each result is displayed.
Example 1: Rectangular Section. Calculate the section properties of the following cross section.

![Rectangular Section Diagram]

**Table of Inputs**

<table>
<thead>
<tr>
<th>$x_c$</th>
<th>$y_c$</th>
<th>$\Delta x$</th>
<th>$\Delta y$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.5</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

**Program Output**

- **Number of Sections?**
  
  $x = 0.0000$

- **Input Section 1; [R/S]**
  
  $x_c = 2.0000$

- **[XEQ SECTI]**
  
  $y_c = 1.5000$
3: Composite Section Properties

\[ R/S \quad I_{xc} = x: 9.0000 \]

\[ R/S \quad I_{yc} = x: 16.0000 \]

\[ R/S \quad I_{xcg} = x: 0.0000 \]

\[ R/S \quad \phi_i = x: 0.0000 \]

\[ R/S \quad I_{xc \phi} = x: 9.0000 \]

\[ R/S \quad I_{yc \phi} = x: 16.0000 \]

\[ R/S \quad J_{\phi} = x: 25.0000 \]
Example 2: Composite Section. Calculate the section properties of the following section.

![Composite Section Diagram]

Table of Inputs

<table>
<thead>
<tr>
<th>(x_c)</th>
<th>(y_c)</th>
<th>(\Delta x)</th>
<th>(\Delta y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>10</td>
<td>2</td>
</tr>
</tbody>
</table>

Number of Sections?

\[x: 25.0000\]

Input Section 1;[R/S]

\[X_c=5.0000\]

\[Y_c=11.5000\]
3: Composite Section Properties

Input Section 2; [R/S]

\[ \begin{array}{llll}
W & = & 6.0000 \\
Xc & = & 1.0000 \\
Yc & = & 6.0000 \\
\end{array} \]

Input Section 3; [R/S]

\[ \begin{array}{llll}
W & = & 2.0000 \\
Xc & = & 7.0000 \\
\end{array} \]
<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Calculation</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yc=1.0000</td>
<td>Yc, xc, w, h</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>W=10.0000</td>
<td>Yc, xc, w, h</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>H=2.0000</td>
<td>Yc, xc, w, h</td>
<td></td>
</tr>
<tr>
<td>R/S</td>
<td></td>
<td>Area</td>
<td>50.0000</td>
</tr>
<tr>
<td>R/S</td>
<td></td>
<td>xc</td>
<td>3.8800</td>
</tr>
<tr>
<td>R/S</td>
<td></td>
<td>Yc</td>
<td>4.6600</td>
</tr>
<tr>
<td>R/S</td>
<td></td>
<td>Ix</td>
<td>1,972.6667</td>
</tr>
<tr>
<td>R/S</td>
<td></td>
<td>Iy</td>
<td>1,346.6667</td>
</tr>
<tr>
<td>R/S</td>
<td></td>
<td>J</td>
<td>3,319.3333</td>
</tr>
</tbody>
</table>

3: Composite Section Properties
\[ \begin{align*}
\text{R/S} & & I_{xy} = x: 629.0000 \\
\text{R/S} & & I_{xc} = x: 886.8867 \\
\text{R/S} & & I_{yc} = x: 593.9467 \\
\text{R/S} & & I_{xyc} = x: -275.0400 \\
\text{R/S} & & \phi = x: 30.9814 \\
\text{R/S} & & I_{xc \phi} = x: 1,052.0261 \\
\text{R/S} & & I_{yc \phi} = x: 428.8072 \\
\text{R/S} & & J_{\phi} = x: 1,480.8333
\end{align*} \]
"SECTION" Program Listing.

Program:

00 ( 395-Byte Prgm )
01 LBL "SECTION"
02 MVAR "Xc"
03 MVAR "Yc"
04 MVAR "W"
05 MVAR "H"

06 LBL 00
07 "Number of "
08 +"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 AIP
25 ÷;[R/S]

26 CF 21
27 AVIEW
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 R00.

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 EXIT ALL
35 RCL "H"
36 RCL× "W"
37 STO 02
38 STO+ 01
39 RCL× "Ye"  
40 STO+ 04
41 RCL "Xe"
42 RCL× 02
43 STO+ 03
44 RCL "Ye"
45 X+2
46 RCL "H"
47 X+2
48 12
49 ÷
50 +
51 RCL× 02
52 STO+ 06
53 RCL "Xe"
54 X+2
55 RCL "W"
56 X+2
57 12
58 ÷
59 +
60 RCL× 02
61 STO+ 07
62 +
63 STO+ 08
64 RCL "Xe"
65 RCL× "Ye"
66 RCL× 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.
Calculates $I_{xy}$.

Displays the area.

Calculates and displays $\overline{x}$.

Calculates and displays $\overline{y}$.

Displays $I_x$ and calculates $I_{xy}$.

Displays $I_y$.

Displays $J$. 

3: Composite Section Properties
105 R↑ Displays $I_{xy}$.
106 RCL 09
107 "Ixy" Calculates $I_y$.
108 XEQ 03

109 R↑ Displays $I_x$.
110 +
111 STO 07 Displays $I_y$.

112 RCL 06 Displays $I_y$.
113 "Ixc"
114 XEQ 03 Displays $I_{xy}$.

115 STO 08 Displays $I_{xy}$.
116 ÷ Calculates $\phi$.
117 "Iyc"
118 XEQ 03

119 STO+ 08
120 -
121 STO 04
122 RCL 10 Calculates $\phi$.
123 "Ixyc"
124 XEQ 03

125 X=0? Displays $I_{xy}$.
126 GTO 02
127 ÷
128 1/X
129 2
130 ×
131 ATAN
132 2
133 ÷
134 ÷/
135 LBL 02
136 STO 05
137 "Δphi"
138 XEQ 03

56 3: Composite Section Properties
Calculates and displays $I_{z\phi}$

Calculates and displays $I_{y\phi}$

Displays $J_{\phi}$.

Returns to the initial prompt.

Displays a result. If results are being printed (flag 55 set), the label and value are printed on a single line.
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.

<table>
<thead>
<tr>
<th>In Equations</th>
<th>Description</th>
<th>In Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X_1 )</td>
<td>First spring length.</td>
<td>( X_1 )</td>
</tr>
<tr>
<td>( F_1 )</td>
<td>Force required to retain spring at length ( X_1 ).</td>
<td>( F_1 )</td>
</tr>
<tr>
<td>( X_2 )</td>
<td>Second spring length.</td>
<td>( X_2 )</td>
</tr>
<tr>
<td>( F_2 )</td>
<td>Force required to retain spring at length ( X_2 ).</td>
<td>( F_2 )</td>
</tr>
<tr>
<td>( k )</td>
<td>Spring constant.</td>
<td>( k )</td>
</tr>
</tbody>
</table>

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 \([\text{SOLVER}]\) 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.

The spring constant is 22.5.
A force of 33.75 Newtons would completely compress the spring (to 2.5 cm).

"SPRING" Program Listing.

```plaintext
00 ( 49-Byte Prgm )
01 LBL "SPRING"
02 MVAR "X1"
03 MVAR "F1"
04 MVAR "X2"
05 MVAR "F2"
06 MVAR "k"
07 RCL "F1"
08 RCL− "F2"
09 RCL "X2"
10 RCL− "X1"
11 ÷
12 RCL− "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.

\[ \Delta \ell = \frac{P \ell}{AE} \quad \Delta \ell \]

or

\[ \theta = \frac{T \ell}{JG} \]
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.

<table>
<thead>
<tr>
<th>In Equations</th>
<th>Description</th>
<th>In Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta l )</td>
<td>Change in length.</td>
<td>( \Delta l )</td>
</tr>
<tr>
<td>( P )</td>
<td>Applied load.</td>
<td>( P )</td>
</tr>
<tr>
<td>( l )</td>
<td>Length.</td>
<td>( l )</td>
</tr>
<tr>
<td>( A )</td>
<td>Cross-sectional area.</td>
<td>( A )</td>
</tr>
<tr>
<td>( E )</td>
<td>Modulus of elasticity.</td>
<td>( E )</td>
</tr>
<tr>
<td>( \theta )</td>
<td>Deflection angle (in radians).</td>
<td>( \Delta l )</td>
</tr>
<tr>
<td>( T )</td>
<td>Applied torque.</td>
<td>( P )</td>
</tr>
<tr>
<td>( J )</td>
<td>Polar moment of the section.</td>
<td>( A )</td>
</tr>
<tr>
<td>( G )</td>
<td>Modulus of elasticity in shear.</td>
<td>( E )</td>
</tr>
</tbody>
</table>

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 \[ SOLVER \] DEF 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$^2$.

\[
\begin{align*}
\text{SOLVER DEFOR} & \quad \text{x: 0.0000} \\
\text{DELTA P L R E} & \\
\text{.001 DELTA} & \quad \text{Delta=0.0010} \\
\text{DELTA P L R E} & \\
50000 \text{ P} & \quad \text{P=50,000.0000} \\
\text{DELTA P L R E} & \\
10 \text{ L} & \quad \text{L=10.0000} \\
\text{DELTA P L R E} & \\
2.068 \times 10^{11} \text{ E} & \quad \text{E=206,800,000,000.} \\
\text{DELTA P L R E} & \\
\text{A} & \quad \text{A=0.0024} \\
\text{DELTA P L R E}
\end{align*}
\]
**"DEFORM" Program Listing.**

<table>
<thead>
<tr>
<th>Line</th>
<th>Description</th>
<th>Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>( 48-Byte Pgm )</td>
<td></td>
</tr>
<tr>
<td>01</td>
<td>LBL &quot;DEFORM&quot;</td>
<td>07 RCL &quot;P&quot;</td>
</tr>
<tr>
<td>02</td>
<td>MVAR &quot;Delta&quot;</td>
<td>08 RCL× &quot;L&quot;</td>
</tr>
<tr>
<td>03</td>
<td>MVAR &quot;P&quot;</td>
<td>09 RCL÷ &quot;A&quot;</td>
</tr>
<tr>
<td>04</td>
<td>MVAR &quot;L&quot;</td>
<td>10 RCL÷ &quot;E&quot;</td>
</tr>
<tr>
<td>05</td>
<td>MVAR &quot;A&quot;</td>
<td>11 RCL− &quot;Delta&quot;</td>
</tr>
<tr>
<td>06</td>
<td>MVAR &quot;E&quot;</td>
<td>12 END</td>
</tr>
</tbody>
</table>

64 3: Linear or Angular Deformation
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:

\[ a = 4.934b \frac{nRT_c^{1.5}}{P_c} \]

\[ b = 0.0867 \frac{nRT_c}{P_c} \]

Variables Used.

<table>
<thead>
<tr>
<th>In Equations</th>
<th>Description</th>
<th>In Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>Absolute pressure.</td>
<td>P</td>
</tr>
<tr>
<td>V</td>
<td>Volume.</td>
<td>V</td>
</tr>
<tr>
<td>n</td>
<td>Number of moles present.</td>
<td>n</td>
</tr>
<tr>
<td>R</td>
<td>Universal gas constant.</td>
<td>R</td>
</tr>
<tr>
<td>T</td>
<td>Absolute temperature.</td>
<td>T</td>
</tr>
<tr>
<td>T_c</td>
<td>Critical temperature.</td>
<td>Tc</td>
</tr>
<tr>
<td>P_c</td>
<td>Critical pressure.</td>
<td>P_c</td>
</tr>
</tbody>
</table>
## Values of the Universal Gas Constant

<table>
<thead>
<tr>
<th>Value of $R$</th>
<th>Units of $R$</th>
<th>Units of $P$</th>
<th>Units of $V$</th>
<th>Units of $T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.314</td>
<td>N-m/g mole-K</td>
<td>N/m$^2$</td>
<td>m$^3$/g mole</td>
<td>K</td>
</tr>
<tr>
<td>83.14</td>
<td>cm$^3$-bar/g mole-K</td>
<td>bar</td>
<td>cm$^3$/g mole</td>
<td>K</td>
</tr>
<tr>
<td>82.05</td>
<td>cm$^3$-atm/g mole-K</td>
<td>atm</td>
<td>cm$^3$/g mole</td>
<td>K</td>
</tr>
<tr>
<td>0.7302</td>
<td>atm-ft$^3$/lb mole-°R</td>
<td>atm</td>
<td>ft$^3$/lb mole</td>
<td>°R</td>
</tr>
<tr>
<td>10.73</td>
<td>psi-ft$^3$/lb molc-°R</td>
<td>psi</td>
<td>ft$^3$/lb mole</td>
<td>°R</td>
</tr>
<tr>
<td>1545</td>
<td>psf-ft$^3$/lb mole-°R</td>
<td>psf</td>
<td>ft$^3$/lb mole</td>
<td>°R</td>
</tr>
</tbody>
</table>

## Critical Temperatures and Pressures

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

4: Equations of State  67
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.


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 $\uparrow$ or $\downarrow$ to enter or solve for $P_e$.

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$^3$ 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.)
Example 2: Using Redlich-Kwong’s Equation. The specific volume of a gas in a container is 800 cm³/g mole. The temperature will reach 400K. Given the following constants, what will the pressure be using the Redlich-Kwong relation?

\[ T_e = 305.5 \text{K} \]
\[ P_e = 48.2 \text{ atm} \]
\[ R = 82.05 \text{ cm}^3 \text{ atm/g mole K} \]
“IDEAL” Program Listing.

```
00 ( 40-Byte Prgm )
01 LBL "IDEAL"
02 MVAR "P"
03 MVAR "V"
04 MVAR "n"
05 MVAR "R"
06 MVAR "T"
07 RCL "n"
08 RCLx "R"
09 RCLx "T"
10 RCL "P"
11 RCLx "V"
12 -
13 END
```
"RK" Program Listing.

00 ( 113-Byte Prgm ) 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 4.934 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.
\[ \lambda_{\text{max}} T = c_3 \]

\[ E_{b(0-\chi)} = \sigma T^4 \]

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

**Variables Used.**

<table>
<thead>
<tr>
<th>In Equations</th>
<th>Description</th>
<th>In Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda_{\text{max}} )</td>
<td>Wavelength of maximum emissivity in microns.</td>
<td>( \lambda )</td>
</tr>
<tr>
<td>( T )</td>
<td>Absolute temperature in °R or K.</td>
<td>( T )</td>
</tr>
<tr>
<td>( E_{b(0-\chi)} )</td>
<td>Total emissive power in Btu/hr-ft² or watts/m².</td>
<td>( E )</td>
</tr>
<tr>
<td>( E_{b\lambda} )</td>
<td>Emissive power at ( \lambda ) in Btu/hr-ft²-μm or watts/m²-μm.</td>
<td>( P )</td>
</tr>
</tbody>
</table>

**Remarks.**

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

<table>
<thead>
<tr>
<th>SI Units (Flag 00 Clear)</th>
<th>English Units (Flag 00 Set)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( c_1 ) ( = 5.9544 \times 10^{-8} ) W-m²</td>
<td>( 1.8887982 \times 10^7 ) Btu-μm⁴/hr-ft²</td>
</tr>
<tr>
<td>( c_2 ) ( = 1.4388 \times 10^4 ) μm-K</td>
<td>( 2.58984 \times 10^4 ) μm-°R</td>
</tr>
<tr>
<td>( c_3 ) ( = 2.8978 \times 10^3 ) μm-K</td>
<td>( 5.216 \times 10^3 ) μm-°R</td>
</tr>
<tr>
<td>( \sigma ) ( = 5.6697 \times 10^{-8} ) W/m²-K⁴</td>
<td>( 1.713 \times 10^{-9} ) Btu/hr-ft²-°R⁴</td>
</tr>
</tbody>
</table>

- 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.

<table>
<thead>
<tr>
<th>To Calculate</th>
<th>You Must Provide</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>T</td>
</tr>
<tr>
<td>T</td>
<td>W</td>
</tr>
<tr>
<td>E</td>
<td>T</td>
</tr>
<tr>
<td>P</td>
<td>W and T</td>
</tr>
</tbody>
</table>

Example. If sunlight has a maximum wavelength of 0.550 μm, 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 $\lambda_{max}$? What is the emissive power at $\lambda = 0.400 \mu m$ (ultraviolet limit) and 0.700 μm (infrared limit)? (Clear flag 00 for SI units.)
The sun's temperature is 5,269K.

The total emissive power is approximately 43,690,000 W/m².

The power at 0.550 μm is $5.2229 \times 10^{-8}$ W/m²-μm.

The power at 0.400 μm is $3.9649 \times 10^{-8}$ W/m²-μm.

The power at 0.700 μm is $4.5934 \times 10^{-8}$ W/m²-μm.

"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 ( 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 ATOX
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] redispays 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, $\sigma$. 

76 4: Black Body Thermal Radiation
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 \( c_3 \).
5

Fluid Dynamics
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 (\( Re \leq 2300 \))

\[ f = \frac{16}{Re} \]

For turbulent flow (\( Re > 2300 \))

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

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.

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

*The Fanning friction factor is one-fourth the Darcy friction factor. That is, \( f = f_D \div 4 \).*
### Fitting Coefficients

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

* $A_{up}$ is the upstream area and $A_{dn}$ is the downstream area.
### Surface Irregularities

<table>
<thead>
<tr>
<th>Material</th>
<th>$\varepsilon$ (Feet)</th>
<th>$\varepsilon$ (Meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawn or smooth tubing</td>
<td>$5.0 \times 10^{-6}$</td>
<td>$1.5 \times 10^{-6}$</td>
</tr>
<tr>
<td>Commercial steel or wrought iron</td>
<td>$1.5 \times 10^{-4}$</td>
<td>$4.6 \times 10^{-5}$</td>
</tr>
<tr>
<td>Asphaltered cast iron</td>
<td>$4.0 \times 10^{-4}$</td>
<td>$1.2 \times 10^{-4}$</td>
</tr>
<tr>
<td>Galvanized iron</td>
<td>$5.0 \times 10^{-4}$</td>
<td>$1.5 \times 10^{-4}$</td>
</tr>
<tr>
<td>Cast iron</td>
<td>$8.3 \times 10^{-4}$</td>
<td>$2.5 \times 10^{-4}$</td>
</tr>
<tr>
<td>Wood stave</td>
<td>$6.0 \times 10^{-4}$</td>
<td>$1.8 \times 10^{-4}$</td>
</tr>
<tr>
<td></td>
<td>$3.0 \times 10^{-3}$</td>
<td>$9.1 \times 10^{-4}$</td>
</tr>
<tr>
<td>Concrete</td>
<td>$1.0 \times 10^{-3}$</td>
<td>$3.0 \times 10^{-4}$</td>
</tr>
<tr>
<td></td>
<td>$1.0 \times 10^{-2}$</td>
<td>$3.0 \times 10^{-3}$</td>
</tr>
<tr>
<td>Riveted steel</td>
<td>$3.0 \times 10^{-3}$</td>
<td>$9.1 \times 10^{-4}$</td>
</tr>
<tr>
<td></td>
<td>$3.0 \times 10^{-2}$</td>
<td>$9.1 \times 10^{-3}$</td>
</tr>
</tbody>
</table>

### 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.
Example. A 60-meter pipe has three 180° 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 $3 \times 10^{-4}$ 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?
Check the Reynolds number and the Fanning friction factor.

```
P=418,351.25598
R=103,225.8065
F=0.0096
```

"FLOW" Program Listing.

```
00 ( 128-Byte Prgm ) 28 LOG
01 LBL "FLOW" 29 3.6
02 MVAR "E" 30 x
03 MVAR "D" 31 1/x
04 MVAR "V" 32 X+2
05 MVAR "B" 33 LBL 00
06 MVAR "L" 34 STO "F"
07 MVAR "K" 35 RCL "L"
08 MVAR "S" 36 RCL "D"
09 MVAR "P" 37 RCL "K"
10 RCL "E" 38 4
11 RCL "D" 39 /
12 3.7 40 +
13 1/111 41 2
14 1.111 42 x
15 Y+X 43 RCL "V"
16 RCL "V" 44 X+2
17 RCL "D" 45 x
18 RCL "B" 46 RCL "P"
19 STO "R" 47 RCL "S"
20 2300 48 -
21 Y>Y? 49 RTN
22 GTO 01 50 LBL 01
23 R+ 51 16
24 1/x 52 RCL "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.

<table>
<thead>
<tr>
<th>In Equation</th>
<th>Description</th>
<th>In Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S )</td>
<td>Slope of the bottom (dimensionless).</td>
<td>( S )</td>
</tr>
<tr>
<td>( n )</td>
<td>Roughness coefficient.</td>
<td>( n )</td>
</tr>
<tr>
<td>( r )</td>
<td>Hydraulic radius (in feet).</td>
<td>( r )</td>
</tr>
<tr>
<td>( Q )</td>
<td>Discharge flow rate (in ft³/sec).</td>
<td>( Q )</td>
</tr>
<tr>
<td>( a )</td>
<td>Cross-sectional area (in ft²).</td>
<td>( a )</td>
</tr>
</tbody>
</table>

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 \( S = 0.001, n = 0.013, R = 5/12 \text{ ft}, \) and \( A = 5.0 \text{ ft}^2. \)
0.001

0.013

0.013

5 ENTER 12 +

5

Q

S = 0.0010

n = 0.0130

r = 8.4167

a = 5.0000

Q = 10.0826

5: Flow With a Free Surface
"MANN" Program Listing.

00 ( 57-Byte Prgm )
01 LBL "MANN"
02 MVAR "S"
03 MVAR "n"
04 MVAR "r"
05 MVAR "Q"
06 MVAR "a"
07 RCL "n"
08 RCL× "Q"
09 X+2
10 2.2082
11 ÷
12 RCL "r"
13 4
14 ENTER
15 3
16 ÷
17 Y+X
18 ÷
19 RCL "a"
20 X+2
21 ÷
22 RCL- "S"
23 END
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
What is the same distance in feet?

Now convert six miles to meters.

Example 2: Force Conversions. Convert a 135 pound force to Newtons. (Key the “FORCE” program into your calculator.)
**LENGTH** Program Listing. This program performs unit conversions using centimeters, meters, kilometers, inches, feet, and miles. The base unit is the meter.

**Program:**

```
00 ( 183-Byte Prgm )
01 LBL "LENGTH"
02 CF 21
03 FS? 55
04 SF 21

05 CLMEN
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 ×
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.
Displays the new value and the unit string.

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).
"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 { 198-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.
Subroutines for each menu key.
Each routine enters a string into the Alpha register and a conversion factor into the X-register.

“TEMP” Program Listing. Conversions between the four temperature scales (Kelvin, °Celsius, °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.
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 ( 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 \times
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 ×  
37 ASTO ST L  
38 CLA  
39 ARCL ST X  
40 +" "  
41 ARCL ST L  
42 AVIEW  
43 GTO A  

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 0.55555555556  
57 0  
58 RTN  
59 LBL 04  
60 "°F"  
61 0.55555555556  
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 (nnn-Byte Prgm)
01 LBL "program name here"
02 CF 21
03 FS? 55
04 SF 21
05 CLMNU
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 ×
28 STO "UNIT"
29 R↓
30 LASTX
31 LBL 00
32 1/x
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.

<table>
<thead>
<tr>
<th>Dimensionless Unit</th>
<th>Abbreviation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arcmin</td>
<td>arcmin</td>
<td>$\frac{1}{21600}$ unit circle</td>
</tr>
<tr>
<td>Arcsec</td>
<td>arcs</td>
<td>$\frac{1}{1296000}$ unit circle</td>
</tr>
<tr>
<td>Degree</td>
<td>°</td>
<td>$\frac{1}{360}$ unit circle</td>
</tr>
<tr>
<td>Grade</td>
<td>grad</td>
<td>$\frac{1}{400}$ unit circle</td>
</tr>
<tr>
<td>Radian</td>
<td>r</td>
<td>$\frac{1}{2\pi}$ unit circle</td>
</tr>
<tr>
<td>Steradian</td>
<td>sr</td>
<td>$\frac{1}{4\pi}$ unit sphere</td>
</tr>
</tbody>
</table>
## 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.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Full Name</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Are</td>
<td>Area</td>
<td>100 m²</td>
</tr>
<tr>
<td>A</td>
<td>Ampere</td>
<td>Electric current</td>
<td>1 A</td>
</tr>
<tr>
<td>acre</td>
<td>Acre</td>
<td>Area</td>
<td>4046.87260987 m²</td>
</tr>
<tr>
<td>arcmin</td>
<td>Minute of arc</td>
<td>Plane angle</td>
<td>4.62962962963E-5</td>
</tr>
<tr>
<td>arcs</td>
<td>Second of arc</td>
<td>Plane angle</td>
<td>7.71604938272E-7</td>
</tr>
<tr>
<td>atm</td>
<td>Atmosphere</td>
<td>Pressure</td>
<td>101325 N/m²</td>
</tr>
<tr>
<td>au</td>
<td>Astronomical unit</td>
<td>Length</td>
<td>149597900000 m</td>
</tr>
<tr>
<td>A°</td>
<td>Angstrom</td>
<td>Length</td>
<td>0.0000000001 m</td>
</tr>
<tr>
<td>b</td>
<td>Barn</td>
<td>Area</td>
<td>1.E-28 m²</td>
</tr>
<tr>
<td>bar</td>
<td>Bar</td>
<td>Pressure</td>
<td>100000 N/m²</td>
</tr>
<tr>
<td>bbl</td>
<td>Barrel, oil</td>
<td>Volume</td>
<td>0.158987294928 m³</td>
</tr>
<tr>
<td>Bq</td>
<td>Becquerel</td>
<td>Activity</td>
<td>1 1/s</td>
</tr>
<tr>
<td>Btu</td>
<td>International Table</td>
<td>Energy</td>
<td>1055.05585262 Kg-m²/s²</td>
</tr>
<tr>
<td>Bu</td>
<td>Bushel</td>
<td>Volume</td>
<td>0.03523907 m³</td>
</tr>
<tr>
<td>c</td>
<td>Speed of light</td>
<td>Velocity</td>
<td>299792458 m/s</td>
</tr>
<tr>
<td>C</td>
<td>Coulomb</td>
<td>Electric charge</td>
<td>1 A-s</td>
</tr>
<tr>
<td>cal</td>
<td>International Table</td>
<td>Energy</td>
<td>4.1868 Kg-m²/s²</td>
</tr>
<tr>
<td>cd</td>
<td>Candela</td>
<td>Luminous intensity</td>
<td>1 cd</td>
</tr>
<tr>
<td>chain</td>
<td>Chain</td>
<td>Length</td>
<td>20.1168402337 m</td>
</tr>
<tr>
<td>Unit</td>
<td>Full Name</td>
<td>Description</td>
<td>Value</td>
</tr>
<tr>
<td>------</td>
<td>---------------</td>
<td>-----------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>Ci</td>
<td>Curie</td>
<td>Activity</td>
<td>$3.7 \times 10^{11}$ s</td>
</tr>
<tr>
<td>ct</td>
<td>Carat</td>
<td>Mass</td>
<td>0.0002 Kg</td>
</tr>
<tr>
<td>cu</td>
<td>US cup</td>
<td>Volume</td>
<td>$2.365882365 \times 4$ m$^3$</td>
</tr>
<tr>
<td>d</td>
<td>Day</td>
<td>Time</td>
<td>86400 s</td>
</tr>
<tr>
<td>dyn</td>
<td>Dyne</td>
<td>Force</td>
<td>0.000001 Kg-m/s$^2$</td>
</tr>
<tr>
<td>erg</td>
<td>Erg</td>
<td>Energy</td>
<td>0.00000001 Kg-m$^2$/s$^2$</td>
</tr>
<tr>
<td>eV</td>
<td>Electron volt</td>
<td>Energy</td>
<td>$1.60219 \times 19$ Kg-m$^2$/s$^2$</td>
</tr>
<tr>
<td>F</td>
<td>Farad</td>
<td>Capacitance</td>
<td>1 A$^2$.s$^4$/Kg-m$^2$</td>
</tr>
<tr>
<td>fath</td>
<td>Fathom</td>
<td>Length</td>
<td>1.82880365761 m</td>
</tr>
<tr>
<td>fbfm</td>
<td>Board foot</td>
<td>Volume</td>
<td>0.002359737216 m$^3$</td>
</tr>
<tr>
<td>fc</td>
<td>Footcandle</td>
<td>Luminance</td>
<td>0.8556574909</td>
</tr>
<tr>
<td>Fdy</td>
<td>Faraday</td>
<td>Electric charge</td>
<td>96487 A-s</td>
</tr>
<tr>
<td>fermi</td>
<td>Fermi</td>
<td>Length</td>
<td>1.5E-15 m</td>
</tr>
<tr>
<td>flam</td>
<td>Footlambert</td>
<td>Luminance</td>
<td>3.4265909964 cd/m$^2$</td>
</tr>
<tr>
<td>ft</td>
<td>International foot</td>
<td>Length</td>
<td>0.3048 m</td>
</tr>
<tr>
<td>ftUS</td>
<td>Survey foot</td>
<td>Length</td>
<td>0.304800609601 m</td>
</tr>
<tr>
<td>g</td>
<td>Gram</td>
<td>Mass</td>
<td>0.001 Kg</td>
</tr>
<tr>
<td>ga</td>
<td>Standard freefall</td>
<td>Acceleration</td>
<td>9.80665 m/s$^2$</td>
</tr>
<tr>
<td>gal</td>
<td>US gallon</td>
<td>Volume</td>
<td>0.003785411784 m$^3$</td>
</tr>
<tr>
<td>galC</td>
<td>Canadian gallon</td>
<td>Volume</td>
<td>0.00454609 m$^3$</td>
</tr>
<tr>
<td>galUK</td>
<td>UK gallon</td>
<td>Volume</td>
<td>0.004546092 m$^3$</td>
</tr>
<tr>
<td>gf</td>
<td>Gram-force</td>
<td>Force</td>
<td>0.00980665 Kg-m/s$^2$</td>
</tr>
<tr>
<td>grad</td>
<td>Grade</td>
<td>Plane angle</td>
<td>0.0025</td>
</tr>
<tr>
<td>grain</td>
<td>Grain</td>
<td>Mass</td>
<td>0.00006479891 Kg</td>
</tr>
<tr>
<td>Gy</td>
<td>Gray</td>
<td>Absorbed dose</td>
<td>1 m$^2$/s$^2$</td>
</tr>
<tr>
<td>h</td>
<td>Hour</td>
<td>Time</td>
<td>3600 s</td>
</tr>
<tr>
<td>H</td>
<td>Henry</td>
<td>Inductance</td>
<td>1 Kg-m$^2$/A$^2$.s$^2$</td>
</tr>
<tr>
<td>Unit</td>
<td>Full Name</td>
<td>Description</td>
<td>Value</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------</td>
<td>-------------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td>hp</td>
<td>Horsepower</td>
<td>Power</td>
<td>745.699871582 Kg-m²/s³</td>
</tr>
<tr>
<td>Hz</td>
<td>Hertz</td>
<td>Frequency</td>
<td>1 1/s</td>
</tr>
<tr>
<td>in</td>
<td>Inch</td>
<td>Length</td>
<td>0.0254 m</td>
</tr>
<tr>
<td>inHg</td>
<td>Inches of mercury</td>
<td>Pressure</td>
<td>3386.38815789 N/m²</td>
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<tr>
<td>inH2O</td>
<td>Inches of water</td>
<td>Pressure</td>
<td>248.84 N/m²</td>
</tr>
<tr>
<td>J</td>
<td>Joule</td>
<td>Energy</td>
<td>1 Kg-m²/s²</td>
</tr>
<tr>
<td>kip</td>
<td>Kilopound-force</td>
<td>Force</td>
<td>4448.22161526 Kg-m/s²</td>
</tr>
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<td>Knot</td>
<td>Speed</td>
<td>0.5144444444444 m/s</td>
</tr>
<tr>
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<td>Kilometer per hour</td>
<td>Speed</td>
<td>0.2777777777778 m/s</td>
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<td>l</td>
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<td>Volume</td>
<td>0.001 m³</td>
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<td>Luminance</td>
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<td>Force</td>
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<td>Illuminance</td>
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<td>Length</td>
<td>9.46052840488E15 m</td>
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<td>Length</td>
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</tr>
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<td>Mho</td>
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<td>Length</td>
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<td>Length</td>
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<td>Time</td>
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<td>Pressure</td>
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<td>Amount of substance</td>
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102 6: Conversion Factors
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<td>Newton</td>
<td>Force</td>
<td>$1 \text{ Kg-m/s}^2$</td>
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<tr>
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<td>Nautical mile</td>
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<tr>
<td>ohm</td>
<td>Ohm</td>
<td>Electric resistance</td>
<td>$1 \text{ Kg-m}^2/\text{A}^2\text{-s}^3$</td>
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<td>Ounce</td>
<td>Mass</td>
<td>0.028349523125 Kg</td>
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<td>ozfl</td>
<td>US fluid oz</td>
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<tr>
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<td>UK fluid oz</td>
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<td>Poise</td>
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<td>Pa</td>
<td>Pascal</td>
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<tr>
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<td>Parsec</td>
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<td>Force</td>
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<td>Volume</td>
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<td>Plane angle</td>
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<td>Radiation exposure</td>
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<tr>
<td>rad</td>
<td>Rad</td>
<td>Absorbed dose</td>
<td>0.01 m$^2$/s$^2$</td>
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<td>Length</td>
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<td>Rem</td>
<td>Dose equivalent</td>
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<td>Second</td>
<td>Time</td>
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</tr>
<tr>
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<td>Siemens</td>
<td>Electric conductance</td>
<td>1 A$^2$-s$^3$/Kg-m$^2$</td>
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<td>Luminance</td>
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<td>Slug</td>
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<td>Solid angle</td>
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<td>Description</td>
<td>Value</td>
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<td>-------------------</td>
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<td>------------------------</td>
</tr>
<tr>
<td>st</td>
<td>Stere</td>
<td>Volume</td>
<td>1 m³</td>
</tr>
<tr>
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<td>Stokes</td>
<td>Kinematic viscosity</td>
<td>0.0001 m²/s</td>
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<tr>
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<td>Sievert</td>
<td>Dose equivalent</td>
<td>1 m²/s²</td>
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<tr>
<td>t</td>
<td>Metric ton</td>
<td>Mass</td>
<td>1000 Kg</td>
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<tr>
<td>T</td>
<td>Tesla</td>
<td>Magnetic flux</td>
<td>1 Kg/A-s²</td>
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<td>Tablespoon</td>
<td>Volume</td>
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<td>Energy</td>
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<td>ton</td>
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<td>Mass</td>
<td>907.18474 Kg</td>
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<tr>
<td>tonUK</td>
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<td>Mass</td>
<td>1016.0469088 Kg</td>
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<tr>
<td>torr</td>
<td>Torr</td>
<td>Pressure</td>
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<tr>
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<td>4.92892159375E-6 m³</td>
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<td>Unified atomic mass</td>
<td>Mass</td>
<td>1.66057E-27 Kg</td>
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<td>Volt</td>
<td>Electric potential</td>
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<td>Watt</td>
<td>Power</td>
<td>1 Kg-m²/s³</td>
</tr>
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<td>Weber</td>
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<td>Year</td>
<td>Time</td>
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<td>Angle</td>
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<td>Degree Celsius</td>
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<td>°F</td>
<td>Degree Fahrenheit</td>
<td>Temperature</td>
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<td>1 K*</td>
</tr>
<tr>
<td>°R</td>
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<tr>
<td>μ</td>
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</table>

*Refer to the "TEMP" program listing starting on page 94.
Step-by-Step Solutions for Your HP-42S Calculator

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

- **Fluid Dynamics**
  Conduit Flow • Flow With a Free Surface

- **Unit Conversions**
  Writing Your Own Unit Conversion Programs • Dimensionless Units of Angle • Conversion Factors