Hewlett-Packard Company makes no express or implied warranty with regard to the keystroke procedures and program material offered or their merchantability or their fitness for any particular purpose. The keystroke procedures and program material are made available solely on an "as is" basis, and the entire risk as to their quality and performance is with the user. Should the keystroke procedures or program material prove defective, the user (and not Hewlett-Packard Company nor any other party) shall bear the entire cost of all necessary correction and all incidental or consequential damages. Hewlett-Packard Company shall not be liable for an incidental or consequential damages in connection with or arising out of the furnishing, use, or performance of the keystroke procedures or program material.
INTRODUCTION

This HP-41C application pac is designed to solve a variety of problems involving fluid flow, gas behavior, and heat transfer. In order to make these solutions more useful a unique Unit Management System is incorporated. This system allows you to specify the units of your inputs and outputs, removing the burden of unit conversion from problem solution.

Each program in this pac is represented by one program in the Application Module and a section in this manual.

The manual provides a description of each program, a set of instructions for using each program, and one or more example problems, each of which includes a list of the keystrokes required for its solution.

Before plugging in your Application Module, turn your calculator off, and be sure you understand the section Inserting and Removing Application Modules. Before using a particular program, take a few minutes to read Format of User Instructions and A Word About Program Usage.

You should first familiarize yourself with a program by running it once or twice while following the complete User Instructions in the manual. Thereafter, the program's prompting should provide the necessary instructions, including which variables are to be input, which keys are to be pressed, and which values will be output.

We hope the Thermal and Transportation Pac will assist you in the solution of numerous problems in your discipline. If you have technical problems with this Pac, refer to your HP-41 owner's handbook for information on Hewlett-Packard "technical support" or "programming assistance."

Note: Application modules are designed to be used in all HP-41 model calculators. The term "HP-41C" is used throughout the rest of this manual, unless otherwise specified, to refer to all HP-41 calculators.
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INSERTING AND REMOVING APPLICATION MODULES

Before you insert an Application Module for the first time, familiarize yourself with the following information.

Up to four Application Modules can be plugged into the ports on the HP-41C. While plugged in, the names of all programs contained in the Module can be displayed by pressing \[ \text{CATALOG} \ 2 \].

**CAUTION**

Always turn the HP-41C off before inserting or removing any plug-in extension or accessories. Failure to turn the HP-41C off could damage both the calculator and the accessory.

To insert Application Modules:

1. Turn the HP-41C off! Failure to turn the calculator off could damage both the Module and the calculator.

2. Remove the port covers. Remember to save the port covers; they should be inserted into the empty ports when no extensions are inserted.

3. Insert the Application Module with the label facing downward as shown, into any port after the last Memory Module. For example, if you have a Memory Module inserted in port 1, you can insert an Application Module in any of ports 2, 3, or 4. (The port numbers are shown on the back of the calculator.) Never insert an Application Module into a lower numbered port than a Memory Module.
4. If you have additional Application Modules to insert, plug them into any port after the last Memory Module. Be sure to place port covers over unused ports.

5. Turn the calculator on and follow the instructions given in this book for the desired application functions.

To remove Application Modules:

1. Turn the HP-41C off! Failure to do so could damage both the calculator and the Module.

2. Grasp the desired Module handle and pull it out as shown.

3. Place a port cap into the empty ports.

Mixing Memory Modules and Application Modules

Any optional accessories (such as the HP 82104A Card Reader, or the HP 82143A Printer) should be treated in the same manner as Application Modules. That is, they can be plugged into any port after the last Memory Module. Also, the HP-41C should be turned off prior to insertion or removal of these extensions.

The HP-41C allows you to leave gaps in the port sequence when mixing Memory and Application Modules. For example, you can plug a Memory Module into port 1 and an Application Module into port 4, leaving ports 2 and 3 empty.
FORMAT OF USER INSTRUCTIONS

The completed User Instruction Form—which accompanies each program—is your guide to operating the programs in this Pac.

The form is composed of five labeled columns. Reading from left to right, the first column, labeled STEP, gives the instruction step number.

The INSTRUCTIONS column gives instructions and comments concerning the operations to be performed.

The INPUT column specifies the input data, the units of data if applicable, or the appropriate alpha response to a prompted question. Data input keys consist of 0 to 9 and the decimal point (the numeric keys), [EEX] (enter exponent), and [CHS] (change sign).

The FUNCTION column specifies the keys to be pressed after keying in the corresponding input data.

The DISPLAY column specifies prompts, intermediate and final answers, and their units, where applicable.

Above the DISPLAY column is a box which specifies the minimum number of data storage registers necessary to execute the program. Refer to the Owner’s Handbook for information on how the SIZE function affects storage configuration.
A WORD ABOUT PROGRAM USAGE

Catalog
When an Application Module is plugged into a port of the HP-41C, the contents of the Module can be reviewed by pressing \( \text{CATALOG} \) 2 (the Extension Catalog). Executing the \( \text{CATALOG} \) function lists the name of each program or function in the Module, as well as functions of any other extensions which might be plugged in.

ALPHA and USER Mode Notation
This manual uses a special notation to signify ALPHA mode. Whenever a statement on the User Instruction Form is printed in gold, the \( \text{ALPHA} \) key must be pressed before the statement can be keyed in. After the statement is input, press \( \text{ALPHA} \) again to return the calculator to its normal operating mode, or to begin program execution. For example, \( \text{XEQ} \) KWONG means press the following keys: \( \text{XEQ} \) ALPHA KWONG ALPHA.

When the calculator is in USER mode, this manual will use the symbols \( \text{A} - \text{J} \) and \( \text{A} - \text{E} \) to refer to the reassigned keys in the top two rows. These key designations will appear on the User Instruction Form and in the keystroke solutions to sample problems.

Optional Printer
When an optional printer is plugged into the HP-41C along with this Application Module, all inputs and results will be printed automatically. The printer mode switch should be set to MANUAL mode.

Downloading Module Programs
If you wish to trace execution, to modify, to record on magnetic cards, or to print a program in this Application Module, it must first be copied into the HP-41C’s program memory. For information concerning the HP-41C’s COPY function, see the Owner’s Handbook. It is not necessary to copy a program in order to run it.
Program Interruption

These programs have been designed to operate properly when run from beginning to end, without turning the calculator off (remember, the calculator may turn itself off). If the HP-41C is turned off, it may be necessary to set flag 21 (SF 21) to continue proper execution.

Use of Labels

You should generally avoid writing programs into the calculator memory that use program labels identical to those in your Application Module. In case of a label conflict, the label within program memory has priority over the label within the Application Pac program.

Label Conflicts With Other Application Pacs

Several labels used in this module have the same name as those used in other modules. If you have this module and another module plugged into your HP-41C at the same time, you should make sure that the module whose programs you want to use is in the lowest-numbered port to avoid conflicting use of these labels.

You will find a list of all the global labels used in this application module at the back of the manual in appendix B, Program Labels. The names of modules or accessories where duplicate labels occur are also listed. Before plugging in two or more modules, check that listing for duplicate label conflicts.

Assigning Program Names

Key assignments to keys \( A - J \) and \( 10 \uparrow A - 10 \uparrow E \) take priority over the automatic assignments of local labels in the Application Module. Be sure to clear previously assigned functions before executing a Module program.
UNIT MANAGEMENT SYSTEM

In many applications the difficulty of computation is secondary to the difficulties of unit conversion and of dimensional homogeneity. The programs in this application pac were written to solve both the computational and dimensional aspects of your problems.

Upon initialization, some of the programs in this application pac will prompt as follows:

UNT CNV? Y/N

If you wish to manage the units yourself key ‘‘N’’ and press \[R/S\]. This clears the unit mode. With unit mode clear all programs will work as long as your inputs have compatible units. If you key ‘‘Y’’ and press \[R/S\] unit mode will be set. The calculator will request both the number and the associated units for each input. For instance, the calculator might prompt for length:

\[ L=? \]

You would respond with a number and press \[R/S\]. The calculator would then ask for the units associated with that number:

UNITS L?

You would key in the abbreviation for the units. In this case ‘‘FT’’ (abbreviation for feet) would be an appropriate response. After keying in the units press \[R/S\]. The calculator should continue to the next input prompt or to the output routine.

Output is very similar to input. If the calculator were ready to output the area A it would display:

UNITS A?

You might respond with ‘‘IN2’’ (the abbreviation for square inches).

If you key in a value or want an output in SI (International System) units, you may ignore the unit prompt and press \[R/S\]. This shortcut is particularly useful when an input of zero has just been made. With the exception of temperature, the units of zero are unimportant.

If the prompt comes right back after you press \[R/S\] an error was found in the unit string. Four common errors are:

1. The units specified were incompatible with the requested input or output (e.g., the prompt was for length and the response was seconds).
2. Unit control characters (*, /, -, 1-9) were incorrectly used (e.g., FT/s/s).
3. More than 12 characters were used to specify the units.
4. The units keyed in are misspelled, used lower case letter, or are not included in the following list (e.g., ‘‘FEET’’ for ‘‘FT’’):
### UNIT CONVERSIONS

<table>
<thead>
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<th>Abbreviation</th>
<th>Name</th>
<th>Multiplicative Conversion Constant</th>
<th>Homogeneous SI UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANG</td>
<td>angstrom</td>
<td>$1.0 \times 10^{-10}$</td>
<td>m</td>
</tr>
<tr>
<td>ATM</td>
<td>atmosphere</td>
<td>$1.01325 \times 10^5$</td>
<td>Pa</td>
</tr>
<tr>
<td>BAR</td>
<td>bar</td>
<td>$1.0 \times 10^5$</td>
<td>Pa</td>
</tr>
<tr>
<td>BBL</td>
<td>barrel of petroleum</td>
<td>$1.589873 \times 10^{-1}$</td>
<td>m$^3$</td>
</tr>
<tr>
<td>BTU</td>
<td>British Thermal Unit (IST)</td>
<td>$1.055056 \times 10^3$</td>
<td>J</td>
</tr>
<tr>
<td>C</td>
<td>degree celsius</td>
<td>$1.0 \times 10^0$</td>
<td>(±273.15) K</td>
</tr>
<tr>
<td>CAL</td>
<td>calorie (IST)</td>
<td>$4.1868 \times 10^0$</td>
<td>J</td>
</tr>
<tr>
<td>CM</td>
<td>centimeter</td>
<td>$1 \times 10^{-2}$</td>
<td>m</td>
</tr>
<tr>
<td>DAY</td>
<td>day (mean solar)</td>
<td>$8.64 \times 10^4$</td>
<td>s</td>
</tr>
<tr>
<td>DYNE</td>
<td>dyne</td>
<td>$1.0 \times 10^{-5}$</td>
<td>N</td>
</tr>
<tr>
<td>ERG</td>
<td>erg</td>
<td>$1.0 \times 10^{-7}$</td>
<td>J</td>
</tr>
<tr>
<td>F</td>
<td>degree Fahrenheit</td>
<td>$5.555555555 \times 10^{-1}$</td>
<td>K</td>
</tr>
<tr>
<td>FT</td>
<td>foot</td>
<td>$3.048 \times 10^{-1}$</td>
<td>m</td>
</tr>
<tr>
<td>FTH20</td>
<td>foot of water</td>
<td>$2.98898 \times 10^3$</td>
<td>Pa</td>
</tr>
<tr>
<td>(39.2°F)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>gram</td>
<td>$1.0 \times 10^{-3}$</td>
<td>kg</td>
</tr>
<tr>
<td>GAL</td>
<td>gallon (U.S.)</td>
<td>$3.785411784 \times 10^{-3}$</td>
<td>m$^3$</td>
</tr>
<tr>
<td>HP</td>
<td>horsepower</td>
<td>$7.4569987 \times 10^2$</td>
<td>W</td>
</tr>
<tr>
<td>(550 ft. lbf/s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR</td>
<td>hour (mean solar)</td>
<td>$3.6 \times 10^3$</td>
<td>s</td>
</tr>
<tr>
<td>IN</td>
<td>inch</td>
<td>$2.54 \times 10^{-2}$</td>
<td>m</td>
</tr>
<tr>
<td>INHG</td>
<td>inch of mercury</td>
<td>$3.37685 \times 10^3$</td>
<td>Pa</td>
</tr>
<tr>
<td>(60°F)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INH20</td>
<td>inches of water</td>
<td>$2.4884 \times 10^2$</td>
<td>Pa</td>
</tr>
<tr>
<td>(60°F)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>joule</td>
<td>$1.0 \times 10^0$</td>
<td>J</td>
</tr>
<tr>
<td>K</td>
<td>kelvin</td>
<td>$1.0 \times 10^0$</td>
<td>K</td>
</tr>
<tr>
<td>KCAL</td>
<td>kilocalorie (IST)</td>
<td>$4.1868 \times 10^3$</td>
<td>J</td>
</tr>
<tr>
<td>KG</td>
<td>kilogram</td>
<td>$1.0 \times 10^0$</td>
<td>kg</td>
</tr>
<tr>
<td>KGF</td>
<td>kilogram force</td>
<td>$9.80665 \times 10^9$</td>
<td>N</td>
</tr>
<tr>
<td>KIP</td>
<td>1000 pounds force</td>
<td>$4.448221615 \times 10^3$</td>
<td>N</td>
</tr>
<tr>
<td>KM</td>
<td>kilometers</td>
<td>$1.0 \times 10^3$</td>
<td>m</td>
</tr>
<tr>
<td>KPA</td>
<td>kilopascals</td>
<td>$1.0 \times 10^3$</td>
<td>Pa</td>
</tr>
<tr>
<td>KW</td>
<td>kilowatt</td>
<td>$1.0 \times 10^3$</td>
<td>W</td>
</tr>
<tr>
<td>LBF</td>
<td>pound force</td>
<td>$4.448221615 \times 10^6$</td>
<td>N</td>
</tr>
<tr>
<td>LBM</td>
<td>pound mass</td>
<td>$4.5359237 \times 10^{-1}$</td>
<td>kg</td>
</tr>
<tr>
<td>L</td>
<td>liter</td>
<td>$1.0 \times 10^{-3}$</td>
<td>m$^3$</td>
</tr>
<tr>
<td>M</td>
<td>meter</td>
<td>$1.0 \times 10^0$</td>
<td>m</td>
</tr>
<tr>
<td>MI</td>
<td>mile</td>
<td>$1.609344 \times 10^3$</td>
<td>m</td>
</tr>
<tr>
<td>MIC</td>
<td>micron</td>
<td>$1.0 \times 10^{-6}$</td>
<td>m</td>
</tr>
<tr>
<td>MIL</td>
<td>1/1000 inch</td>
<td>$2.54 \times 10^{-5}$</td>
<td>m</td>
</tr>
</tbody>
</table>
You can combine units using the unit control characters. For instance, an acceleration of feet per second squared would be keyed in as:

\[
\text{FT/S}^2
\]

or

\[
\text{FT/S} \times \text{S}
\]

Legal options for volumetric flow rate include, but are far from limited too:

\[
\begin{align*}
\text{FT}^3/\text{S} \\
\text{M} \times \text{CM} \times \text{IN}/\text{S} \\
\text{FT}^3 \times \text{HR}/\text{S}^2 \\
\end{align*}
\]

etc.

Only one divide is allowed in the unit string. Thus all units to the right of the divide sign are included in the denominator.

The dash or minus character stands for “convert to”. Thus,

\[
\text{FT}^3 - \text{M}^3
\]

is read “feet cubed, converted to meters cubed.” Only one dash is allowed in a unit string.

Digits one through nine indicate the power to which a unit should be raised.
Automatic Unit Conversion in Your Programs

The *Unit Management System* of this application pac is completely subroutineable. You may take advantage of its capabilities from your programs or from the keyboard.

Two functions form the basis of the capability. They are \(-SI\) and \(SI-\).

The abbreviations stand for "to International System of Units" and "from International System of Units." In the simplest mode of operation, these functions take values in the X-register and transform them to or from SI units according to the unit string in the ALPHA-register. The base SI units used in this pac are:

<table>
<thead>
<tr>
<th>Pac Abbreviation</th>
<th>Name</th>
<th>Type of Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>kelvin</td>
<td>temperature</td>
</tr>
<tr>
<td>M</td>
<td>meter</td>
<td>length</td>
</tr>
<tr>
<td>KG</td>
<td>kilogram</td>
<td>mass</td>
</tr>
<tr>
<td>S</td>
<td>seconds</td>
<td>time</td>
</tr>
<tr>
<td>MOLE</td>
<td>mole</td>
<td>amount of material</td>
</tr>
</tbody>
</table>

Other SI units are formed from combinations of these base units.

Both \(-SI\) and \(SI-\) modify X, and LAST X. They do not alter any other registers. In the case of "DATA ERROR" nothing is altered except flag 25 which is cleared if it was set.

Example of \(-SI\) and \(SI-\):

Convert 12 inches to meters.

**Keystrokes**

```
[Fix] 2
12
[Alpha] IN
[Alpha]
[XEQ] [Alpha] -SI [Alpha]
```

**Display**

```
12
IN
12.00
0.30
```

Convert the result to feet.

```
[Alpha] FT [Alpha]
[XEQ] [Alpha] SI- [Alpha]
```

**Display**

```
0.30
1.00
```

The functions \(-SI\) and \(SI-\) can also be used to do more complicated conversions by employing the dash or *to* operator.

Example of \(-SI\) and \(SI-\) using the *to* operator:

Convert 12 inches to feet using \(-SI\) and the *to* operator.
An important advantage of using the \textit{to} operator is that dimensional homogeneity is checked. When using the \textit{to} operator, attempts to convert between incompatible units such as feet and seconds will result in "DATA ERROR."

Four other routines in this application pac are of interest if you wish to write programs using the Unit Management System. Skip the following discussion if you do not wish to write your own programs.

1. \textsc{sz?} does a paper advance and checks to see if size is adequate for program execution. The necessary size must be placed in X on input. The routine halts displaying:

\begin{verbatim}
SIZE>=NNN
\end{verbatim}

If size is inadequate, otherwise it returns to the point of call.

\begin{verbatim}
17*LBL "SZ?"
CF 01 ADV "SIZE>="
ARCL X SF 25 1 -
RCL IND X FS?C 25 RTN
PROMPT

29*LBL 02
"RE-XEQ FNC" PROMPT
GTO 02
\end{verbatim}

2. \textsc{unit?} Sets the two unit control flags (00,01), checks \textsc{size} and stores null alpha strings in R01 and R002. Since \textsc{unit?} calls \textsc{sz?}, the minimum allowable register size must be in X when \textsc{unit?} is called.

\begin{verbatim}
01*LBL "UNIT?"
CF 00 XEQ "SZ?" "Y"
ASTO Y "UNT CHG? Y/N" AON PROMPT ASTO X
X=Y? 3F 00 AOFF CLA
ASTO 01 ASTO 02 RTN
\end{verbatim}
3. INPUT increments R00, prompts for an input, optionally prompts for the units of that input, converts the input to the units specified by R01 and R02, stores the input, and prints the input if a printer is being used. If flag 00 is set the unit conversion option is invoked. However, if flag 01 is set flag 00 is ignored. Flag 01 is cleared on exit. Flag 00 is not changed.

Upon entry, the following register usage is required:

a. R00 contains the address minus one of the register into which the data should be placed;

b. The ALPHA register should contain the variable name (5 characters or less);

c. Registers 01 and 02 should contain a 12 character alpha string specifying the units, to which the User's input must be converted for proper program execution. A null string in R01 and R02 will default conversion to SI units. No homogeneity checking is possible in this case.

Upon exit, the user's input (including units) is printed. R01 and R02 are unchanged. R00 has been incremented by one. The converted input value is stored in the register currently pointed to by R00 and is also in the X-register.

```
33•LBL "INPUT"
CF 22 1 ST+ 00
RCL IND 00 ASTO Y
"?=?" CF 21 AVIEW
SF 21 CLA ARCL Y STOP
STO L ASTO Y CLA
ASTO Z ASTO T ARCL Y
FS?C 01 CTO 00 FC? 22
CTO 00 FS? 00 XEQ 01
```

4. OUTPUT takes a value in X, optionally prompts the user for the output units, converts the output to those units and prints or displays the result. Flags 00 and 01 are used in a manner analogous to their use in INPUT.

Upon entry, the following register usage is required:

a. The ALPHA register contains the name of the variable (5 characters or less);

b. The X register contains the calculated value;
c. Registers 01 and 02 contain a 12 character string specifying the units of the calculated value. A null string implies that the calculated value is in SI units but no homogeneity checking is possible for null strings. Upon exit, the alpha register contains the formatted answer which is either printed or displayed. Registers 01 and 02 are unchanged.

```
70*LBL "OUTPUT"
STO L FS?C 01 GTO 00
FS? 00 GTO 00 SF 01
BEEP

78*LBL 01
ASTO Y "UNITS " ARCL Y
"?=" AON CF 23 PROMPT
AOFF FC? 23 CLA
FC? 23 ARCL 01 FC? 23
ARCL 02 ASTO Z ASHF
ASTO T CLA ARCL Z
ARCL T "=" ARCL 01
ARCL 02 SF 25 FS? 01
XEQ "SI=" FC? 01
XEQ "-SI" CLA ARCL Y
FC?C 25 GTO 01 FC?C 01
RTN "=" ARCL X "="
ARCL Z ARCL T AVIEW
RTN

120*LBL 00
"=" ARCL X AVIEW RTN
```
Example program using Unit Management System:
Given a mass $M$ and an acceleration $A$ compute the force $F$.

FLOWCHART $F = MA$

START

NEED 5 REG

DOES THE USER WANT AUTO CONV ?

INPUT M STO → 3

INPUT A STO → 4

CALCULATE

OUTPUT F

RTN
PROGRAM F=MA

Program Line | Comments
---|---
LBL F=MA | Uses 5 registers.
5 XEQ UNIT? | Initialize. At user's option select automatic unit conversion.
2 STO 00 | Start storing inputs at R03.
"KG" ASTO 01 † | First input is to be converted to kilograms.
"M" XEQ INPUT | The name of the first input is M.
"M/S2" ASTO 01 † | Get input (and units).
"A" XEQ INPUT | The second input is to be converted to meters per second per second.
RCL 03 | The name of the second input is A.
RCL 04 * | Get input.
"N" ASTO 01 † | Calculate answer.
"F" XEQ OUTPUT | The calculated answer is in newtons.
RTN | The name of the answer is F.

† Optional, but deletion will eliminate homogeneity checking.

Example of program F=MA:

A car with a mass of 2500 pounds accelerates at 3 miles per hour per second. What force in pounds is being applied?

Keystrokes (SIZE> = 005) | Display
---|---
(FIRST KEY THE PROGRAM IN AND INSERT THE APPLICATION MODULE).

| | | |
---|---|---|
| | | |
| | | |

UNT CNV? Y/N
M=?
UNIT=M?
A=?
UNITS A=?
UNITS F=?
F=341.89 LBF
EQUATIONS OF STATE

This program solves for any one of the following four variables, given the other three:

1. pressure;
2. volume;
3. mass (or number of moles);
4. temperature.

The ideal gas rule is selected by executing IDEAL. The Redlich-Kwong model of real gas behavior is selected by executing KWONG. The Redlich-Kwong solution requires the critical temperature and pressure of the gas.

Solution may be on a mass or mole basis. When the program prompts for molecular weight key in 1.00 if you wish solution on a mole basis. If you wish solution on a mass basis specify the actual molecular weight. The program will subsequently prompt or label output using the character ‘‘N’’ for number of moles or ‘‘M’’ for mass.

The Unit Management System may be used with this program. If the Unit Management System is used the ideal gas constant R is automatically selected. If the system is not used you must supply R in units compatible with your other inputs.

Values of the Universal Gas Constants

<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>8314.34</td>
<td>N·m/kg·mole·K</td>
<td>N/m²</td>
<td>m³/kg mole</td>
<td>K</td>
</tr>
<tr>
<td>83.1434</td>
<td>cm³·bar/g·mole·K</td>
<td>bar</td>
<td>cm³/g mole</td>
<td>K</td>
</tr>
<tr>
<td>82.05</td>
<td>cm³·atm/g·mole·K</td>
<td>atm</td>
<td>cm³/g mole</td>
<td>°R</td>
</tr>
<tr>
<td>0.7302</td>
<td>atm·ft³/lb·mole·°R</td>
<td>atm</td>
<td>ft³/lb mole</td>
<td>°R</td>
</tr>
<tr>
<td>10.73</td>
<td>psi·ft³/lb·mole·°R</td>
<td>psi</td>
<td>ft³/lb mole</td>
<td>°R</td>
</tr>
<tr>
<td>1545</td>
<td>psf·ft³/lb·mole·°R</td>
<td>psf</td>
<td>ft³/lb mole</td>
<td>°R</td>
</tr>
</tbody>
</table>
Equations of State

Critical Temperatures and Pressures

<table>
<thead>
<tr>
<th>Substance</th>
<th>$T_c, \text{K}$</th>
<th>$T_c, \text{°R}$</th>
<th>$P_c, \text{ATM}$</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>

Equations:

Ideal gas: \( PV = nRT \)

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

\[ a = 4.934 \, b \, nR T_c^{1.5} \]

\[ b = 0.0867 \, \frac{nR T_c}{P_c} \]

where:

- \( P \) is the absolute pressure;
- \( V \) is the volume;
- \( n \) is the number of moles present;
- \( R \) is the universal gas constant;
- \( T \) is the absolute temperature;
- \( T_c \) is the critical temperature;
- \( P_c \) is the critical pressure.
Remarks:
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, nor 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.

<table>
<thead>
<tr>
<th>STEP</th>
<th>INSTRUCTIONS</th>
<th>INPUT</th>
<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td></td>
<td>IDEAL</td>
<td>UNT CNV? Y/N</td>
</tr>
<tr>
<td>2</td>
<td>If you wish automatic unit conversion key &quot;Y&quot;, if not key &quot;N&quot;.</td>
<td>Y or N</td>
<td>R/S</td>
<td>(R=?)</td>
</tr>
<tr>
<td>3</td>
<td>If you answered yes above you will not see the &quot;R=?” prompt and you may skip to step 5.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Key in ideal gas constant.</td>
<td>R</td>
<td>R/S</td>
<td>M WT=?</td>
</tr>
<tr>
<td>5</td>
<td>Key in molecular weight if you wish to work on a mole basis.</td>
<td></td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td>6</td>
<td>If you know pressure key it in, if not press R/S.</td>
<td>P</td>
<td>R/S</td>
<td>V=?</td>
</tr>
<tr>
<td>7</td>
<td>If you know the volume key it in.</td>
<td>V</td>
<td>R/S</td>
<td>N=? or M=?</td>
</tr>
<tr>
<td>8</td>
<td>If you know number of moles or mass key it in.</td>
<td>N or M</td>
<td>R/S</td>
<td>T=?</td>
</tr>
<tr>
<td>9</td>
<td>If you know temperature key it in.</td>
<td>T</td>
<td>R/S</td>
<td>SELECT KEY: P V M/N T</td>
</tr>
<tr>
<td>10</td>
<td>By now you should have keyed in three of the four inputs in steps six through nine. Calculate remaining value. Press A for pressure, B for volume, C for amount of material, or D for temperature.</td>
<td>A, B, C or D</td>
<td></td>
<td>P=;V=;M=; N=; or T= P=?</td>
</tr>
<tr>
<td>11</td>
<td>For a new case involving the same gas go to step 6. For a totally new case go to step 1. It is not necessary to key in any values which do not change. Ignore the prompt and press R/S.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Press R/S if you are not using a printer.
Example 1:

0.63 g moles of air are enclosed in a 25,000 cm³ space at 1200 K. What is the pressure in bars? Assume an ideal gas. Do not use the Unit Management option.

Keystrokes (SIZE $\geq 014$)

```
[2][FIX]
[XEQ] ALPHA IDEAL ALPHA
N R/S
```
Select R (cm³ · bar/g · mole · K).

```
83.1434 R/S
```
For a mole basis key 1.00.

```
1 R/S
25000 R/S
.63 R/S
1200 R/S
```

```
A
```

Display

```
UNIT CNV? Y/N
R=?
```
```
M WT=?
```
```
P=?
V=?
N=?
T=?
"SELECT KEY:"
```
P V M T
```
```
P=2.51 (bar)
```

Example 2:

What is the specific volume (ft³/lbm) of a gas at atmospheric pressure and at a temperature of 55°F? The molecular weight is 29. Assume an ideal gas. Use Unit Management.

Keystrokes (SIZE $\geq 014$)

```
[2][FIX]
[XEQ] ALPHA IDEAL ALPHA
Y R/S
29 R/S
1 R/S
ATM R/S
R/S
1 R/S
LBM R/S
55 R/S
F R/S
```

```
B
FT3 R/S
```

Display

```
UNIT CNV? Y/N
```
```
M WT=?
P=?
UNITS P?
V=?
M=?
UNITS M?
T=?
UNITS T?
"SELECT KEY:"
P V M T
```
```
UNITS V?
```
```
V=12.96 FT3
```

If the pressure were increased to 19.40 psi what would V be?

\[
\frac{19.4}{R/S} \text{ PSI} \frac{R/S}{R/S} \frac{R/S}{R/S} \frac{B}{R/S} \text{ FT}^3
\]

Example 3:
The specific volume of a gas in a container is 800 cm\(^3\)/g \cdot mole. The temperature will reach 127°C. What will the pressure (psi) be according to the Redlich-Kwong relation? Use Unit Management.

\[
P_c = 48.2 \text{ atm} \\
T_c = 305.5 \text{ K}
\]

Keystrokes (SIZE \text{ \geq} 020)

Display

\[
\text{Fix} 2
\]

\[
\text{XEQ} \text{ ALPHA} \text{ KWONG ALPHA}
\]

\[
\begin{align*}
Y & \quad \text{R/S} \\
305.5 & \quad \text{R/S} \\
K & \quad \text{R/S} \\
48.2 & \quad \text{R/S} \\
\text{ATM} & \quad \text{R/S} \\
1 & \quad \text{R/S} \\
800 & \quad \text{R/S} \\
\text{CM}\text{3} & \quad \text{R/S} \\
1 & \quad \text{R/S} \\
\text{G*MOLE} & \quad \text{R/S} \\
127 & \quad \text{R/S} \\
\text{C} & \quad \text{R/S} \\
A & \\
\text{PSI} & \quad \text{R/S}
\end{align*}
\]

\[
\begin{align*}
\text{UNT CVN? Y/N} \\
Tc=? \\
\text{UNITS Tc?} \\
Pc=? \\
\text{UNITS Pc?} \\
M \text{ WT=?} \\
P=? \\
V=? \\
\text{UNITS V?} \\
N=? \\
\text{UNITS N?} \\
T=? \\
\text{UNITS T?} \\
\text{"SELECT KEY:"} \\
P \ V \ N \ T \\
\text{UNITS P?} \\
P=533.27 \text{ PSI}
\end{align*}
\]

* Press \( \text{R/S} \) if you are not using a printer.
Example 4:

264 grams of carbon dioxide gas (molecular weight 44) are held at a pressure of 50 atmospheres, and at a temperature of 441°F. What is the volume in liters? Use the Redlich-Kwong relation.

\[ T_c = 304.2 \text{ K} \]
\[ P_c = 72.9 \text{ atm} \]

**Keystrokes (SIZE \(\geq 020\)**

- **Display**
  - **UNT CNV? Y/N**
  - **Tc=?**
  - **UNITS Tc?**
  - **Pc=?**
  - **UNITS Pc?**
  - **M WT=?**
  - **P=?**
  - **UNITS P?**
  - **V=?**
  - **M=?**
  - **UNITS M?**
  - **T=?**
  - **UNITS T?**
  - **"SELECT KEY:"**
  - **P V M T**
  - **UNITS V?**
  - **V=4.70 L**

How many grams could be contained at this temperature and pressure in 5 liters?

- **Display**
  - **P=?**
  - **V=:?**
  - **UNITS V?**
  - **M=?**
  - **T=?**
  - **"SELECT KEY:"**
  - **P V M T**
  - **UNITS M?**
  - **M=280.83 G**

* Press **R/S** if you are not using a printer.
POLYTROPIC PROCESSES FOR AN IDEAL GAS

This program solves interchangeably between pressure ratio, volume ratio, temperature ratio, and density ratio for polytropic processes involving ideal gases. These processes are defined by the relationship

$$ PV^N = \text{constant} $$

which is shown graphically below.

If the polytropic processes are reversible and adiabatic, they are called isentropic. Then the value used for $N$ is $k$, the specific heat ratio for the gas.

Equations:

$$ \frac{P_2}{P_1} = \left( \frac{V_2}{V_1} \right)^{-N} = \left( \frac{T_2}{T_1} \right)^{\frac{N}{N-1}} = \left( \frac{D_2}{D_1} \right)^N $$

where:

- $P_2/P_1$ is the final pressure divided by the initial pressure;
- $V_2/V_1$ is the final volume divided by the initial volume;
- $T_2/T_1$ is the final temperature divided by the initial temperature;
- $D_2/D_1$ is the final density divided by the initial density;
- $N$ is the polytropic constant.
### Example:

An air compressor has a compression ratio \( (V_1/V_2) \) of 8.5 to 1. The polytropic constant is 1.43. If the inlet air is at atmospheric pressure 14.7 psi, what is the outlet pressure? What is the final temperature if the inlet is 65°F?

#### Keystrokes (SIZE > 003)

<table>
<thead>
<tr>
<th>INPUT</th>
<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>POLYTRP</td>
<td>N=?</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td>P2/P1=?</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>V2/V1=?</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>T2/T1=?</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td>D2/D1=?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VALUE</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>P2/P1=</td>
<td></td>
<td>21.33</td>
</tr>
<tr>
<td>V2/V1=</td>
<td></td>
<td>0.12</td>
</tr>
<tr>
<td>T2/T1=</td>
<td></td>
<td>2.51</td>
</tr>
<tr>
<td>D2/D1=</td>
<td></td>
<td>8.50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Example:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Press [R/S] if you are not using a printer.</td>
<td></td>
</tr>
</tbody>
</table>

*Press [R/S] if you are not using a printer.*

**Since the top row of keys has been auto-assigned as [A], [B], [C], and [D], you must go out of USER mode to use [1/X].
ISENTROPIC FLOW FOR IDEAL GASES

This program replaces isentropic flow tables for a specified heat ratio k. The following values are correlated:

- M is the Mach number;
- T/T₀ is the ratio of flow temperature T to stagnation or zero velocity temperature T₀;
- P/P₀ is the ratio of flow pressure P to stagnation pressure P₀;
- D/D₀ is the ratio of flow density D to stagnation density D₀;
- a/a* and A/A* are the ratios of flow area A to the throat area A* in converging-diverging passages. a/a* refers to subsonic flow while A/A* refers to supersonic flow.

Equations:

\[
\frac{T}{T_0} = \frac{2}{2 + (k - 1) M^2}
\]

\[
\frac{P}{P_0} = \left(\frac{T}{T_0}\right)^{k/(k - 1)}
\]

\[
\frac{D}{D_0} = \left(\frac{T}{T_0}\right)^{1/(k - 1)}
\]

\[
\frac{a}{a^*} \text{ and } \frac{A}{A^*} = \frac{1}{M} \left[ \left(\frac{2}{k + 1}\right) \left(1 + \frac{k - 1}{2} M^2\right)\right]^{\frac{k + 1}{2(k - 1)}}
\]
### Isentropic Flow for Ideal Gas

**STEP** | **INSTRUCTIONS** | **INPUT** | **FUNCTION** | **DISPLAY**
---|---|---|---|---
1 | Initialize program. |  |  | 
2 | Key in specific heat ratio. | k | R/S | K=?
3 | Select input:  
  to input Mach number;  
  to input temperature ratio;  
  to input pressure ratio;  
  to input density ratio;  
  to input supersonic area ratio;  
  to input subsonic area ratio. | A, B, C, D, E | MTPDA,a | 
4 | Key in selected value and compute all values: | VALUE | R/S | M=?
  | | | | T/T0=?
  | | | | P/P0=?
  | | | | D/D0=?
  | | | | A/A*=?
  | | | | a/a*=?
5 | For a new input go to step 3. For a new case, go to step 1. |  |  | 
  *Press if you are not using a printer.

#### Example 1:

A pilot is flying at Mach 0.93 and reads an air temperature of 15 degrees Celsius (288 K) on a thermometer that reads stagnation temperature $T_0$. What is the true temperature assuming that $k = 1.38$?

**Keystrokes (SIZE $\geq$ 008)**

![FIX 4](https://example.com)  
![XEQ ALPHA](https://example.com)  
![ISNFLOW ALPHA](https://example.com)  
1.38 R/S

![A](https://example.com)  
.93 R/S  
R/S *

**Display**

$K=?$  
"SELECT KEY:"  
$M T P D A,a$  
$M=?$  
$M=0.9300$  
$T/T0=0.8589$  
$P/P0=0.5755$  
$D/D0=0.6701$  
$a/a*=1.0043$  
$M T P D A,a$  
247.3632  
-25.6368

*(K)  
*(°C)*  

*Press [R/S] if you are not using a printer.*
If the same pilot reads a stagnation pressure $P$ of 700 millimeters of mercury, what is the true air pressure?

$$\text{.5755 ENTER} \quad 700 \times \quad 402.8500 \text{ (mm Hg)}$$

**Example 2:**

A converging, diverging passage has supersonic flow in the diverging section. At an area ratio $A/A^\#$ of 1.60, what are the isentropic flow ratios for temperature, pressure and density? What is the Mach number? $k = 1.74$.

**Keystrokes**

- [FIX 4]
- [XEQ ALPHA] ISNFLW ALPHA
- 1.74 [R/S]

- [E]
- 1.6 [R/S]
- [R/S] *
- [R/S] *
- [R/S] *
- [R/S] *

**Display**

- $K =$
- "SELECT KEY:"
- $M\ T\ P\ D\ A,a$
- $A/A^\# =$?
- $M=2.1054$
- $T/T_0=0.3788$
- $P/P_0=0.1020$
- $D/D_0=0.2693$
- $A/A^\#=1.6000$
- $M\ T\ P\ D\ A,a$

* Press [R/S] if you are not using a printer.
CONDUIT FLOW

This program solves for the average velocity or the pressure drop, of viscous incompressible flow in conduits. For round conduits the volumetric flow rate is also computed.

The program includes the *Unit Management System* which is explained in the front of this manual.

A special program feature allows automatic storage of the properties of water at room temperature. This option is selected by executing H20 instead of FLOW.

**Equations:**

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

For laminar flow (Re < 2300)

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

For turbulent flow (Re > 2300)

\[ \frac{1}{\sqrt{f}} = 1.737 \ln \frac{D}{\epsilon} + 2.28 - 1.737 \ln \left( 4.67 \frac{D}{\epsilon \ Re \sqrt{f}} + 1 \right) \]

is solved by Newton’s method.

\[ \frac{1}{\sqrt{f_0}} = 1.737 \ln \frac{D}{\epsilon} + 2.28 \]

is used as an initial guess in the iteration.

\[ Q = v A \]

where:

- Re is the Reynolds number, defined as \( \rho D v / \mu \).
- D is the pipe diameter;
- \( \epsilon \) is the dimension of irregularities in the conduit surface (see table 2);
- f is the Fanning friction factor for conduit flow;
- \( \Delta P \) is the pressure drop along the conduit;
\( \rho \) is the density of the fluid;
\( \mu \) is the viscosity of the fluid;
\( L \) is the conduit length;
\( v \) is the average fluid velocity;
\( \Sigma K \) is the total of the applicable fitting coefficients in table 1;
\( Q \) is the volumetric flow rate.

### Table 1
**Fitting Coefficients**

<table>
<thead>
<tr>
<th>Fitting</th>
<th>( K )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glove valve, wide open</td>
<td>7.5—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—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—0.9</td>
</tr>
<tr>
<td>Standard 45° elbow</td>
<td>0.35—0.42</td>
</tr>
<tr>
<td>Tee, through side outlet</td>
<td>1.5</td>
</tr>
<tr>
<td>Tee, straight through</td>
<td>.4</td>
</tr>
<tr>
<td>180° bend</td>
<td>1.6</td>
</tr>
<tr>
<td>Entrance to circular pipe</td>
<td>0.25—0.50</td>
</tr>
<tr>
<td>Sudden expansion</td>
<td>((1 - 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.

### Table 2
**Surface Irregularities**

<table>
<thead>
<tr>
<th>Material</th>
<th>( \epsilon ) (feet)</th>
<th>( \epsilon ) (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} ) to</td>
<td>( 1.8 \times 10^{-4} ) to</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} ) to</td>
<td>( 3.0 \times 10^{-4} ) to</td>
</tr>
<tr>
<td></td>
<td>( 1.0 \times 10^{-2} )</td>
<td>( 3.0 \times 10^{-3} )</td>
</tr>
<tr>
<td>Rivetted Steel</td>
<td>( 3.0 \times 10^{-3} ) to</td>
<td>( 9.1 \times 10^{-4} ) to</td>
</tr>
<tr>
<td></td>
<td>( 3.0 \times 10^{-2} )</td>
<td>( 9.1 \times 10^{-3} )</td>
</tr>
</tbody>
</table>
Conduit Flow

Reference:

Remarks:
If the conduit is not circular, an equivalent diameter may be calculated using the formula below:

\[ D_{eq} = 4 \frac{\text{cross sectional area}}{\text{wetted perimeter}} \]

Values of Q generated using an equivalent diameter will be inaccurate. In such cases use:

\[ Q = vA \]

where A is the section area and v is the average fluid velocity.

If \(2300 < Re < 4000\) flow is neither laminar nor turbulent. In this region, the correlation may yield meaningless results. The calculator will halt displaying "TRANSITION". Pressing [R/S] will cause computation to continue but results may have little or no physical significance.

You may wish to write your own routines similar to H2O which automatically store fluid properties. Such routines should do the following:

1. Start with the steps:
   LBL XYZ
   18
   XEQ SZ?
   CLA
   ASTO 01
   ASTO 02
   SF 00
   CF 01

2. Continue with code which stores the viscosity in N \cdot s/m² in register 16 and the density in kg/m³ in register 17.

3. Complete your program with:
   GTO FLOW2
<table>
<thead>
<tr>
<th>STEP</th>
<th>INSTRUCTIONS</th>
<th>INPUT</th>
<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program: For water at room temperature. For other substances.</td>
<td></td>
<td>[XEQ] H20</td>
<td>IRREG=?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>[XEQ] FLOW</td>
<td>UNT CNV? Y/N</td>
</tr>
<tr>
<td>2</td>
<td>For water skip to step 6.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>If you wish automatic conversions key &quot;Y&quot; otherwise key &quot;N&quot;.</td>
<td>Y or N</td>
<td>R/S</td>
<td>VIS=?</td>
</tr>
<tr>
<td>4</td>
<td>Key in viscosity of fluid.</td>
<td>viscosity</td>
<td>R/S</td>
<td>DEN=?</td>
</tr>
<tr>
<td>5</td>
<td>Key in density of fluid.</td>
<td>density</td>
<td>R/S</td>
<td>IRREG=?</td>
</tr>
<tr>
<td>6</td>
<td>Key in height of conduit surface irregularities.</td>
<td>ε</td>
<td>R/S</td>
<td>L=?</td>
</tr>
<tr>
<td>7</td>
<td>Key in length of conduit.</td>
<td>length</td>
<td>R/S</td>
<td>D=?</td>
</tr>
<tr>
<td>8</td>
<td>Key in equivalent diameter of conduit.</td>
<td>diameter</td>
<td>R/S</td>
<td>ΣK=?</td>
</tr>
<tr>
<td>9</td>
<td>Key in sum of fitting coefficients.</td>
<td>ΣK</td>
<td>R/S</td>
<td>&quot;SELECT KEY:&quot;</td>
</tr>
<tr>
<td></td>
<td>If you know P, press [A]. If you know V, press [B]. If you know Q, press [C].</td>
<td></td>
<td></td>
<td>P= ?</td>
</tr>
<tr>
<td>10</td>
<td>If you know P, press [A]. If you know V, press [B]. If you know Q, press [C].</td>
<td></td>
<td></td>
<td>V= ?</td>
</tr>
<tr>
<td></td>
<td>Key in P, V, or Q and calculate the remaining two variables.</td>
<td>P, V or Q</td>
<td>R/S</td>
<td>P= or V=</td>
</tr>
<tr>
<td></td>
<td>Key in P, V, or Q and calculate the remaining two variables.</td>
<td></td>
<td>R/S</td>
<td>V= or Q=</td>
</tr>
<tr>
<td>11</td>
<td>Key in P, V, or Q and calculate the remaining two variables.</td>
<td></td>
<td>R/S</td>
<td>VIS= ?</td>
</tr>
<tr>
<td>12</td>
<td>For a totally new case, go to step 1. To change only selected inputs, go to step 4. For values that do not change, ignore the prompt and press [R/S].</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Press [R/S] if you are not using a printer. †Q has no meaning if the conduit is not circular and flowing full.
Example 1:
A heat exchanger has 20, 3 meter tube passes (60 m of pipe) with 180 degree bends connecting each pair of tubes (from table 1, $K_T = 10 \times 1.6$). The fluid viscosity is $9.3 \times 10^{-4} \text{N}\cdot\text{s}/\text{m}^2$ and the density is 1000 $\text{Kg}/\text{m}^3$. The surface roughness is $3 \times 10^{-4} \text{m}$ and the diameter is $2.54 \times 10^{-2} \text{m}$. If the flow rate is $1.545 \times 10^{-3} \text{m}^3/\text{s}$, what is the pressure loss?

Keystrokes (SIZE $\geq 018$)

\[
\begin{align*}
\text{ENG} & \quad 3 \\
\text{XEQ} \quad \text{ALPHA} \quad \text{FLOW} \quad \text{ALPHA} \\
\text{N} & \quad \text{R/S} \\
9.3 & \quad \text{EE} \quad \text{CHS} \quad 4 \quad \text{R/S} \\
1000 & \quad \text{R/S} \\
3 & \quad \text{EE} \quad \text{CHS} \quad 4 \quad \text{R/S} \\
60 & \quad \text{R/S} \\
2.54 & \quad \text{EE} \quad \text{CHS} \quad 2 \quad \text{R/S} \\
16 & \quad \text{R/S} \\
\text{C} \\
1.545 & \quad \text{EE} \quad \text{CHS} \quad 3 \quad \text{R/S} \\
\end{align*}
\]

Display

\[
\begin{align*}
\text{UNT CVN? Y/N} \\
\text{VIS=} & \quad ? \\
\text{DEN=} & \quad ? \\
\text{IRREG=} & \quad ? \\
\text{L=} & \quad ? \\
\text{D=} & \quad ? \\
\Sigma K= & \quad ? \\
\text{"SELECT KEY:"} \\
P V Q \\
Q=} & \quad ? \\
P= & \quad 521.6E3 \quad (\text{N}/\text{m}^2)
\end{align*}
\]

Example 2:
For the system shown, what is the volumetric flow rate? Use the unit conversion option and the $H2O$ routine for the properties of water.

\[
\begin{align*}
\text{Water tank} \\
\text{250 ft} \\
\text{78 ft. of water} \\
\text{3/4 open gate valve} \\
\text{D = 3 in} \\
\text{E = 3.33} \times 10^{-6} \text{ ft} \\
K_T = K_0 + K_1 + K_2 \\
= 1 + .4 + 0.85 = 2.25
\end{align*}
\]
Keystrokes (SIZE \geq 018)

- **FIX** 2
- **XEQ** ALPHA H20 ALPHA
- 3.33 EEX CHS 6 R/S
- FT R/S
- 250 R/S
- FT R/S
- 3 R/S
- IN R/S
- 2.25 R/S

- A
- 78 R/S
- FTH20 R/S
- FT/S R/S
- R/S *
- FT3/S R/S

Display

IRREG=?
UNITS IRREG?
L=?
UNITS L?
D=?
UNITS D?
ΣK=?
"SELECT KEY:"
P V Q
P=?
UNITS P?
UNITS V?
V=17.71 FT/S
UNITS Q?
Q=0.87 FT3/S

*Press \( R/S \) if you are not using a printer.
ENERGY EQUATION FOR STEADY FLOW

This program uses a control volume approach to solve a wide variety of problems involving fluid flow. Differences in height, pressure, and velocity between the entrance and exit of the control volume are converted to flow energy. Power may also be supplied or extracted between the entrance and exit.

The *Unit Management System* is automatically invoked by this program. The *Unit Management System* is explained in the front of this manual.

Equations:

\[
PWRIN = \dot{m} \left[ \left( \frac{V_2^2 - V_1^2}{2} \right) + g(Z_2 - Z_1) + \frac{(P_2 - P_1)}{\rho} \right]
\]

where:

- \(PWRIN\) is the power supplied within the control volume;
- \(\dot{m}\) is the mass flow rate;
- \(Q\) is the volumetric flow rate;
- \(V_2\) and \(V_1\) are the exit and entrance fluid velocities;
- \(g\) is the acceleration of gravity.
- \(Z_2\) and \(Z_1\) are the exit and entrance heights above a reference datum;
- \(P_2\) and \(P_1\) are the exit and entrance pressures;
- \(\rho\) is the fluid density.
<table>
<thead>
<tr>
<th>STEP</th>
<th>INSTRUCTIONS</th>
<th>INPUT</th>
<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td></td>
<td>ENERGY</td>
<td>DENS=?</td>
</tr>
<tr>
<td>2</td>
<td>Key in fluid density.</td>
<td>ρ</td>
<td>R/S</td>
<td>MDOT=?</td>
</tr>
<tr>
<td>3a</td>
<td>Key in mass flow rate.</td>
<td>m</td>
<td>R/S</td>
<td>V1=?</td>
</tr>
<tr>
<td>3b</td>
<td>If you know volumetric flow rate, instead of mass flow rate press R/S to get the prompt, then key in volumetric flow rate.</td>
<td>Q</td>
<td>R/S</td>
<td>V1=?</td>
</tr>
<tr>
<td>4</td>
<td>Key in initial fluid velocity.</td>
<td>V1</td>
<td>R/S</td>
<td>V2=?</td>
</tr>
<tr>
<td>5</td>
<td>Key in the final fluid velocity.</td>
<td>V2</td>
<td>R/S</td>
<td>Z2—Z1=?</td>
</tr>
<tr>
<td>6</td>
<td>Key in height difference.</td>
<td>Z2—Z1</td>
<td>R/S</td>
<td>P2—P1=?</td>
</tr>
<tr>
<td>7</td>
<td>Key in pressure difference. (The next step is skipped automatically if m=0.)</td>
<td>P2—P1</td>
<td>R/S</td>
<td>PWRIN=?</td>
</tr>
<tr>
<td>8</td>
<td>Key in input power.</td>
<td>PWRIN</td>
<td>R/S</td>
<td>SELECT KEY: V Z P PWR</td>
</tr>
<tr>
<td>9</td>
<td>Calculate the unknown value: velocity, change in height, change in pressure, or power input.</td>
<td></td>
<td>A</td>
<td>V1= or V2=</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>B</td>
<td>dZ=</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C</td>
<td>dP=</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>D</td>
<td>PWRIN=</td>
</tr>
<tr>
<td>10</td>
<td>For a new case go to step 1. This clears V1, V2, Z2—Z1, P2—P1 and PWRIN but leaves ρ and m unchanged. To modify the existing case, go to step 4. You do not need to key in unchanged values. Ignore the prompt and press R/S.</td>
<td></td>
<td>R/S *</td>
<td>V1=?</td>
</tr>
</tbody>
</table>

*Press R/S if you are not using a printer.
Example 1:

A water tower is 100 feet high. If 10,000 pounds of water are pumped to the top of the tower every hour, at a velocity of 20 ft/s, with a frictional pressure drop of 2 psi, how much horsepower is needed at the pump? The density of water is 62.4 lbm/ft³.

Keystrokes (SIZE = 012)

```
FIX 2
XEQ ALPHA ENERGY ALPHA
62.4 R/S
LBM/FT3 R/S
10000 R/S
LBM/HR R/S
```

Display

```
DENS=?
UNITS DENS?
MDOT=?
UNITS MDOT?
V1=?
```
Since $V_1 = 0$ and is automatically set to zero on initialization, skip the input.

\[ R/S \]
\[ V_2 = ? \]
\[ \text{UNITS V2?} \]
\[ Z_2 - Z_1 = ? \]
\[ \text{UNITS Z2-Z1?} \]
\[ P_2 - P_1 = ? \]
\[ \text{UNITS P2-P1?} \]
\[ \text{PWRIN} = ? \]

Since this is the unknown, skip the input.

\[ R/S \]
\[ D \]
\[ \text{HP R/S} \]

\[ \text{SELECT KEY:} \]
\[ V Z P \text{ PWR} \]
\[ \text{UNITS PWRIN?} \]
\[ \text{PWRIN} = 0.56 \text{HP} \]
Example 2:

An incompressible fluid ($\rho = 735 \text{ kg/m}^3$) flows through the converging passage shown below. At point 1 the velocity is 3 m/s and at point 2 the velocity is 15 m/s. The elevation difference between points 1 and 2 is 3.7 meters. Assuming frictionless flow, what is the static pressure difference between points 1 and 2? The flow rate is 20 m$^3$/s. Since all values are given in SI units you may ignore all unit prompts by simply pressing $\text{R/S}$.

Keystrokes (SIZE > 012)  

```
FIX 2  
XEQ ALPHA ENERGY ALPHA  
735 R/S  
R/S  
R/S  
20 R/S  
R/S  
3 R/S  
R/S  
15 R/S  
R/S  
3.7 CHS R/S  
R/S  
R/S  
R/S  
C  
R/S  
```

Display

```
DEN= ?  
UNITS DENS?  
MDOT= ?  
Q= ?  
UNITS Q?  
V1= ?  
UNITS V1?  
V2= ?  
UNITS V2?  
Z2-Z1= ?  
UNITS Z2-Z1?  
P2-P1= ?  
PWRIN= ?  
SELECT KEY:  
V Z P PWR  
UNITS P2-P1?  
P2-P1= 52,710.82 PA  
```
HEAT EXCHANGERS

This program allows analysis (except where phase changes are involved) of counterflow, parallel flow, parallel-counterflow, and crossflow heat exchangers.

The Unit Management System may be used through this program. The Unit Management System is explained in the front of this manual.

Figure 1:

![Counterflow Diagram]

Figure 2:

![Parallel Flow Diagram]
Figure 3: **Parallel-Counterflow**  
*(even number of tube passes)*

**Crossflow**

Equations:

Heat exchanger effectiveness $E$ is the ratio of actual heat transfer to maximum possible heat transfer.

$$E = \frac{Q}{C_{\text{min}} (T_{\text{hin}} - T_{\text{cin}})} = \frac{C_{\text{h}} (T_{\text{hin}} - T_{\text{ho}})}{C_{\text{min}} (T_{\text{hin}} - T_{\text{cin}})} = \frac{C_{\text{c}} (T_{\text{co}} - T_{\text{cin}})}{C_{\text{min}} (T_{\text{hin}} - T_{\text{cin}})}$$

where:

- $Q$ is the actual heat transfer;
- $T_{\text{hin}}$ and $T_{\text{cin}}$ are the inlet temperatures of the hot and cold fluids, respectively;
- $T_{\text{ho}}$ and $T_{\text{co}}$ are the outlet temperatures of the hot and cold fluids, respectively;
- $T_{\text{hin}} \neq T_{\text{ho}}$; $T_{\text{cin}} \neq T_{\text{co}}$;
$C_h$ and $C_c$ are the heat capacities of the hot and cold fluids, respectively, e.g., $C_h = m_h \times c_{ph}$, where $m_h$ is the flow rate and $c_{ph}$ is the specific heat capacity of the hot fluid;

$C_{\text{min}}$ and $C_{\text{max}}$ are the smaller and larger values of $C_h$ and $C_c$.

Effectiveness can be related to the product of the surface area ($A$) of the heat exchanger and the overall heat transfer coefficient ($U$) for specific geometries. The product is designated $AU$. The geometrics considered in this paper have the following correlations:

Counterflow (see figure 1)

$$E = \frac{AU}{C_{\text{min}}} \frac{1 - \frac{C_{\text{min}}}{C_{\text{max}}}}{1 - \left(\frac{C_{\text{min}}}{C_{\text{max}}}\right)^{AU} \frac{1 - \frac{C_{\text{min}}}{C_{\text{max}}}}{1 - \frac{C_{\text{min}}}{C_{\text{max}}}}}$$

For $C_{\text{min}}/C_{\text{max}} = 1$

$$E = \frac{AU/C_{\text{min}}}{1 + AU/C_{\text{min}}}$$

Parallel Flow (see figure 2)

$$E = \frac{1 - \frac{AU}{C_{\text{min}}} (1 + C_{\text{min}}/C_{\text{max}})}{1 + C_{\text{min}}/C_{\text{max}}}$$

For $C_{\text{min}}/C_{\text{max}} = 0$, $C_{\text{min}}$ is set to 1.

Parallel-Counterflow (well mixed with an even number of tube passes; see figure 3)

$$E = \frac{2}{\left(1 + \frac{C_{\text{min}}}{C_{\text{max}}}\right) + \sqrt{1 + \left(\frac{C_{\text{min}}}{C_{\text{max}}}\right)^2 \left[\frac{1 + e^{-x}}{1 - e^{-x}}\right]}}$$

where:

$$x = \frac{AU}{C_{\text{min}}} \sqrt{1 + \left(\frac{C_{\text{min}}}{C_{\text{max}}}\right)^2}$$
Crossflow (both fluids unmixed; see figure 4)

No exact expression exists for this case, but the following is a very good approximation. Note that it cannot be stated explicitly in terms of $AU$ and thus requires an iterative solution.

$$
E = 1 - e^{-\left( -\frac{AU}{C_{\text{max}}} - \frac{C_{\text{min}}}{C_{\text{max}}} \right) - 1} \left( \frac{C_{\text{max}}}{C_{\text{min}}} \right)^{0.22}
$$

where:

$$
y = \left( \frac{C_{\text{min}}}{AU} \right)^{0.22}
$$

References:


Remarks:

The solution for $AU$ in the crossflow configuration takes significantly longer than other solutions because of the iterative technique required.

The program must be allowed to solve for all values ($AU$, $Q$, $T_{co}$, and $E$). It is quite possible for the heat balance equations to yield physically meaningless solutions for a particular configuration. However, the message ‘‘2ND LAW ERR’’ will be displayed if the 2$^{nd}$ law of thermodynamics has been violated during the calculation of $AU$ or $Q$.

This program is organized into five routines. The first routine performs heat balance calculations and acts as a controller for the four configuration routines. Each configuration routine has two sections that calculate $AU$ and $E$ for that heat exchanger. The controller executes the section of the desired configuration routine based on the configuration you select. This technique allows you to create your own configuration routines that can be executed by the controller.
A sample routine for a configuration called BOIL must be in the following format:

```
LBL ABOIL

(calculates AU for this configuration)

RTN
LBL EBOIL

(calculates E for this configuration)

END
```

BOIL must be one to five ALPHA characters. It must be preceded by an A and used to label the AU calculation section, and preceded by an E and used to label the E calculation section. When the program asks you to spell the configuration, you would key in BOIL instead of the configuration names that are included in the pac program.

For cases where the inlet and outlet temperatures of one of the fluids are equal (change of phase), use zero for the heat capacity of that fluid.

<table>
<thead>
<tr>
<th>STEP</th>
<th>INSTRUCTIONS</th>
<th>INPUT</th>
<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td></td>
<td>XEQ</td>
<td>HEATEX</td>
</tr>
<tr>
<td>2</td>
<td>Input inlet temperature of cold fluid.</td>
<td>$T_{cin}$</td>
<td>R/S</td>
<td>TH IN=?</td>
</tr>
<tr>
<td>3</td>
<td>Input inlet temperature of hot fluid.</td>
<td>$T_{hin}$</td>
<td>R/S</td>
<td>MC=?</td>
</tr>
<tr>
<td>4</td>
<td>Input mass flow rate of cold fluid.</td>
<td>$m_c$</td>
<td>R/S</td>
<td>MH=?</td>
</tr>
<tr>
<td>5</td>
<td>Input mass flow rate of hot fluid.</td>
<td>$m_n$</td>
<td>R/S</td>
<td>CPC=?</td>
</tr>
<tr>
<td>6</td>
<td>Input specific heat of cold fluid.</td>
<td>$C_{pc}$</td>
<td>R/S</td>
<td>CPH=?</td>
</tr>
</tbody>
</table>

SIZE: 023
### Heat Exchangers

<table>
<thead>
<tr>
<th>STEP</th>
<th>INSTRUCTIONS</th>
<th>INPUT</th>
<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Input specific heat of hot fluid.</td>
<td>$C_{ph}$</td>
<td>R/S</td>
<td>SPELL CNFG: PRC, CNT, PAR or CRS</td>
</tr>
<tr>
<td>8</td>
<td>Spell desired configuration: counterflow</td>
<td>CNT</td>
<td>R/S</td>
<td>SELECT KEY: E AU Q TC TH</td>
</tr>
<tr>
<td></td>
<td>or parallel flow</td>
<td>PAR</td>
<td>R/S</td>
<td></td>
</tr>
<tr>
<td></td>
<td>or parallel-counterflow</td>
<td>PRC</td>
<td>R/S</td>
<td></td>
</tr>
<tr>
<td></td>
<td>or crossflow</td>
<td>CRS</td>
<td>R/S</td>
<td></td>
</tr>
<tr>
<td></td>
<td>or a configuration you create.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>9</td>
<td>Select the known value: heat exchanger effectiveness</td>
<td>A</td>
<td></td>
<td>E=?</td>
</tr>
<tr>
<td></td>
<td>area-heat transfer coefficient product</td>
<td>B</td>
<td></td>
<td>AU=?</td>
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<tr>
<td></td>
<td>heat transfer</td>
<td>C</td>
<td></td>
<td>Q=?</td>
</tr>
<tr>
<td></td>
<td>outlet temperature of cold fluid</td>
<td>D</td>
<td></td>
<td>TCO=?</td>
</tr>
<tr>
<td></td>
<td>outlet temperature of hot fluid</td>
<td>E</td>
<td></td>
<td>THO=?</td>
</tr>
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<td>10</td>
<td>Input the known value.</td>
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<td>R/S</td>
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<tr>
<td></td>
<td>AU</td>
<td>R/S</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Q</td>
<td>R/S</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TCO</td>
<td>R/S</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>THO</td>
<td>R/S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>The four variables other than the one you input will be output. The output order will vary depending on which value was input. If the 2nd law of thermodynamics is violated, the message '2ND LAW ERR' will be displayed.</td>
<td></td>
<td></td>
<td>E=?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S</td>
<td>AU=?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S</td>
<td>Q=?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S</td>
<td>TCO=?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S</td>
<td>THO=?</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>For a new configuration, go to step 8. For a new problem, go to step 1. It is not necessary to key in any values which do not change. Ignore the prompts and press R/S. *Press if you do not have a printer.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Press R/S if you do not have a printer.
Example 1:

Water \( (c_p = 1 \text{ Btu/lbm \circ F}) \) is used to cool an oil \( (c_p = .53 \text{ Btu/lbm \circ F}) \) from 200 \( \circ \text{F} \) to 110 \( \circ \text{F} \). The water flow rate is 20,000 pounds per hour while the oil flows at 37,000 pounds per hour. If the water inlet temperature is 55 \( \circ \text{F} \) and \( U \) is 25 \( \text{Btu/hr \cdot ft^2 \circ F} \) for the heat exchangers being considered, what are the area requirements for counterflow, parallel flow, parallel-counterflow, and crossflow? Use the Unit Management System.

**Knowns:**
\[
\begin{align*}
T_{cin} &= 55 \text{ F} \\
T_{hin} &= 200 \text{ F} \\
m_c &= 20,000 \text{ lbm/hr} \\
m_h &= 37,000 \text{ lbm/hr} \\
c_{pc} &= 1 \text{ Btu/lbm \circ F} \\
c_{ph} &= 0.53 \text{ Btu/lbm \circ F} \\
T_{ho} &= 110 \text{ F} \\
U &= 25 \text{ Btu/hr \cdot ft^2 \circ F}
\end{align*}
\]

**Keystrokes (SIZE > 023)**

```
[HEATEX] [ENG] [2]
[HEATEX] [XEQ] [ALPHA]
[HEATEX] [ALPHA]
[HEATEX] [ALPHA]

Y [R/S]
55 [R/S]
F [R/S]
200 [R/S]
F [R/S]
20000 [R/S]
LBM/HR [R/S]
37000 [R/S]
LBM/HR [R/S]
1 [R/S]
BTU/LBM*F [R/S]
.53 [R/S]
BTU/LBM*F [R/S]

SELECT KEY:
E AU Q TC TH
THO=?
UNITS THO?
E=621.E-3
UNITS AU?
```

Select counterflow configuration.
Select parallel flow configuration.

Use the calculated effectiveness since it is the same for all configurations.

Select parallel-counterflow configuration.

Select crossflow configuration.

Go out of ALPHA mode to calculate areas.

*Press R/S if you do not have a printer.
Example 2:
If a counterflow exchanger with an area of 1000 ft² and an overall heat transfer coefficient of 27 Btu/hr · ft² · °F is available, how close will the outlet temperature of the oil be to 110 F? What will the total heat transfer and outlet water temperature be? All unspecified values remain the same as example 1.

Keystrokes
Go back to ALPHA mode to continue.

CTN,PAR,PRC,CRS
SELECT KEY:
E AU Q TC TH
AU=?
UNITS AU?
UNITS Q?
Q=1.66E6 BTU/HR
UNITS TCO?
TCO=138.E0 F
UNITS THO?
THO=116.E0 F
E=583.E-3

*Press if you do not have a printer.
BLACK BODY THERMAL RADIATION

Bodies with finite temperatures emit thermal radiation. The higher the absolute temperature, the more thermal radiation emitted. Bodies which emit the maximum possible amount of energy at every wavelength for a specified temperature are said to be black bodies. While black bodies do not actually exist in nature, many surfaces may be assumed to be black for engineering considerations.

Equations:

\[ L_{\text{MAX}} = \frac{c_3}{T} \]

\[ E_b = \sigma T^4 \]

\[ E_b L = \frac{2\pi c_1}{L^5 (e^{c_2/LT} - 1)} \]

\[ E_b 12 = \int_{L_1}^{L_2} \frac{2\pi c_1}{L^5 (e^{c_2/LT} - 1)} dL \]
where:

LMAX is the wavelength of maximum emissivity;
T is the absolute temperature;
Eb is the total emissive power;
EbL is the emissive power at L;
L1 and L2 are the upper and lower wavelengths;
Eb12 is the total emissive power for all wavelengths between L1 and L2.

c_1 = 5.9544 \times 10^{-17} \text{ W} \cdot \text{m}^2

\begin{align*}
c_2 &= 1.4388 \times 10^{-2} \text{ m} \cdot \text{K} \\
c_3 &= 2.8978 \times 10^{-3} \text{ m} \cdot \text{K} \\
\sigma &= 5.6693 \times 10^{-8} \text{ W/(m}^2 \cdot \text{K)}
\end{align*}

Reference:

<table>
<thead>
<tr>
<th>STEP</th>
<th>INSTRUCTIONS</th>
<th>INPUT</th>
<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td></td>
<td>XEO BLKBODY</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Key in units of energy (not units of power).</td>
<td>UNITS E</td>
<td>R/S</td>
<td>UNITS E?</td>
</tr>
<tr>
<td>3</td>
<td>Key in units of wavelength.</td>
<td>UNITS WVL</td>
<td>R/S</td>
<td>UNITS AREA?</td>
</tr>
<tr>
<td>4</td>
<td>Key in units of area.</td>
<td>UNITS AREA</td>
<td>R/S</td>
<td>UNITS TIME?</td>
</tr>
<tr>
<td>5</td>
<td>Key in units of time.</td>
<td>UNITS TIME</td>
<td>R/S</td>
<td>T=?</td>
</tr>
<tr>
<td>6</td>
<td>Key in temperature.</td>
<td>T</td>
<td>R/S</td>
<td>UNITS T?</td>
</tr>
<tr>
<td>7</td>
<td>Key in units of temperature and calculate total emissive power, and wavelength of maximum emissivity.</td>
<td>UNITS T</td>
<td>R/S</td>
<td>Eb=</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R/S *</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Key in lower limit of integration and calculate the emissive power at that wavelength.</td>
<td>L1</td>
<td>R/S</td>
<td>EbL=</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R/S *</td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td>R/S *</td>
<td>L1=?</td>
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<td></td>
<td></td>
<td>R/S *</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R/S *</td>
<td>L2=?</td>
</tr>
</tbody>
</table>
**Example:**

What percentage of the radiant output of a lamp is in the visible range (0.4 to 0.7 microns) if the filament of the lamp is assumed to be a black body at 2200°C? What is the percentage at 2300°C? What is the ratio of light for these two temperatures?

**Keystrokes (SIZE ≥ 020)**

<table>
<thead>
<tr>
<th>Key</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>END 3</td>
<td>UNITS E?</td>
</tr>
<tr>
<td>XEQ ALPHA</td>
<td>UNITS WVL?</td>
</tr>
<tr>
<td>BLKBODY</td>
<td>UNITS AREA?</td>
</tr>
<tr>
<td>R/S</td>
<td>UNITS TIME?</td>
</tr>
<tr>
<td>J</td>
<td>T=?</td>
</tr>
<tr>
<td>R/S</td>
<td>UNITS T?</td>
</tr>
<tr>
<td>MIC R/S</td>
<td>Eb=212.1E0</td>
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<tr>
<td>CM2 R/S</td>
<td>J/SCM2</td>
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<tr>
<td>S R/S</td>
<td>LMAX=1.172E0 MIC</td>
</tr>
<tr>
<td>2200 R/S</td>
<td>L1=?</td>
</tr>
<tr>
<td>C R/S</td>
<td>EbL=1.763E0</td>
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<tr>
<td>R/S *</td>
<td>J/SCM2*MIC</td>
</tr>
<tr>
<td>R/S *</td>
<td>EbL=54.73E0</td>
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<tr>
<td>.4 R/S</td>
<td></td>
</tr>
<tr>
<td>R/S *</td>
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</tr>
<tr>
<td>.7 R/S</td>
<td></td>
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</tbody>
</table>

* Press [R/S] if you are not using a printer.

### Table

<table>
<thead>
<tr>
<th>STEP</th>
<th>INSTRUCTIONS</th>
<th>INPUT</th>
<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Key in upper limit of integration and calculate the emissive power at that wavelength, and the total emissive power between L1 and L2.</td>
<td>L2</td>
<td>R/S</td>
<td>EbL= UNITS EbL</td>
</tr>
<tr>
<td></td>
<td>*Press [R/S] if you are not using a printer.</td>
<td></td>
<td>R/S</td>
<td>Eb12= UNITS Eb12</td>
</tr>
<tr>
<td>10</td>
<td>For a new case with the same units go to step 6. For new units go to step 1. Any values which remain unchanged need not be keyed in. Ignore the prompt and press [R/S].</td>
<td></td>
<td></td>
<td>T=?</td>
</tr>
</tbody>
</table>

*Please note: The table and example calculations are for reference only and may not be executed directly on the device.*
To find the percentage, divide the emissive power in the visible range by the total power.

at 2200°C:

$$6.662 \times 212.1 \div 100 \times 3.14100 \%$$

at 2300°C:

$$9.702 \times 248.5 \div 100 \times 3.90400 \%$$

To find the ratio of power at 2200°C to that at 2300°C divide the visible range powers.

$$6.662 \times 9.702 \div 686.7 - 03$$

* Press [R/S] if you are not using a printer.
### APPENDIX A

## PROGRAM DATA

<table>
<thead>
<tr>
<th>Program</th>
<th># Regs. to Copy</th>
<th>Data Registers</th>
<th>Flags</th>
<th>Display Format</th>
<th>Subprograms Called</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equations of State</td>
<td>61</td>
<td>00 STORAGE INDEX</td>
<td>00 Unit conversion</td>
<td>UNIT?</td>
<td>INPUT</td>
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<tr>
<td></td>
<td></td>
<td>01 UNIT CONVERSION</td>
<td>01 Ignore flag 00</td>
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<td>OUTPUT</td>
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<tr>
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<td></td>
<td>02 UNIT CONVERSION</td>
<td>02 Kwong</td>
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<td>KEY</td>
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<tr>
<td></td>
<td></td>
<td>03 T,</td>
<td>03 Input</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>04 P,</td>
<td>04 Mass basis</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>05 R</td>
<td>05 Do a,b SUB.</td>
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<td></td>
<td>06 M Wt</td>
<td>21 Stop on output</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>07 P</td>
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<td>08 V</td>
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<td></td>
<td></td>
<td>09 M or N</td>
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<td></td>
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<td>10 T</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>11 &quot;M&quot; or &quot;N&quot;</td>
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<td>12 INDIRECT CONTROL</td>
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<td>18 (V+ b)</td>
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<td>19 (V– b)</td>
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<tr>
<td>Polytropic Processes for an Ideal Gas</td>
<td>23</td>
<td>00 P₂/P₁</td>
<td>21 Stop on output</td>
<td></td>
<td>SZ?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>01 N</td>
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<td>KEY</td>
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<td>02 V₂/V₁</td>
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<td>OUTPUT</td>
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</table>
Isentropic Flow for an Ideal Gas

Conduit Flow

Program Data
<table>
<thead>
<tr>
<th>Energy Equation</th>
<th>38</th>
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<th>UNIT?</th>
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<td>for Steady Flow</td>
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<td>INPUT</td>
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<td>02 UNIT CONVERSION</td>
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<td>OUTPUT</td>
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<td>06 V1</td>
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<th>109</th>
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<th>UNIT?</th>
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<td>01 Ignore 00</td>
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<td>02 Stop after THO</td>
<td>OUTPUT</td>
</tr>
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<td></td>
<td>03 TC IN</td>
<td>03 Stop after E</td>
<td>KEY</td>
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<td>04 TH IN</td>
<td>04 Stop after AU</td>
<td>AO</td>
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<td>06 Stop after TCO</td>
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<td>21 Stop on output</td>
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<td>23 Alpha input?</td>
<td>APAR</td>
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55

Program Data

16 MH
17 C_{pc}
18 C_{ph}
19 AU_{i-1}
20 F (AU_i)
21 F (AU_{i-1})
22 NAME CONFIGURATION

Black Body Thermal Radiation

<table>
<thead>
<tr>
<th>62</th>
<th>00 STORAGE INDEX</th>
<th>00 Unit conversion</th>
<th>SZ?</th>
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<tbody>
<tr>
<td>03</td>
<td>T</td>
<td>21 Stop on output</td>
<td>INPUT</td>
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<td>1/L</td>
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