HEWLETT hp PACKARD

HP-65

CHEMICAL ENGR. PAC 1

(THERMAL AND TRANSPORT SCIENCE)

TABLE OF CONTENTS

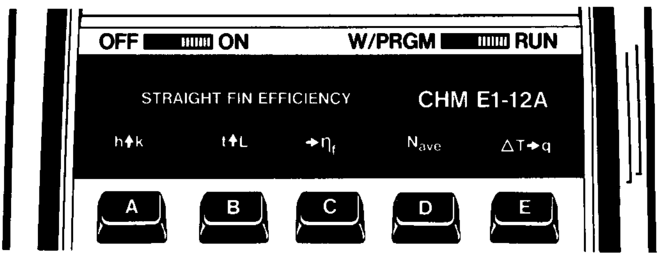
USING CHEMICAL ENGINEERING PAC 1

Chemical Engineering Pac I is a collection of programs designed to aid the engineer in thermodynamic and transport process calculations. Each program includes a general description, formulas used in the program solution, general user instructions, example problems with keystroke solutions, and a program listing.

By using the keyboard functions of the HP-65 in combination with *Chemical Engineering Pac I,* complex problems can be solved in an easy, consistent manner. Very rarely will intermediate answers need to be written down for later use. Where possible, inputs are stored in consistent registers and remain unaltered from program card to program card. This allows similar programs to be linked with little or no reinput of data.

PRERECORDED MAGNETIC CARDS

The prerecorded magnetic cards supplied with *Chemical Engineering Pac I* incorporate a shorthand set of operating instructions. This should make it possible to run the programs without referencing the manual. A typical card inserted in the window slot of an HP-65 is shown below:



Above the **A** key are the input variables h and k separated by an ↑, the symbol for **ENTER↑**. This means key in h, press **ENTER↑**; key in k, then press **A**. The variables associated with the **B** key work in the same manner as those associated with the **A** key. The horizontal arrow pointing at the variable η_f means calculate. Therefore, pressing the **C** key will initiate the calculation of η_f. A variable by itself (N_{ave} above **D**) indicates input by pressing the corresponding user definable key. The symbols above the **E** key, as you have probably guessed, mean key in ΔT and press **E** resulting in the calculation of q. Another symbol used throughout the pac is an arrow pointing down to a variable ▼. This indicates that the key may be used for both calculation and input. If a zero is displayed when the user definable key is pressed, the calculator calculates the value. Any other displayed value will be stored.

As you probably noticed in the example, execution was from left to right. Left to right input is always safe. However, input order is generally immaterial to the program.

FORMAT OF USER INSTRUCTIONS

The completed User Instruction Form, which accompanies each program, is your guide to operating the programs in this pac. On page 4 is a sample user instruction form for *Straight Fin Efficiency*, CHM E1–12A.

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-DATA/UNITS column specifies the input data, and the units of data if applicable. Data input keys consist of [0] to [9] and decimal point (the numeric keys), [EEX] (enter exponent), and [CHS] (change sign).

The KEYS column specifies the keys to be pressed after keying in the corresponding input data. Where the [ENTER↑] key is used, it is indicated by ↑. All other key designations are identical to those appearing on the HP-65. Ignore any blank spaces in the KEYS columns.

The INPUT-DATA/UNITS column shows abbreviations for the input variables. The OUTPUT-DATA/UNITS column shows what should be in the display after the operation shown in the KEYS column is performed. In many cases it is possible to run programs by referring only to the INPUT-DATA/UNITS column and the KEYS column. However, important information in the INSTRUCTIONS column may be overlooked in this manner.

The OUTPUT-DATA/UNITS column specifies intermediate and final outputs and their units where applicable.

Format of User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Input				
	Convective coefficient	h	↑		h
	then conductive coefficient	k	A		h
	and				
	Fin thickness	t	↑		t
	then fin length	L	B		t/2
3	Calculate fin efficiency		C		η_f
4	Input the average number of				
	fins per unit surface length	N_{ave}	D		N_{ave}*
5	Input temperature difference				
	and compute heat transfer per				
	unit surface area	ΔT	E		q
6	For new ΔT go to step 5. For				
	new N_{ave} go to step 4. For new				
	fin parameters go to step 2.				

*Flashing zeros indicate that more fins than possible have been added.

STEP 1: Step 1 of the example user instruction form is "Enter program". This calls for the entry of the prerecorded magnetic card into the HP-65 (See *Entering a Program,* on page 6).

STEP 2: This step specifies the input of the convective coefficient h, the conductive coefficient k, the fin thickness t, and the fin length L. The inputs are broken into two groups by the word "and". One group is the convective and conductive coefficients. The other indicates the thickness and length. Either group can be input first since there is no order implied by the word "and". However, note that within the groups order is important. The convective coefficient must be keyed in and entered before the conductive coefficient. The same is true of the thickness and length. The word "then" is used in both cases to specify the order.

STEP 3: This step triggers calculation of fin efficiency. Note that since nothing is specified in the INPUT-DATA/UNITS column, the condition of the operational stack is immaterial. This means that any number of intermediate calculations could have been done between STEP 2 and STEP 3 with no effect upon the calculation of η_f. Data storage registers must not be disturbed, however. A register usage table is included on page 92 to give you information concerning spare registers and data position.

STEP 4: This step specifies the input of the number of fins per unit surface length. First, key in N_{ave} and then press **D**. N_{ave} should still be displayed when execution stops. As noted by the asterisk, flashing zeros indicate an error in the value of the input.

STEP 5: This step specifies the input of ΔT and the calculation of q.

STEP 6: This step specifies the procedure for modifying the problem or starting a new case.

USER SUPPLEMENTAL PROGRAMMING

In forty programs we could not hope to solve every problem in chemical engineering. Hopefully, we have addressed some of the more important topics and built a basis from which you can build an HP-65 program library for your specific needs. The register usage chart in Appendix A should be helpful in integrating your programs with those of *Chemical Engineering Pac I.*

ACKNOWLEDGMENT

Chemical Engineering Pac I has been enhanced considerably by the helpful comments, suggestions, and useful examples from many practicing engineers. We especially wish to thank Mr. Dean Lampman for his expertise and assistance in reviewing this text.

ENTERING A PROGRAM

Select a program card from the card case supplied with this application pac.

Set W/PRGM-RUN switch to RUN.

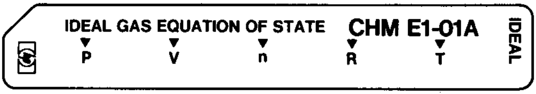
Turn the calculator ON. You should see 0.00.

Gently insert the card (printed side up) in the right, lower slot as shown. When the card is part way in, the motor engages it and passes it out the left side of the calculator. Sometimes the motor engages but does not pull the card in. If this happens, push the card a little farther into the machine. Do not impede or force the card; let it move freely. (The display will flash if the card reads improperly. In this case, press [CLX] and reinsert the card.)

When the motor stops, remove the card from the left side of the calculator and insert it in the upper "window slot" on the right side of the calculator.

The program is now stored in the calculator. It remains stored until another program is entered or the calculator is turned off.

IDEAL GAS EQUATION OF STATE



This program provides an interchangeable solution between the five variables of the ideal gas law.

Table I
Values of the Universal Gas Constant

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

Equations:

$$PV = nRT$$

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.

Remarks:

At low temperatures or high pressures the ideal gas law does not represent the behavior of real gases.

P, V, and T must have units compatible with R.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Input four of the following:				
	Absolute pressure	P	A		0.00
	Volume	V	B		0.00
	Number of moles	n	C		0.00
	Universal gas constant	R	D		0.00
	Absolute temperature	T	E		0.00
3	Calculate one of the following:				
	Absolute pressure	0.00	A		P
	Volume	0.00	B		V
	Number of moles	0.00	C		n
	Universal gas constant	0.00	D		R
	Absolute temperature	0.00	E		T
4	For a new case go to step 2 and				
	change appropriate inputs.				

Example 1:

0.63 g-moles of air are enclosed in a 25,000 cm^3 space at 1200 K. What is the pressure in bars? In atmospheres?

Keystrokes **See Displayed**

25000 [B] 0.63 [C] 83.14 [D] 1200 [E] [A] ⟶ 2.51 bars

82.05 [D] [A] ⟶ 2.48 atm

Example 2:

What is the specific volume (ft^3/lb) of a gas at atmospheric pressure and at a temperature of 513 °R? The molecular weight is 29 lb/lb-mole.

Keystrokes **See Displayed**

513 [E] 29 [g] [1/x] [C] 0.7302 [D] 1 [A] [B] ⟶ 12.92 ft^3/lb

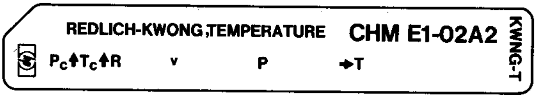
What is the density?

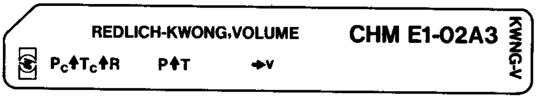
[g] [1/x] [DSP] [•] [3] ⟶ 0.077 lb/ft^3

What is the density at 1.32 atmospheres and 555 °R?

1.32 [A] 555 [E] [B] [g] [1/x] ⟶ 0.094 lb/ft^3

REDLICH-KWONG EQUATION OF STATE





The Redlich-Kwong equation is a two constant equation of state which takes some of the adverse properties of real gases into account. It is generally a better approximation of the behavior of real gases than either the ideal gas law or van der Waals' equation.

The first card of the Redlich-Kwong set solves for pressure P. The inputs are critical pressure P_c, critical temperature T_c, the universal gas constant R, temperature T and volume v. The second and third cards are similar, but solve for temperature and volume instead of pressure.

Table I
Critical Temperatures and Pressures*

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

*Values of the universal gas constant may be found in Table 1 of *Ideal Gas Equation of State,* CHM E1–1A, page 8.

Equations:

$$P = \frac{RT}{v - b} - \frac{a}{T^{1/2}\, v\,(v + b)}$$

$$a = 4.934\, b\, RT_c^{\,1.5}$$

$$b = 0.0867\, \frac{RT_c}{P_c}$$

Remarks:

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.

Solutions for both v and T require an iterative technique—Newton's method is employed using the ideal gas law to generate the initial guess. Iteration time is generally a function of the amount of deviation from ideal gas behavior. For extreme cases, the routine may fail to converge entirely resulting in flashing zeros.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	To calculate pressure go to step				
	2. To calculate temperature go				
	to step 9. To calculate volume				
	go to step 16.				
2	Enter CHM E1-02A1				
3	Input critical pressure	P_c	↑		P_c
4	Input critical temperature	T_c	↑		T_c
5	Input universal gas constant	R	A		R
6	Input both of the following:				
	Absolute temperature	T	B		T
	Specific volume	v	C		v
7	Calculate pressure		D		P
8	For a new pressure calculation				
	using the same critical values, go				
	to step 6 and change either				
	temperature or volume. For a				
	new case go to step 1.				

(Continued)

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
9	Enter CHM E1-02A2				
10	Input critical pressure	P_c	↑		P_c
11	Input critical temperature	T_c	↑		T_c
12	Input universal gas constant	R	A		R
13	Input both of the following:				
	Specific volume	v	B		v
	Absolute pressure	P	C		P
14	Calculate absolute temperature		D		T
15	For a new temperature calcula-				
	tion using the same critical				
	values, go to step 13 and change				
	either specific volume or ab-				
	solute pressure. For a new case				
	go to step 1.				
16	Enter CHM E1-02A3				
17	Input critical pressure	P_c	↑		P_c
18	Input critical temperature	T_c	↑		T_c
19	Input universal gas constant	R	A		R
20	Input absolute pressure	P	↑		P
21	Input absolute temperature	T	B		P
22	Calculate specific volume		C		v
23	For a new volume calculation				
	using the same critical values,				
	go to step 20. For a new case				
	go to step 1.				

Example 1:

The specific volume of a gas in a container must be 800 cm^3/g mole, the temperature is to be 400 K. What will the pressure be?

$P_c = 48.2$ atm

$T_c = 305.5$ K

$R = 82.05$ cm^3 – atm/g mole-K

Keystrokes	**See Displayed**
Using card CHM E1–02A1	
48.2 [↑] 305.5 [↑] 82.05 [A] 400 [B] 800 [C] [D] ⟶	36.27 atm

Example 2:

Carbon dioxide gas is held at a pressure of 50 atmospheres, and at a temperature of 500 K. What is the volume in cm^3/g mole?

From Table I — $T_c = 304.2$ K, $P_c = 72.9$ atm

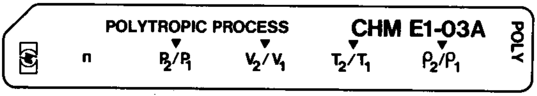
From Table I CHM E1–1A — $R = 82.05$ cm^3 – atm/g mole-K

Keystrokes	**See Displayed**
Using card CHM E1–02A3	
72.9 [↑] 304.2 [↑] 82.05 [A] 50 [↑] 500 [B] [C] ⟶	782.64 cm^3/g mole

To obtain a specific volume of 600 cm^3/g mole what would the temperature have to be if all other variables are unchanged?

Keystrokes	**See Displayed**
Using card CHM E1–02A2	
600 [B] [D] ⟶	405.77 K

REVERSIBLE POLYTROPIC PROCESS FOR AN IDEAL GAS



This program may be used to solve interchangeably between pressure ratio, volume ratio, temperature ratio, and density ratio for polytropic processes involving ideal gases. Polytropic processes are defined by the relation

$$PV^n = C$$

which is shown graphically in Figure 1.

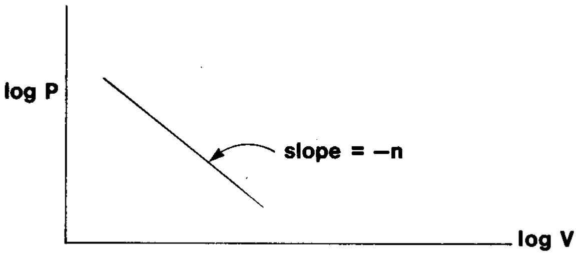


Figure 1.

Isentropic processes are special cases of polytropic processes. For isentropic processes, k, the specific heat ratio, is equal to n.

Equations:

$$\frac{P_2}{P_1} = \left(\frac{V_2}{V_1}\right)^{-n} = \left(\frac{T_2}{T_1}\right)^{\frac{n}{n-1}} = \left(\frac{\rho_2}{\rho_1}\right)^{n}$$

where

P_2/P_1 is the final pressure divided by the inital 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;

ρ_2/ρ_1 is the final density divided by the initial density.

Remarks:

Zero is an invalid input since the calculator interprets zero as a signal to calculate.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter program		[ ] [ ]	
2	Input polytropic constant*	n	[A] [ ]	n
3	Input one of the following:		[ ] [ ]	
	Pressure ratio	P_2/P_1	[B] [ ]	0.00
	Volume ratio	V_2/V_1	[C] [ ]	0.00
	Temperature ratio	T_2/T_1	[D] [ ]	0.00
	Density ratio	ρ_2/ρ_1	[E] [ ]	0.00
4	Calculate one fo the following:		[ ] [ ]	
	Pressure ratio	0.00	[B] [ ]	P_2/P_1
	Volume ratio	0.00	[C] [ ]	V_2/V_1
	Temperature ratio	0.00	[D] [ ]	T_2/T_1
	Density ratio	0.00	[E] [ ]	ρ_2/ρ_1
5	For another calculation based		[ ] [ ]	
	on the same input press [0] and		[ ] [ ]	
	go to step 4. For a new input go		[ ] [ ]	
	to step 3, for a new polytropic		[ ] [ ]	
	constant go to step 2.		[ ] [ ]	

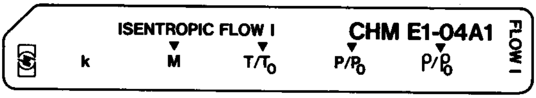
* If a value for k was previously input using an isentropic flow card, n need not be reinput.

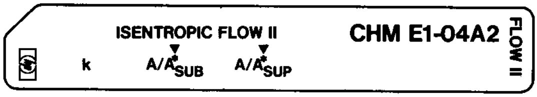
Example

A compressor has a compression ratio of 8.5 (V_1/V_2). The polytropic constant is 1.43. If inlet air is at 300 K, what is outlet temperature? What is the pressure in atmospheres if the inlet pressure is one atmosphere?

Keystrokes	See Displayed
1.43 [A] 8.5 [g] [1/x] [C] [D] →	2.51 (T_2/T_1)
300 [×] →	752.96K
0 [B] →	21.33 (P_2/P_1)
1 [×] →	21.33 atm

ISENTROPIC FLOW FOR IDEAL GASES





These two cards replace isentropic flow tables for a specified specific heat ratio k. Inputs and outputs are interchangeable with the exception of k.

The following values are correlated:

- M the mach number;
- T/T_0 the ratio of flow temperature T to static or zero velocity temperature T_0;
- P/P_0 the ratio of flow pressure P to static pressure P_0;
- ρ/ρ_0 the ratio of flow density ρ to static density ρ_0;
- A/A^*_{sub}, and A/A^*_{sup} are the ratios of flow area A to the throat area A* in converging–diverging passages. A/A^*_{sub} refers to subsonic flow while A/A^*_{sup} refers to supersonic flow.

Equations:

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

$$P/P_0 = (T/T_0)^{k/(k-1)}$$

$$\rho/\rho_0 = (T/T_0)^{1/(k-1)}$$

$$A/A^* = \frac{1}{M}\left[\left(\frac{2}{k+1}\right)\left(1 + \frac{k-1}{2}M^2\right)\right]^{\frac{k+1}{2(k-1)}}$$

In the last equation M^2 is determined using Newton's method. The initial guess used is as follows with a positive exponent for supersonic flow:

$$M_0{}^2 = \left(\sqrt{\text{Frac}\,(A/A^*)} + A/A^*\right)^{\pm 3}$$

Remarks:

After an input of A/A* the program begins to iterate to find M^2 for future use. This iteration will normally take less than one minute, but may take longer on occasion and for extreme values of k (1.4 is optimum) may fail to converge at all. Flashing zeros will eventually halt the routine if it goes out of control.

A/A* values of 1.00 are illegal inputs. Instead input an M of 1.00.

Zero is always an invalid input since the calculator interprets zero as a signal to calculate.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter *Isentropic Flow I,*				
	CHM E1-4A1 or *Isentropic*				
	Flow II, CHM E1-4A2				
2	Input specific heat ratio of gas*	k	A		k
3	Input one of the following:				
	Mach number	M	B		0.00
	Temperature ratio	T/T_0	C		0.00
	Pressure ratio	P/P_0	D		0.00
	Density ratio	ρ/ρ_0	E		0.00
	or if *Isentropic Flow II,*				
	CHM E1-4A2 was entered in				
	step 1 input one of the				
	following:				
	Subsonic area ratio	A/A_{sub}*	B		0.00
	Supersonic area ratio	A/A_{sup}*	C		0.00
4	Calculate one of the following				
	with CHM E1-4A1 in program				
	memory				
	Mach number	0.00	B		M
	Temperature ratio	0.00	C		T/T_0
	Pressure ratio	0.00	D		P/P_0
	Density ratio	0.00	E		ρ/ρ_0
	or with CHM E1-4A2 in				
	program memory calculate one				
	of the following:				
	Subsonic area ratio	0.00	B		A/A_{sub}*
	Supersonic area ratio	0.00	C		A/A_{sup}*
5	For another calculation based				
	on the same input value press				
	zero and go to step 4. For a new				
	input with same specific heat				
	ratio go to step 3. For a new				
	specific heat ratio go to step 2.				

* If k was previously input on another gas dynamics card, it need not be input again.

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	See Displayed
Using card CHM E1–04A1	
1.38 [A] .93 [B] [C] →	0.86
288 [×] →	247.35 K
273 [−] →	−25.65 °C

If the same pilot reads a stagnation pressure P_0 of 28 inches of mercury, what is the true air pressure?

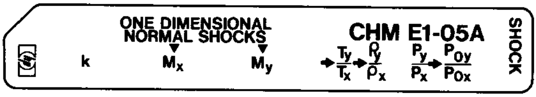
0 [D] →	0.58
28 [×] →	16.11 in. Hg

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	See Displayed
Using card CHM E1–04A2	
1.74 [A] 1.60 [C] →	0.00
Using card CHM E1–04A1	
0 [C] →	0.38 (T/T_o)
0 [D] →	0.10 (P/P_o)
0 [E] →	0.27 (ρ/ρ_o)
0 [B] →	2.11 (M)

ONE DIMENSIONAL NORMAL SHOCKS FOR IDEAL GASES



This card replaces one dimensional normal shock tables for a specified specific heat ratio k.

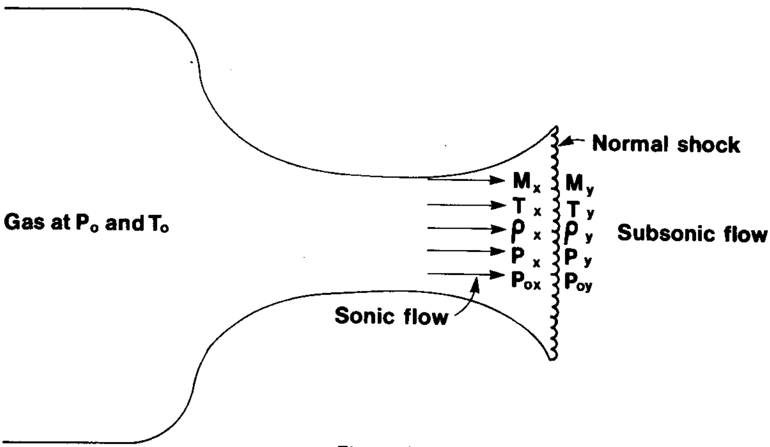


Figure 1.

The following values are correlated in the program.

M_x is the mach number immediately before the shock.

M_y is the mach number immediately after the shock.

T_y/T_x is the temperature ratio across the shock.

ρ_y/ρ_x is the density ratio across the shock.

P_y/P_x is the pressure ratio across the shock.

P_{oy}/P_{ox} is the stagnation pressure ratio across the shock.

M_x and M_y may be either inputs or outputs. All other values are output only.

Equations:

$$M_y^2 = \frac{M_x^2 + \frac{2}{k-1}}{\frac{2k}{k-1} M_x^2 - 1}$$

$$\frac{T_y}{T_x} = \frac{1 + \frac{k-1}{2} M_x^2}{1 + \frac{k-1}{2} M_y^2}$$

$$\frac{P_y}{P_x} = \sqrt{\frac{M_x^2 \, T_y}{M_y^2 \, T_x}}$$

$$\frac{\rho_y}{\rho_x} = \frac{P_y \, T_x}{P_x \, T_y}$$

$$\frac{P_{oy}}{P_{ox}} = \frac{P_y}{P_x} \left(\frac{T_y}{T_x} \right)^{\frac{k}{1-k}}$$

It should be remembered that T_{oy}/T_{ox}, the stagnation temperature ratio, is equal to 1.00 across a normal shock.

Remarks:

Zero is an invalid input.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Input specific heat ratio of gas*	k	A		k
3	Input one of the following:				
	Mach number before shock	M_x	B		0.00
	Mach number after shock	M_y	C		0.00
4	Calculate any or all of the				
	following:				
	Mach number before shock	0.00	B		M_x
	Mach number after shock	0.00	C		M_y
	Temperature ratio across				
	shock		D		T_y/T_x
	then density ratio across shock		D		ρ_y/ρ_x
	Pressure ratio across shock		E		P_y/P_x
	then stagnation pressure ratio				
	across shock		E		P_{oy}/P_{ox}
5	For new mach number go to				
	step 3. For new specific heat				
	ratio go to step 2.				

* If k was previously input on another gas dynamics card, it need not be input again.

Example 1:

The converging, diverging nozzle of Figure 1 (page 20) has a normal shock at its exit. The mach number immediately after the shock is 0.73. The gas has a specific heat ratio of 1.47. What are the property ratios across the shock?

Keystrokes	See Displayed
1.47 A .73 C B →	1.43 (M_x)
D →	1.32 (T_y/T_x)
D →	1.71 (ρ_y/ρ_x)
E →	2.25 (P_y/P_x)
E →	0.95 (P_{oy}/P_{ox})

Example 2:

A normal shock occurs at the entrance of the supersonic diffuser in Figure 2.

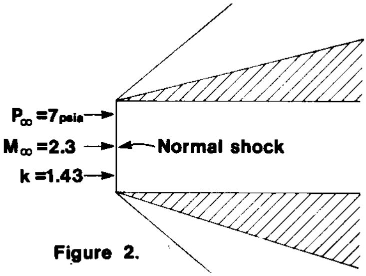
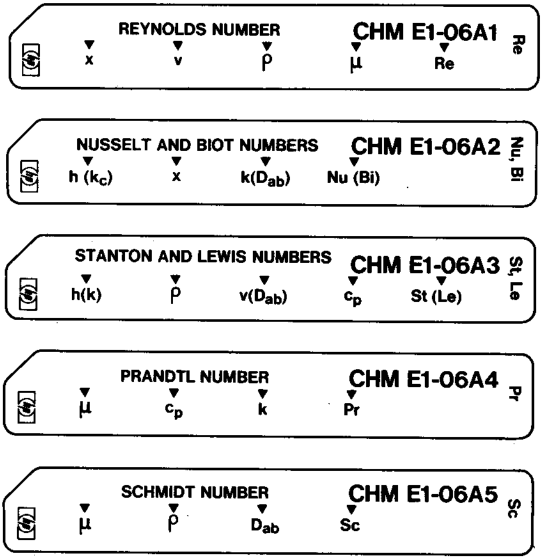


Figure 2.

What pressure and mach number exist behind the shock?

Keystrokes	See Displayed
1.43 A 2.3 B C	0.54 (M)
E 7 ×	42.34 psia

FLUID TRANSPORT NUMBERS



It is common practice in the fields of heat, mass, and momentum transfer to lump the many variables involved into dimensionless groups. These dimensionless groups, or fluid transport numbers, greatly simplify correlating experimental data and handling calculations once correlations have been obtained. Programming using dimensionless groups is greatly simplified since no unit conversion considerations are necessary. Also, programs using dimensionless inputs and outputs are of general applicability no matter what system of units is in favor. The disadvantage of dimensionless groups is that you, the user, must bear the responsibility of dimensional consistency. It is imperative that you do not try to add apples and oranges to get pears. More specifically, calculating the Nusselt number Nu by inputting h in Btu/°F-hr-ft^2, x in centimeters and k in Joules/°C-sec-m will not yield the correct result.

Before you start to solve a problem, pick a unit system. For instance, make the units of length feet, the units of temperature degrees Fahrenheit, the units of time hours and the units of energy British thermal units. Once you have a unit system in mind, convert all of your variables to that system before storing them for program use by the HP-65. To calculate Nusselt number using the system just outlined, the inputs would have to be in the following units:

h:Btu/°F-hr-ft^2 x:ft   k:Btu/°F-hr-ft

The dimensionless groups used throughout this pac are Reynolds number Re, Nusselt number Nu, Nusselt number for mass transfer Nu_{ab}, Lewis number Le, Schmidt number Sc, Stanton number St and Prandtl number Pr. All of these numbers are correlated using interchangeable solutions. This allows computation and automatic storage of the dimensionless groups for use by correlations in the pac. Where possible it also allows calculation of the desired property with no reentry of data after a correlation has been run.

Table of Equations

Number	Symbol	Formula	Use
Reynolds	Re	ρ x v/μ or $\frac{x\,v}{\nu}$	Momentum, mass and heat transfer where velocity and viscosity must be considered.
Nuesselt-heat	Nu	h x/k	Convective heat transfer.
Biot	Bi	h x/k	Combinations of convective and conductive transport systems.
Nusselt-mass	Nu_{ab}	$k_c\ x/D_{ab}$	Convective mass transfer.
Stanton	St	$h/\rho\ v\ c_p$	Convective heat transfer.
Lewis	Le	$k_c/\rho\ c_p\ D_{ab}$	Convective mass transfer.
Schmidt	S_c	$\mu/\rho\ D_{ab}$	Convective mass transfer.
Prandtl	Pr	$\mu\ c_p/k$	Convective heat transfer.

In the Table of Equations on page 25

ρ is fluid density;

μ is fluid viscosity;

v is the average fluid velocity;

x is the critical dimension (diameter for pipes and spheres and distance over which flow has occurred for flat plates);

h is the convective heat transfer coefficient;

k is the conductive heat transfer coefficient of the fluid or in the case of the Biot number, the object;

D_{ab} is the mass diffusivity;

k_c is the mass transfer coefficient;

ν is kinematic viscosity μ/ρ;

c_p is heat capacity.

REYNOLDS NUMBER

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter *Reynolds Number,*				
	CHM E1-06A1				
2	Input four of the following:				
	Significant dimension	x	A		0.00
	Fluid velocity	v	B		0.00
	Fluid density	ρ	C		0.00
	Fluid viscosity	μ	D		0.00
	Reynolds number	Re	E		0.00
3	Calculate the remaining value				
	Significant dimension	0.00	A		x
	Fluid velocity	0.00	B		v
	Fluid density	0.00	C		ρ
	Fluid viscosity	0.00	D		μ
	Reynolds number	0.00	E		Re
4	For new case go to step 2 and				
	change appropriate inputs.				

NUSSELT AND BIOT NUMBERS

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter *Nusselt and Biot Numbers,*		[ ] [ ]	
	CHM E1-06A2		[ ] [ ]	
2	Input three of the following:		[ ] [ ]	
	Convective heat (or mass)		[ ] [ ]	
	transfer coefficient	h (k_c)	[A] [ ]	0.00
	Significant dimension	x	[B] [ ]	0.00
	Conductive heat transfer		[ ] [ ]	
	coefficient (or mass diffu-		[ ] [ ]	
	sivity)	k (D_{ab})	[C] [ ]	0.00
	Nusselt (or Biot number)	Nu (Bi)	[D] [ ]	0.00
3	Calculate the remaining value		[ ] [ ]	
	Convective heat (or mass)		[ ] [ ]	
	transfer coefficient	0.00	[A] [ ]	h (k_c)
	Significant dimension	0.00	[B] [ ]	x
	Conductive heat transfer		[ ] [ ]	
	coefficient (or mass diffusi-		[ ] [ ]	
	vity)	0.00	[C] [ ]	h(D_{ab})
	Nusselt (or Biot number)	0.00	[D] [ ]	Nu (Bi)
4	For new case go to step 2 and		[ ] [ ]	
	change appropriate inputs		[ ] [ ]	

STANTON AND LEWIS NUMBERS

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter *Stanton And Lewis*		[ ] [ ]	
	Numbers, CHM E1-06A3		[ ] [ ]	
2	Input four of the following:		[ ] [ ]	
	Convective (or conductive)		[ ] [ ]	
	transfer coefficient	h (k)	[A] [ ]	0.00
	Fluid density	ρ	[B] [ ]	0.00
	Fluid velocity (or mass		[ ] [ ]	
	diffusivity)	$v\ (D_{ab})$	[C] [ ]	0.00
	Fluid heat capacity	c_p	[D] [ ]	0.00
	Stanton (or Lewis) number	St (Le)	[E] [ ]	0.00
3	Calculate the remaining value		[ ] [ ]	
	Convective (or conductive)		[ ] [ ]	
	transfer coefficient	0.00	[A] [ ]	h (k)
	Fluid density	0.00	[B] [ ]	ρ
	Fluid velocity (or mass		[ ] [ ]	
	diffusivity)	0.00	[C] [ ]	$v\ (D_{ab})$
	Fluid heat capacity	0.00	[D] [ ]	c_p
	Stanton (or Lewis) number	0.00	[E] [ ]	St (Le)
4	For new case go to step 2 and		[ ] [ ]	
	change appropriate inputs.		[ ] [ ]	

PRANDTL NUMBER

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter *Prandtl Number,*		[ ] [ ]	
	CHM E1-06A4		[ ] [ ]	
2	Input three of the following:		[ ] [ ]	
	Fluid viscosity	μ	[A] [ ]	0.00
	Fluid heat capacity	c_p	[B] [ ]	0.00
	Fluid heat conductivity	k	[C] [ ]	0.00
	Prandtl number	Pr	[D] [ ]	0.00
3	Calculate the remaining value		[ ] [ ]	
	Fluid viscosity	0.00	[A] [ ]	μ
	Fluid heat capacity	0.00	[B] [ ]	c_p
	Fluid heat conductivity	0.00	[C] [ ]	k
	Prandtl number	0.00	[D] [ ]	Pr
4	For a new case go to step 2 and		[ ] [ ]	
	change appropriate inputs.		[ ] [ ]	

SCHMIDT NUMBER

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter *Schmidt Number,*		[ ] [ ]	
	CHM E1-06A5		[ ] [ ]	
2	Input three of the following:		[ ] [ ]	
	Fluid viscosity	μ	[A] [ ]	0.00
	Fluid density	ρ	[B] [ ]	0.00
	Mass diffusivity	D_{ab}	[C] [ ]	0.00
	Schmidt number	Sc	[D] [ ]	0.00
3	Calculate the remaining value		[ ] [ ]	
	Fluid viscosity	0.00	[A] [ ]	μ
	Fluid density	0.00	[B] [ ]	ρ
	Mass diffusivity	0.00	[C] [ ]	D_{ab}
	Schmidt number	0.00	[D] [ ]	Sc
4	For a new case go to step 2 and		[ ] [ ]	
	change appropriate inputs.		[ ] [ ]	

Example 1:

At 60°F the properties of water are:

$\rho = 62.3$ lb/ft^3

$c_p = 1.00$ Btu/lb °F

$\mu = 0.760 \times 10^{-3}$ lb/ft sec

$\nu = 1.22 \times 10^{-5}$ ft^2/sec

k = 0.340 Btu/hr-ft-°F

Assume that fluid velocity is 37 feet per second and that the critical dimension is 6 inches. Calculate the Reynolds number using viscosity μ and desnity ρ. Then calculate Reynolds number using kinematic viscosity ν. (Input ν inplace of μ but replace ρ with the value 1.00.) Calculate the Prandtl number.

Keystrokes	See Displayed
Using card CHM E1–06A1	
6 [↑] 12 [÷] [A] 37 [B] 62.3 [C] .76 [EEX] [CHS] 3 [D]	
[E] [DSP] [3] ——→	1.517×10^6
6 [↑] 12 [÷] [A] 37 [B] 1 [C] 1.22 [EEX] [CHS] 5 [D] [E] ——→	1.516×10^6
Using card CHM E1–06A4	
.760 [EEX] [CHS] [3] [A] 1.00 [B] .340 [↑] 3600 [÷] [C] [D] ——→	8.047

Note that the value of k had to be divided by 3600 seconds per hour to hold dimensional consistency.

Example 2:

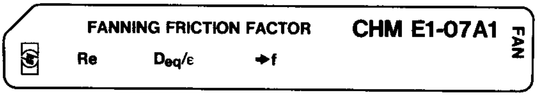
A Nusselt number of 6.47 was calculated using the Prandtl number and Reynolds number just calculated. What is h?

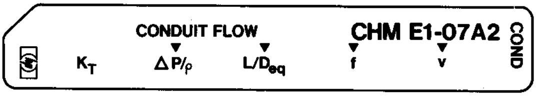
Keystrokes	See Displayed
Using card CHM E1–06A2	

By looking at the register allocation table on page 92, you can tell that R8, where x was stored during the Reynolds number calculation and R6, where k was stored during the Prandtl number calculation are unchanged. Therefore, it is only necessary to input Nu to get the answer.

6.47 [D] [A] ——→	1.222×10^{-3} Btu/sec-ft^2-°F

FANNING FRICTION FACTOR AND CONDUIT FLOW





These cards may be used to solve a variety of problems involving viscous conduit flow. To utilize the cards to full potential, the Reynolds number should be calculated using *Reynolds Number,* CHM E1–06A1. The Reynolds Number card automatically stores Reynolds number Re, equivalent diameter D_{eq}, and average fluid velocity v for later use.

In cases where the fluid velocity is unknown, make an educated guess in the Reynolds number calculation and proceed through the calculation of velocity. If your guess was different from the calculated value, the Reynolds number will be updated automatically and you may go directly to *Fanning Friction Factor* CHM E1–07A1 for a new friction factor value. The process of alternately computing velocities and friction factors is continued until successive approximations are within desired tolerances. The second sample problem should make this procedure clear.

Equations in *Fanning Friction Factor,* CHM E1–07A1:

For laminar flow (Re < 2300)

$$f = 16/\text{Re}$$

For turbulent flow (Re > 2300)

$$\frac{1}{\sqrt{f}} = 1.737 \ln \frac{D_{eq}}{\epsilon} + 2.28 - 1.737 \ln\left(4.67 \frac{D_{eq}}{\epsilon \,\text{Re} \sqrt{f}} + 1\right)$$

is solved by Newton's method.

$$\frac{1}{\sqrt{f_0}} = 1.737 \ln \frac{D_{eq}}{\epsilon} + 2.28$$

is used as an initial guess in the iteration.

Equations in *Conduit Flow,* CHM E1–07A2:

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

$$K_T = K_1 + K_2 + K_3 \ldots . K_n$$

where

Re is Reynolds number as defined in *Fluid Transport Numbers,* CHM E1–06A1.

D_{eq} is the equivalent conduit diameter.

$$D_{eq} = 4\,\frac{\text{cross sectional area}}{\text{wetted perimeter}}$$

ϵ is the dimension of irregularities in the conduit surface (See table 2);

f is the Fanning friction factor for closed conduit flow;

ΔP is the pressure drop along the conduit;

ρ is the density of the fluid (The units of $\Delta P/\rho$ must be length squared over time squared);

L is the conduit length;

v is the average fluid velocity;

K_T is the total of the applicable fitting coefficients in Table 1.

Reference:

Welty, Wicks, Wilson; *Fundamentals of Momentum, Heat and Mass Transfer,* John Wiley and Sons, Inc.,1969.

Table I
Fitting Coefficients

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

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

Table 2

Material	ϵ (inches)	ϵ (centimeters)
Drawn or Smooth Tubing	6.0×10^{-5}	1.5×10^{-4}
Commerical Steel or Wrought Iron	1.8×10^{-3}	4.6×10^{-3}
Asphalted Cast Iron	4.8×10^{-3}	1.2×10^{-2}
Galvanized Iron	6.0×10^{-3}	1.5×10^{-2}
Cast Iron	1.0×10^{-2}	2.5×10^{-2}
Wood Stave	7.2×10^{-3} to 3.6×10^{-2}	1.8×10^{-2} to 9.1×10^{-2}
Concrete	1.2×10^{-2} to 1.2×10^{-1}	3.0×10^{-2} to 3.0×10^{-1}
Riveted Steel	3.6×10^{-2} to 3.6×10^{-1}	9.1×10^{-2} to 9.1×10^{-1}

Remarks:

The correlation gives meaningless results in the region $2300 < Re < 4000$.

Zero is an invalid input with the exception of K_T.

Dimensional consistency must be maintained.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	If you know the Fanning				
	friction factor go to step 6				
2	Enter CHM E1-06A1 and cal-				
	culate the Reynolds number.				
	(If you don't know the fluid				
	velocity assume a reasonable				
	value.)				
3	Enter CHM E1-07A1				
4	Input the roughness ratio	D_{eq}/ϵ	B		D_{eq}/ϵ
	(Input Re if it was not cal-				
	culated using CHM E1-06A1 by				
	pressing A)				
5	Calculate the Fanning				
	friction factor		C		f
6	Enter CHM E1-07A2				
7	Input K_T and three of the				
	following:	K_T	A		0.00
	Pressure-density ratio	$\Delta P/\rho$, L^2/t^2	B		0.00
	Length-diameter ratio	L/D_{eq}	C		0.00
	Fanning friction factor				
	(only if step 5 was skipped)	f	D		0.00
	Average fluid velocity				
	(only if step 2 was skipped)	v	E		0.00
8	Calculate unknown value				
	Pressure density ratio	0.00	B		$\Delta P/\rho$, L^2/t^2
	Length-diameter ratio	0.00	C		L/D_{eq}
	Fanning friction factor	0.00	D		f
	Average fluid velocity	0.00	E		v
9	If you have reached a final an-				
	swer go to step 1 for a new case.				
	If you are using an iterative solu-				
	tion for v, enter CHM E1-07A1				
	go to step 5. Re was automati-				
	cally updated when v was calcu-				
	lated. All inputs of step 7 are				
	still stored.				

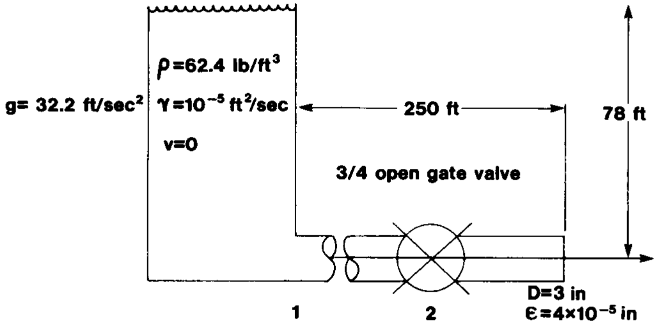
Example 1:

A heat exchanger has twenty, 10 foot tube passes with 180 degree bends connecting each pair of tubes. The fluid is water ($\nu = 10^{-5}$ ft^2/sec, $\rho = 62.4$ lbm/ft^3). The surface roughness is 1.0×10^{-2} inches and the inside pipe diameter is 1.0 inch. If the fluid velocity is 10 ft/sec, what is the pressure loss in psi?

Keystrokes	See Displayed
Using card CHM E1–06A1	
1 [↑] 12 [÷] [A] 10 [B] 1 [C] [EEX] [CHS] 5 [D] [E] ⟶	83333.33 (Re)
Using card CHM E1–07A1	
1 [↑] [EEX] [CHS] 2 [÷] [B] [C] [DSP] [•] [3] ⟶	0.010 (f)
Using card CHM E1–07A2	
Compute and store length over diameter	
20 [↑] 10 [×] 1 [↑] 12 [÷] [÷] [C] ⟶	0.000
1.6 [↑] 10 [×] [A] ⟶	0.000
Since f and v are stored from previous calculations, calculate $\Delta P/\rho$	
[B] ⟶	163.809 (ft^2/sec^2)
62.4 [↑] 32.2 [÷] [÷] ⟶	84.530 lb/ft^2
144 [÷] ⟶	0.587 psi

Example 2:

For the system shown, what is the volume flow rate?



$K_T = K_0 + K_1 + K_2$
$= 1 + .4 + 0.85 = 2.25$

Keystrokes | **See Displayed**

Using card CHM E1–06A1

Guess a v of 10 ft/sec

3 [↑] 12 [÷] [A] 10 [B] 1 [C] [EEX] [CHS] 5 [D] [E] ⟶ 250000.00 (Re)

Using card CHM E1–07A1

3 [↑] 4 [EEX] [CHS] 5 [÷] [B] [C] [DSP] [•] [3] ⟶ 0.004 (f)

Using card CHM E1–07A2

2.25 [A] 78 [↑] 32.2 [×] [B] 250 [↑] 3 [↑] 12 [÷] [÷]
[C] [E] ⟶ 17.012 ft/sec

Using card CHM E1–07A1

[C] ⟶ 0.003 (f)

Using card CHM E1–07A2

0 [E] ⟶ 17.729 ft/sec

Using card CHM E1–07A1

[C] ⟶ 0.003 (f)

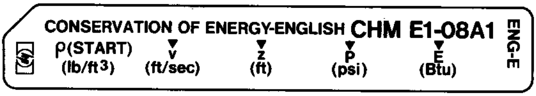
Using card CHM E1–07A2

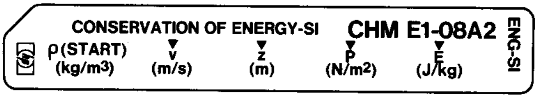
0 [E] ⟶ 17.784 ft/sec

Since the last two velocities calculated are reasonably close to each other, we may take the last value obtained as the answer.

1.5 [↑] 12 [÷] [↑] [×] [g] [π] [×] [×] ⟶ 0.873 ft³/sec

CONSERVATION OF ENERGY





These cards convert kinetic energy, potential energy and pressure-volume work to energy. CHM E1–08A1 is for English units while CHM E1–08A2 is for SI or metric units. Energy is stored as a running total. When a zero is displayed, pressing the **B**, **C**, **D** or **E** keys will cause the running total to be converted to an equivalent velocity, height, pressure or energy per unit mass. The cards may be used in a large number of fluid flow problems, where velocity, elevation and pressure change along the path of flow.

Equations:

$$\frac{v_1{}^2}{2} + gz_1 + \frac{P_1}{\rho} + \frac{E_1}{\dot{m}} = \frac{v_2{}^2}{2} + gz_2 + \frac{P_2}{\rho} + \frac{E_2}{\dot{m}}$$

where

v is the fluid velocity;

z is the height above a reference datum;

P is the pressure;

E is an energy term which could represent inputs of work or friction loses (negative value);

g is the acceleration of gravity;

ρ is the fluid density;

$\dot{m}$ is the mass flow rate (assumed to be unity);

subscripts 1 and 2 refer to upstream and downstream values respectively.

Remarks:

Downstream values should be input as negatives. However, when an output is called for, the calculator displays the relative value with no regard to upstream or downstream location.

Flashing zeros will result when the total energy sum stored in register 8 is negative and an attempt is made to calculate velocity.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	For English units (pounds, feet,				
	seconds, Btus), enter				
	CHM E1-08A1. For SI units				
	(kilograms, meters, seconds,				
	watts), enter CHM E1-08A2.				
2	Input fluid density	ρ	A		g
3	Input the following (negative				
	values are downstream values):				
	Fluid velocity	v	B		0.00
	Height from reference datum	z	C		0.00
	Pressure	P	D		0.00
	Energy input	E	E		0.00
4	Repeat step 3 for all input				
	values				
5	Calculate the unknown:				
	Fluid velocity	0.00	B		v
	Height from reference datum	0.00	C		z
	Pressure	0.00	D		P
	Energy	0.00	E		E
6	For new case go to step 2, or				
	store 0.00 in register 8 and go				
	to step 3.				

Example 1:

A water tower is 100 feet high. What is the zero flow rate pressure at the base? The density of water is 62.4 lb/ft^3.

Keystrokes	**See Displayed**
Using card CHM E1–08A1	
62.4 A 100 C D ——→	43.33 psig

If water is flowing out of the tower at a velocity of 10 ft/sec, what is the static pressure?

10 CHS B D ——→	42.66 psig

What is the maximum frictionless flow velocity which could be achieved with the 100 foot tower?

62.4 A 100 C B ——→	80.21 ft/sec

If 10000 pounds of water are pumped to the top of the tower every hour, at a velocity of 20 ft/sec, with a frictional pressure drop of 2 psi, how much power is needed at the pump?

62.4 A 20 B 2 D 100 C E ——→	0.14 Btu/lb
10000 × ——→	1424.29 (Btu/hr)

Example 2:

An incompressible fluid ($\rho = 735$ kg/m^3) flows through the converging passage of Figure 1. 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?

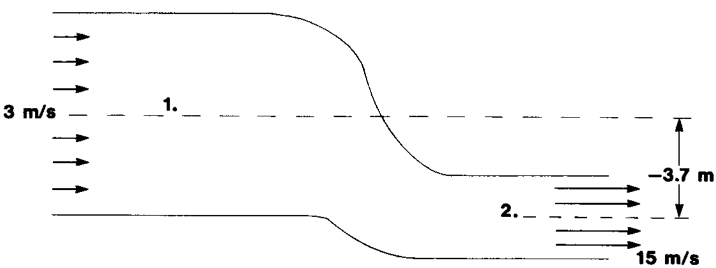


Figure 1.

Keystrokes	See Displayed
Using card CHM E1–08A2	
735 [A] 3 [B] 3.7 [C] 15 [CHS] [B] [D] →	–52710.82 (Nt/m^2)

Example 3:

A reservoir's level is 25 meters above the discharge pond. Assuming 85% power generation efficiency, how much power can be generated with a flow rate of 20 m^3/s?

$$\rho = 1000 \text{ kg/m}^3$$

Keystrokes	See Displayed
Using card CHM E1–08A2	
1000 [A] 25 [C] [E] →	245.17 (joule/kg)
.85 [×] →	208.39 (joule/kg)
20 [↑] 1000 [×] →	20000 (kg/s)
[×] →	4167826.25 (watts)

VON KÁRMÁN ANALOGY FOR HEAT AND MASS TRANSFER

The von Kármán analogy forms a link between momentum, heat, and mass transfer for conduit flow. If any of the transport coefficients, f, h, or k_c, are known, the others can be found using this program and the appropriate fluid transport numbers. For heat transfer, the Prandtl number can be calculated using CHM E1–06A4. For mass transfer, use the Schmidt number calculated with CHM E1–06A5. The values will be automatically stored for access by this program. If *Fanning Friction Factor,* CHM E1–07A1, or *Conduit flow,* CHM E1–07A2, are used to calculate the Fanning friction, factor, the value will be stored automatically.

Equations:

Heat transfer

$$St = \frac{f/2}{1 + 5\sqrt{f/2}\ (Pr - 1 + \ln\ [1 + 5/6\ (Pr - 1)])}$$

Mass transfer

$$\frac{k_c}{v} = \frac{f/2}{1 + 5\sqrt{f/2}\ (Sc - 1 + \ln\ [1 + 5/6\ (Sc - 1)])}$$

In both cases, f is solved for using Newton's method with the Colburn analogy as the initial guess f_0.

$$\frac{f_0}{2} = St\ Pr^{2/3} = \frac{k_c}{v}\ Sc^{2/3}$$

where

St is the Stanton number.

f is the Fanning friction factor.

Pr is the Prandtl number.

Sc is the Schmidt number.

k_c is the convective mass transfer coefficient.

v is the average fluid velocity.

Reference:

Welty, Wicks, Wilson; *Fundamentals of Momentum Heat and Mass Transfer,* John Wiley and Sons, Inc., 1969.

Remarks:

No form drag may be present. Fanning friction factors should be less than 0.02 and greater than 0.0001.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	If not previously stored, input:				
	Prandtl number (heat trans-				
	fer) or	Pr	A		0.00
	Schmidt number (mass trans-				
	fer)	Sc	A		0.00
	Input one of the following if				
	not previously stored:				
	Stanton number (heat trans-				
	fer) or	St	B		0.00
	Mass transfer, velocity ratio				
	(mass transfer) or	k_c/v	B		0.00
	Fanning friction factor	f	C		0.00
3	Calculate the unknown:				
	Stanton number	0.00	B		St
	Mass transfer, velocity ratio	0.00	B		k_c/v
	Fanning friction factor	0.00	C		f
4	For a new case go to step 2.				

Example 1:

The Schmidt number for a mild acid flowing through a metal pipe has been found to be 3.7. The Fanning friction factor is 0.011. If the fluid velocity is 15 feet per second, what is the convective mass transfer coefficient?

Keystrokes	See Displayed
3.7 [A] .011 [C] [B] [DSP] [•] [4] ⟶	0.0023 (k_c/v)
15 [×] ⟶	0.0338 ft/sec

Example 2:

Air at 100°F flows through a 2 foot duct, 120 feet long at a velocity of 3 feet per second. The head loss is 0.04 psf. Using *Conduit Flow,* CHM E1–07A2, find the Fanning friction factor. Then find the Stanton number for heat transfer considerations and convert it to a convective heat transfer coefficient using *Stanton and Lewis numbers,* CHM E1–06A3.

Air Properties:

$Pr = 0.703$

$\rho = 0.0710$ lb/ft^3

$C_p = 0.24$ Btu/lb °F

Keystrokes	See Displayed
Using card CHM E1–07A2	
0 [A] .04 [↑] 32.2 [×] .071 [÷] [B] 120 [↑] 2 [÷] [C] [3] [E] [D] [DSP] [•] [4] ⟶	0.0168
Using card CHM E1–09A	
.703 [A] [B] ⟶	0.0114
Using card CHM E1–06A3	
0.24 [D] 3 [C] 0.0710 [B] [A] ⟶	0.0006 (Btu/ft^2-sec-°F)
3600 [×] ⟶	2.1068 (Btu/ft^2-hr-°F)

HEAT EXCHANGER ANALYSIS

HEAT EXCHANGER EFFECTIVENESS CHM E1-10A1 HE-E

T_{cin}↑ $\dot{m}_c$ ↑ c_{pc} | T_{hin}↑ $\dot{m}_h$ ↑ c_{ph} | T_{co}→E | T_{ho}→E | q→E

HEAT EXCHANGER HEAT TRANSFER CHM E1-10A2 HE-q

T_{cin}↑ T_{hin} | $\dot{m}_c$ ↑ c_{pc}↑ $\dot{m}_h$ ↑ c_{ph} | E | →q | →T_{co}→T_{ho}

COUNTER-FLOW HEAT EXCHANGER CHM E1-10A3 HE CNT

$\dot{m}_c$↑c_{pc}↑ $\dot{m}_h$↑c_{ph} | AU→E | E→AU

PARALLEL-FLOW HEAT EXCHANGER CHM E1-10A4 HE PAR

$\dot{m}_c$↑c_{pc}↑ $\dot{m}_h$↑c_{ph} | AU→E | E→AU

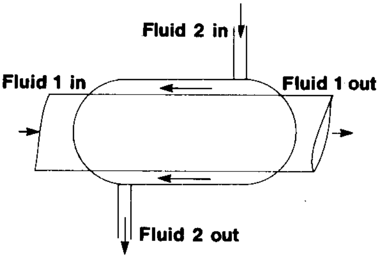


Figure 1.

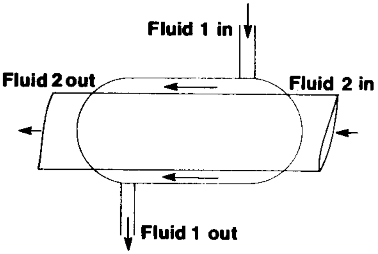


Figure 2.

PARALLEL-COUNTER-FLOW, (SHELL MIXED, EVEN NUMBER) CHM E1-10A5 HE P-C

$\dot{m}_c$↑c_{pc}↑ $\dot{m}_h$↑c_{ph} | AU→E | E→AU

CROSS-FLOW WITH FLUIDS UNMIXED CHM E1-10A6 HE CRS

C_c↑C_h | AU→E | E→AU

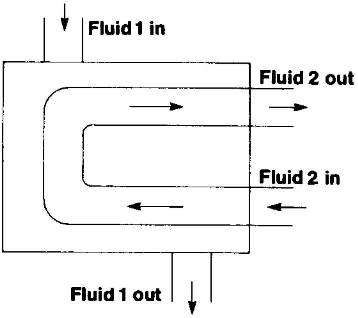


Figure 3.

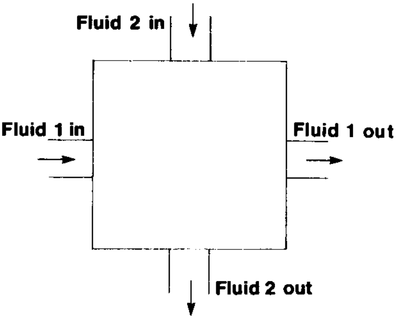


Figure 4.

This set of cards allows analysis of heat exchangers. Cards 1 and 2 are of general applicability. They use heat balance techniques to evaluate effectiveness, heat transfer and outlet temperatures. The remaining cards are configuration cards for particular types of heat exchangers.

Equations:

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

$$E = \frac{q}{C_{min}(T_{hin} - T_{cin})} = \frac{C_h(T_{hin} - T_{ho})}{C_{min}(T_{hin} - T_{cin})} = \frac{C_c(T_{co} - T_{cin})}{C_{min}(T_{hin} - T_{cin})}$$

where

- q is the actual heat transfer;
- T_{hin} and T_{cin} are the inlet temperatures of the hot and cold fluids respectively;
- T_{ho} and T_{co} are the outlet temperatures of the hot and cold fluids respectively;
- C_h and C_c are the heat capacities of the hot and cold fluids respectively, e.g. $C_h = \dot{m}_h \times c_{ph}$ where $\dot{m}_h$ is the flow rate and c_{ph} is the specific heat capacity of the hot fluid;
- C_{min} and C_{max} (which are used later) are the smaller and larger values of C_h and C_c.

Effectiveness can be related to the product of the surface area of an exchanger and the overall transfer coefficient for specific geometries. This product is designated AU. The geometries considered in this pac have the following correlations:

Counter-Flow (See Figure 1)

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

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

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

Parallel-Flow (See Figure 2)

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

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

Parallel-Counter-Flow; Shell Mixed with an Even Number of Tube Passes (See Figure 3)

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

where

$$x = \frac{AU}{C_{min}}\sqrt{1 + \left(\frac{C_{min}}{C_{max}}\right)^2}$$

Cross-Flow; 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.

$$E = 1 - e^{\left[\left(e^{\left(-\frac{AU}{C_{min}}\frac{C_{min}}{C_{max}}y\right)} - 1\right)\left(\frac{C_{max}}{C_{min}}\frac{1}{y}\right)\right]}$$

where

$$y = \left[\frac{C_{min}}{AU}\right]^{0.22}$$

References:

W. M. Kays and A. L. London, *Compact Heat Exchangers,* National Press, 1955.

Eckert and Drake, *Heat and Mass Transfer,* McGraw-Hill.

Remarks:

With the exception of the parallel configuration card, C_{min} must not be zero.
Solution for AU using CHM E1–10A6 takes considerably longer than other calculations because it is an iterative solution.

Once values for flow rate, temperature, and heat capacity are input, they will remain stored for later access.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Organize your problem—make		[ ] [ ]	
	a list of knowns and unknowns.		[ ] [ ]	
2	If your list contains $\dot{m}_c$, c_{pc},		[ ] [ ]	
	$\dot{m}_h$, and c_{ph}, go to step 3. If		[ ] [ ]	
	your list does not contain all		[ ] [ ]	
	these values, you may be able		[ ] [ ]	
	to calculate the missing ones		[ ] [ ]	
	from a heat balance or you will		[ ] [ ]	
	have to guess the values and use		[ ] [ ]	
	a repetitive approach to conver-		[ ] [ ]	
	ge to the desired result.		[ ] [ ]	
3	If, in addition to the values		[ ] [ ]	
	mentioned in step 2, you know		[ ] [ ]	
	AU, go to step 4 to calculate *E*.		[ ] [ ]	
	If you know *E* go to step 4 to		[ ] [ ]	
	calculate AU. If you know		[ ] [ ]	
	T_{cin} and T_{hin} and either T_{co},		[ ] [ ]	
	T_{ho}, or q, go to step 8 to cal-		[ ] [ ]	
	culate *E*. If you know T_{cin},		[ ] [ ]	
	T_{hin}, and *E*, go to step 13 to		[ ] [ ]	
	calculate q, T_{co}, and T_{ho}.		[ ] [ ]	
4	Select and enter proper ex-		[ ] [ ]	
	changer configuration card.		[ ] [ ]	
5	If you selected *Cross-Flow with*		[ ] [ ]	
	Fluids Unmixed, CHM E1-10A6		[ ] [ ]	
	input C_c ($\dot{m}_c \cdot c_{pc}$)	C_c	[↑] [ ]	C_c
	then C_h ($\dot{m}_h \cdot c_{ph}$)	C_h	[A] [ ]	C_{max}/C_{min}
	For other exchanger configu-		[ ] [ ]	
	ration cards		[ ] [ ]	

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
	input $\dot{m}_c$	$\dot{m}_c$	↑		$\dot{m}_c$
	then c_{pc}	c_{pc}	↑		c_{pc}
	then $\dot{m}_h$	$\dot{m}_h$	↑		$\dot{m}_h$
	then c_{ph}	c_{ph}	A		C_c
6	To calculate *E* from AU	AU	B		*E*
	To calculate AU from *E*	*E*	C		AU
7	If your final answer has not				
	been found, add *E* or AU to				
	your "known list" and go to				
	step 3.				
8	Enter *Heat Exchanger*				
	Effectiveness, CHM E1-10A1				
9	Input T_{cin}	T_{cin}	↑		T_{cin}
	then $\dot{m}_c$	$\dot{m}_c$	↑		$\dot{m}_c$
	then c_{pc}	c_{pc}	A		T_{cin}
	and T_{hin}	T_{hin}	↑		T_{hin}
	then $\dot{m}_h$	$\dot{m}_h$	↑		$\dot{m}_h$
	then c_{ph}	c_{ph}	B		T_{hin}
10	Input T_{co}	T_{co}	C		*E*
	or T_{ho}	T_{ho}	D		*E*
	or q to calculate *E*	q	E		*E*
11	Optional:				
	Display q		g	R↓	q
	Display T_{co}		g	R↓	T_{co}
	Display T_{ho}		g	R↓	T_{ho}
12	If your final answer has not				
	been found, add *E* to your				
	"known list" and go to step 3.				
13	Enter *Heat Exchanger Heat*				
	Transfer, CHM E1-10A2				

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
14	Input T_{cin}	T_{cin}	↑		T_{cin}
	then T_{hin}	T_{hin}	A		T_{cin}
	and $\dot{m}_c$	$\dot{m}_c$	↑		$\dot{m}_c$
	then c_{pc}	c_{pc}	↑		c_{pc}
	then $\dot{m}_h$	$\dot{m}_h$	↑		$\dot{m}_h$
	then c_{ph}	c_{ph}	B		C_c
	and E	E	C		E
15	Calculate:				
	q		D		q
	or T_{co}		E		T_{co}
	then T_{ho}		E		T_{ho}
16	If you have not reached a final				
	answer, try a heat balance to				
	add to your "known list" and				
	go to step 3.				

Example 1:

Water (c_p = 1 Btu/lb-°F) is used to cool an oil (c_p = .53 Btu/lb-°F) from 200°F to 110°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°F and U is 25 Btu/ft²-hr-°F for the heat exchangers being considered, what are the area requirements for counter-flow, parallel-flow, parallel-counter-flow and cross-flow?

Knowns:

c_{pc} = 1.0 Btu/lb-°F

$\dot{m}_c$ = 20,000 lb/hr

c_{ph} = 0.53 Btu/lb-°F

$\dot{m}_h$ = 37,000 lb/hr

T_{cin} = 55°F

T_{hin} = 200°F

T_{ho} = 110°F

U = 25 Btu/ft²-hr-°F

Keystrokes	**See Displayed**
Using card CHM E1–10A1	
55 [↑] 20000 [↑] 1 [A] 200 [↑] 37000 [↑] .53 [B]	
110 [D] ——→	.62 *(E)*
Counter Flow, using card CHM E1–10A3	
[C] ——→	31587.76(AU)
25 [÷] ——→	1263.51 ft²
Parallel Flow, using card CHM E1–10A4	
Note from register allocation that *E* is stored in register 5.	
[RCL] [5] [C] ——→	(Flashing zeros indicate that a parallel flow exchanger cannot do the job.)
[CLX] ——→	(Stop flashing zeros)
Parallel-Counter Flow, using card CHM E1–10A5	
[RCL] [5] [C] ——→	(Flashing zeros.)
[CLX] ——→	(Stop flashing zeros.)
Cross-Flow Exchanger, using card CHM E1–10A6	
[RCL] [5] [C] 25 [÷] ——→	1575.35 ft²

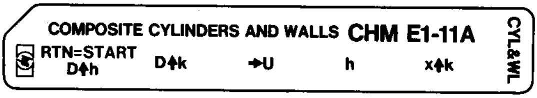
(Do not alter storage registers if you intend to continue with example 2.)

Example 2:

If a counter flow exchanger with an area of 1000 ft^2 and an overall heat transfer coefficient of 27 Btu/ft^2-hr-°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	See Displayed
Using card CHM E1–10A3	
1000 [↑] 27 [×] [B] →	0.58 *(E)*
Using card CHM E1–10A2	
[D] →	1656452.69 Btu/hr (q)
[E] →	137.82 °F(H_2O)
[E] →	115.53 °F(Oil)
110 [−] →	5.53 °F

HEAT TRANSFER THROUGH COMPOSITE CYLINDERS AND WALLS



This program can be used to calculate the overall heat transfer coefficient for composite tubes and walls from individual section conductances and surface coefficients.

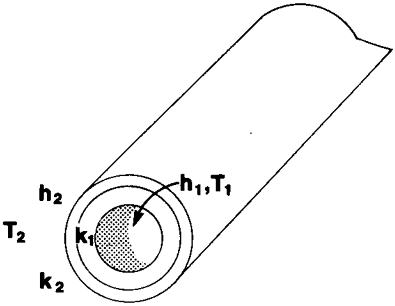


Figure 1.—Composite tube

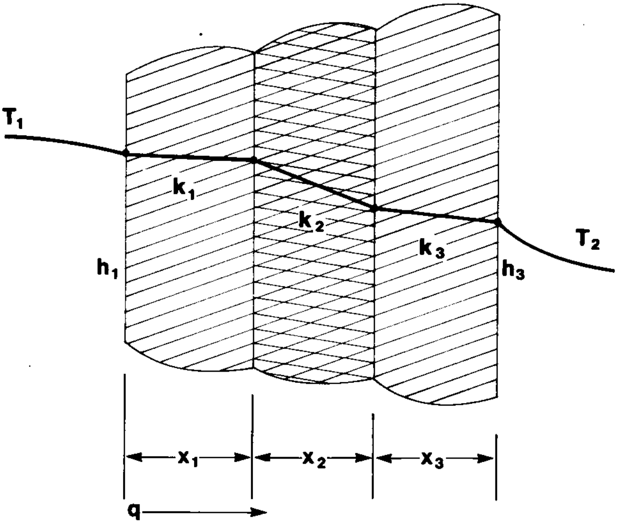


Figure 2. —Composite wall

Equations:

The overall heat transfer coefficient U is defined by:

$$q/L = U\,\Delta T$$

or

$$q/A = U\,\Delta T$$

where ΔT is the total temperature difference $(T_2 - T_1)$, q/L is the heat transfer per unit length of pipe, and q/A is the heat transfer per unit area of wall.

For cylinders

$$U = \frac{2\pi}{\dfrac{2}{h_1 D_1} + \dfrac{\ln D_2/D_1}{k_1} + \dfrac{\ln D_3/D_2}{k_2} + \ldots + \dfrac{2}{h_n D_n}}$$

For walls

$$U = \frac{1}{\dfrac{1}{h_1} + \dfrac{x_1}{k_1} + \dfrac{x_2}{k_2} + \ldots + \dfrac{1}{h_n}}$$

where

h is the convective surface coefficient;

D_n is the outside diameter of the annulus;

k is the conductive coefficient;

x is the thickness of a wall section.

Remarks:

These equations are for steady state heat transfer through materials with constant properties in all directions.

Inputs must start with the inside convective coefficient and work out in the case of composite cylinders.

Zero is an invalid input for D, k, and h.

Dimensional consistency must be maintained.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	For a composite wall go to				
	step 9.				
3	Input the inner diameter	D_{in}	↑		D_{in}
4	Input the inner convective				
	coefficient	h_{in}	A		2/hD
5	Input next diameter value	D	↑		D
	and corresponding coefficient	k or h	B		
6	Go to step 5 for next surface				
	or go to step 3 for outside				
	surface*				
7	Calculate overall heat transfer				
	coefficient		C		U
8	To calculate another overall				
	coefficient, go to step 2				
9	Input the coefficients for each				
	section of the wall:				
	Convective coefficient	h	D		1/h
	or length of conductive path	x	↑		
	and conductive coefficient	k	E		x/k
10	Go to step 9 for next input*				
11	Calculate overall heat transfer				
	coefficient		C		U
12	To calculate another overall				
	coefficient, go to step 2				

* Press RTN to restart a calculation.

Example 1:

A steel pipe with an inside diameter of 4 inches and a thickness of 0.5 inches has a conductivity of 25 Btu/ft-hr-°F. Two inches of asbestos (k = 0.1 Btu/hr-ft-°F) enclose the pipe bringing the total diameter to 9 inches. If the inside convective coefficient is 1000 Btu/hr-ft²-°F and the outside coefficient is 5 Btu/hr-ft²-°F, what is the overall heat transfer coefficient? What is the heat loss for 100 feet of pipe if ΔT is 115°F?

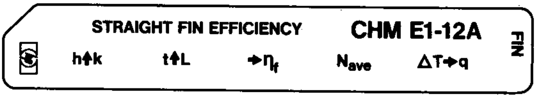
Keystrokes	See Displayed
4 [↑] 12 [÷] 1000 [A] 5 [↑] 12 [÷] 25 [B] 9 [↑] 12 [÷] 0.1 [B] 9 [↑] 12 [÷] 5 [A] [C] →	0.98 Btu/hr-ft-°F
115 [×] →	112.44 Btu/hr-ft
100 [×] →	11244.20 Btu/hr

Example 2:

A wall is composed of 1 foot of brick (k = 0.4 Btu/hr-ft-°F), and 1 inch of wood (k = 0.12 Btu/hr-ft-°F). The convective coefficient on one side is 23 Btu/hr-ft²-°F. The convective coefficient of the other side is 5 Btu/hr-ft²-°F. What is the overall coefficient? What is the heat flux if the temperature difference is 70°F?

Keystrokes	See Displayed
[RTN] 1 [↑] 0.4 [E] 1 [↑] 12 [÷] .12 [E] 23 [D] 5 [D] [C] →	0.29 Btu/ft²-hr-°F
70 [×] →	20.36 Btu/ft²-hr

STRAIGHT FIN EFFICIENCY



This program evaluates fin efficiency. Given the number of fins per unit of surface length and the temperature difference, the total heat transfer can also be found.

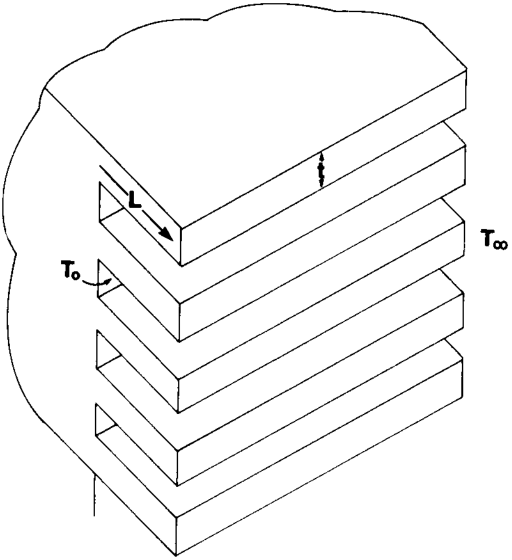
Equations:

$$\eta_f = \frac{\tanh(x)}{x}$$

$$x = (L + t/2)^{\frac{3}{2}} \sqrt{2h/ktL}$$

$$q = h\ [(1 - N_{ave}t) + \eta_f\, N_{ave}\,(2L + t)]\ \Delta T$$

$$\Delta T = |T_o - T_\infty|$$



where

η_f is fin efficiency;

L is fin length;

t is fin thickness;

h is the convective coefficient;

k is the conductive coefficient;

N_{ave} is the average number of fins per unit length of surface area;

q is the total heat flux per unit area;

T_o is the temperature of the base of the fin;

T_∞ is the fluid temperature.

Remarks:

Dimensional consistency must be maintained.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Input				
	Convective coefficient	h	↑		h
	then conductive coefficient	k	A		h
	and				
	Fin thickness	t	↑		t
	then fin length	L	B		t/2
3	Calculate fin efficiency		C		η_f
4	Input the average number of				
	fins per unit surface length	N_{ave}	D		N_{ave}*
5	Input temperature difference				
	and compute heat transfer per				
	unit surface area	ΔT	E		q
6	For new ΔT go to step 5. For				
	new N_{ave} go to step 4. For new				
	fin parameters go to step 2.				

* Flashing zeros indicate that more fins than possible have been added.

Example 1:

The oil pan of a race car is to be cooled by adding aluminum fins (k = 133 Btu/hr-°F-ft). The convective coefficient is about 50 Btu/hr-°F-ft². The fins are to be 0.1 inch thick, 0.5 inches long and average 15 per square foot. If T_o is taken to be 300°F and T_∞ is 100°F, what is the total heat transfer? What is the heat transfer without any fins?

Keystrokes	See Displayed
50 [↑] 133 [A] 0.1 [↑] 12 [÷] 0.5 [↑] 12 [÷] [B] [C] →	.94 (η_f)
15 [D] 300 [↑] 110 [−] [E] →	20537.02 Btu/hr-ft² (with fins)
0 [D] 300 [↑] 110 [−] [E] →	9500.00 Btu/hr-ft² (without fins)

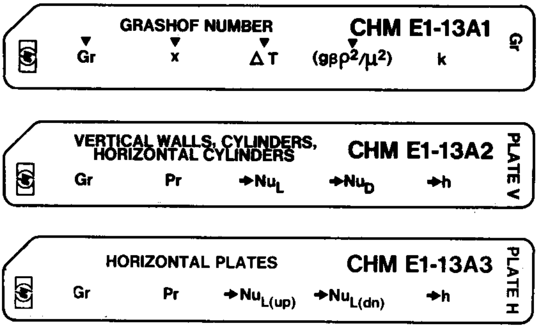
Example 2:

The back plate of an electronic device must dissipate 45 watts (153.58 Btu/hr) of power per square foot. The convective coefficient is 5 Btu/hr-°F-ft² and the air temperature is 80°F. If the back plate is aluminum (k = 132 Btu/hr-°F-ft) and fins will be 0.25 inches long and 0.1 inches wide, how many fins per foot are needed to keep the back plate temperature below 90°F?

Keystrokes	See Displayed
5 [↑] 132 [A] 0.1 [↑] 12 [÷] 0.25 [↑] 12 [÷] [B] [C]	
[DSP] [•] [4] →	.9977 (η_f)
Guess N_{ave} = 10 fins/ft	
10 [D] 90 [↑] 80 [−] [E] [DSP] [•] [2] →	70.78 Btu/hr
Guess N_{ave} = 100 fins/ft	
100 [D] 10 [E] →	257.77 Btu/hr
Guess N_{ave} = 50 fins/ft	
50 [D] 10 [E] →	153.88 Btu/hr

This is in close agreement with the desired 153.58 Btu/hr. Therefore, 50 fins per foot is the desired result.

NATURAL CONVECTION



These cards can be used to estimate convective heat transfer coefficients for isothermal vertical walls, vertical cylinders, horizontal cylinders and flat plates.

Equations:

For vertical walls and cylinders

$$Nu_L = 0.555(Gr_L Pr)^{0.25} \qquad Gr_L Pr < 3 \times 10^9$$

$$Nu_L = 0.021(Gr_L Pr)^{0.4} \qquad Gr_L Pr > 3 \times 10^9$$

$$Nu_D = 0.53(Gr_D Pr)^{0.25} \qquad 10^4 < Gr_D Pr < 10^9$$

For heated plates facing upward or cooled plates facing downward

$$Nu_{L(up)} = 0.54(Gr_L Pr)^{0.25} \qquad 10^5 < Gr_L Pr < 2 \times 10^7$$

$$Nu_{L(up)} = 0.14(Gr_L Pr)^{\frac{1}{3}} \qquad 2 \times 10^7 < Gr_L Pr < 3 \times 10^{10}$$

For heated plates facing downward or cooled plates facing upward.

$$Nu_{L(dn)} = 0.27(Gr_L Pr)^{\frac{1}{4}} \qquad 3 \times 10^5 < Gr_L Pr < 10^{10}$$

where

Nu is the Nusselt number (Nu = hx/k);

Pr is the Prandtl number as defined in *Fluid Transport Numbers*, CHM E1–06A.

Gr is the Grashof number

$$Gr = \frac{g\beta\rho^2\ x^3\Delta T}{\mu^2}$$

g is the acceleration of gravity;

β is the coefficient of thermal expansion;

ρ is the fluid density;

x is the significant dimension;

ΔT is the temperature difference between ambient conditions and the surface;

μ is the fluid viscosity.

n is the convective heat transfer coefficient

All fluid properties should be evaluated at the film temperature T_f

$$T_f = (T_\infty + T_{surface})/2$$

For vertical walls and cylinders, the significant dimension x is equal to the height of the wall or cylinder.

For horizontal cylinders, x is equal to the diameter of the cylinder.

For flat rectangular plates

$$x = (\text{side } 1 + \text{side } 2)/2$$

For flat rectangular discs

$$x = 0.9 \text{ diameter}$$

Remarks:

Flashing zeros result when the equation limits are exceeded.

Natural convection is a complicated phenomenon. Assumptions such as constant surface temperature and constant fluid properties are implicit to these relations. Since these conditions are seldom achieved in nature, surface coefficients obtained by calculation should be viewed as estimates rather than exact values.

Reference:

McAdams, William H., *Heat Transmission,* McGraw-Hill Inc., 1954.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Evaluate or estimate the film				
	temperature of the surface and				
	obtain the fluid properties k,				
	Pr, ρ, β, and μ				
2	Enter CHM E1-13A1 and input				
	three of the following:				
	Grashof number	Gr	A		0.00
	Significant dimension	x	B		0.00
	Temperature difference	ΔT	C		0.00
	Quantity ($g\beta\rho^2/\mu^2$)	$g\beta\rho^2/\mu^2$	D		0.00
3	Calculate the remaining values				
	Grashof number	0.00	A		Gr
	Significant dimension	0.00	B		x
	Temperature difference	0.00	C		ΔT
	Quantity ($g\beta\rho^2/\mu^2$)	0.00	D		$g\beta\rho^2/\mu^2$
4	If you have obtained a final				
	solution go to step 2 for a new				
	case				
5	To compute the Nusselt num-				
	ber only, go to step 6. For a				
	calculation of the convective				
	coefficient, input the conduc-				
	tive coefficient of the fluid	k	E		k
6	Enter the card corresponding to				
	the geometry of interest—				
	CHM E1-13A2 or CHM E1-13A3				
7	Input the Prandtl number	Pr	B		Pr
8	Calculate the Nusselt number				
	corresponding to the geometry				
	of the problem		C		Nu_L or $Nu_{L(up)}$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
			D		Nu_D or $Nu_{L(dn)}$
9	Calculate the convective coef-				
	ficient		E		h
10	To calculate heat transfer recall				
	ΔT and multiply		RCL	5	
			x		q
11	Go to step 1 for new case or to				
	repeat the calculation using				
	improved data. All previous				
	inputs will remain stored for				
	iterative procedures.				

Example 1:

A 4 inch horizontal pipe has a surface temperature of 120°F. The surrounding air is at 80°F. What is the heat transfer per square foot of pipe? All fluid properties should be evaluated at the film temperature (100°F).

$Pr = 0.703$

$g\beta\rho^2/\mu^2 = 1.76 \times 10^6 \text{ ft}^3/°F$

$k = 0.0156$ Btu/hr-ft-°F

Keystrokes **See Displayed**

Using card CHM E1–13A1

4 [↑] 12 [÷] [B] 40 [C] 1.76 [EEX] 6 [D] [A] ——→ 2607407.41 (Gr)

.0156 [E] ——→ 0.02

Using card CHM E1–13A2

.703 [B] [D] ——→ 19.50 (Nu_D)

[E] ——→ 0.91 Btu/ft²-hr-°F

Noting that ΔT is stored in register 5.

[RCL] [5] [×] ——→ 36.51 Btu/hr-ft²

Example 2:

The 2 foot circular top of a shielding case for radioactive material must dissipate 300 Btu/hr-ft^2. The case is immersed in water at 55°F. What is the surface temperature of the case?

Make a first approximation by assuming the surface temperature is 65°F and that the film temperature is 60°F, yielding the following properties for water:

$Pr = 8.07$

$g\beta\rho^2/\mu^2 = 17.2 \times 10^6$

$k = 0.34$ Btu/hr-ft-°F

Keystrokes	See Displayed
Using card CHM E1–13A1	
2 [↑] .9 [×] [B] 10 [C] 17.2 [EEX] 6 [D] [A]	1.003104×10^9 (Gr)
.34 [E]	0.34
Using card CHM E1–13A3	
8.07 [B] [C]	281.10 ($Nu_{L(up)}$)
[E]	53.10 Btu/hr-ft^2
Noting that ΔT is stored in Register 5.	
[RCL] [5] [×]	530.98 Btu/hr-ft^2
Using the same film temperature, drop the surface temperature 3°F to 62°F.	
Using card CHM E1–13A1	
7 [C] [A]	7.021728×10^8 (Gr)
Using card CHM E1–13A3	
[C]	249.59 (Nu)
[E]	47.15 Btu/hr-ft^2-°F
Noting that ΔT is stored in Register 5.	
[RCL] [5] [×]	330.02 Btu/hr-ft^2
Drop the surface temperature 1°F to 61°F.	
Using card CHM E1–13A1.	
6 [C] [A]	6.018624×10^8

Using card CHM E1–13A3

C ——————→ 237.09 (Nu)

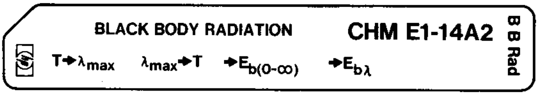
E ——————→ 44.78 Btu/hr-ft^2-°F

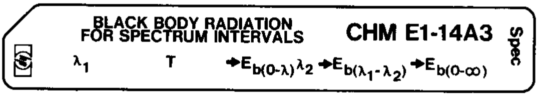
RCL 5 × ——————→ 268.71 Btu/hr-ft^2

$$\therefore\ 62°F > T > 61°F$$

$$T \approx 61.5°F$$

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.

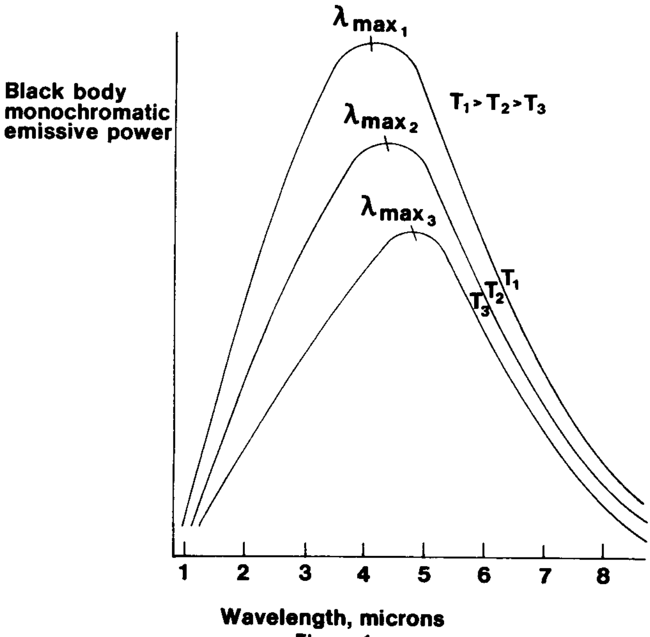


Figure 1.

Figure 1 is a representation of black body thermal emission as a function of wavelength. Note that as temperature increases the area under the curves (total emissive power $E_{b(0-\infty)}$) increases. Also note that the wavelength of maximum emissive power λ_{max} shifts to the left as temperature increases.

Card CHM E1–14A2 can be used to calculate 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 and the emissive power at a particular wavelength. CHM E1–14A3 can be used to calculate the emissive power from zero to an arbitrary wavelength, the emissive power between two wavelengths or the total emissive power. CHM E1–14A1 is used to store constants necessary for the operation of CHM E1–14A2 and CHM E1–14A3. Both English and SI (metric) constants are available. The Stefan-Boltzmann constant may be converted from the theoretical value to the experimental value by pressing **C** .

Equations:

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

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

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

$$E_{b(0-\lambda)} = \int_0^{\lambda} E_{b\lambda}\, d\lambda$$

$$= 2\pi c_1 \sum_{k=1}^{\infty} -T/kc_2 \; e^{-\frac{kc_2}{T\lambda}} \left[\left(\frac{1}{\lambda}\right)^3 + \frac{3T}{\lambda^2 kc_2} + \frac{6}{\lambda}\left(\frac{T}{kc_2}\right)^2 + 6\left(\frac{T}{kc_2}\right)^3 \right]$$

$$E_{b(\lambda_1-\lambda_2)} = E_{b(0-\lambda_2)} - E_{b(0-\lambda_1)}$$

where

λ_{max} is the wavelength of maximum emissivity in microns;

T is the absolute temperature in °R or K;

$E_{b(0-\infty)}$ is the total emissive power in Btu/hr-ft^2 or Watts/cm^2;

$E_{b\lambda}$ is the emissive power at λ in Btu/hr-ft^2-μm or Watts/cm^2-μm;

$E_{b(0-\lambda)}$ is the emissive power for wavelengths less than λ in Btu/hr-ft^2 or Watts/cm^2;

$E_{b(\lambda_1-\lambda_2)}$ is the emissive power for wavelengths between λ_1 and λ_2 in Btu/hr-ft^2 or Watts/cm^2.

$c_1 = 1.8887982 \times 10^7$ Btu-μm^4/hr-ft^2

$= 5.9544 \times 10^3$ Wμm^4/cm^2

$c_2 = 2.58984 \times 10^4$ μm-°R $= 1.4388 \times 10^4$ μm-K

$c_3 = 5.216 \times 10^3$ μm-°R $= 2.8978 \times 10^3$ μm-K

$\sigma = 1.713 \times 10^{-9}$ Btu/hr-ft^2-°R^4 $= 5.6693 \times 10^{-12}$ W/cm^2-K^4

$\sigma_{exp} = 1.731 \times 10^{-9}$ Btu/hr-ft^2-°R^4 $= 5.729 \times 10^{-12}$ W/cm^2-K^4

Remarks:

A minute or more may be required to obtain $E_{b(0-\lambda)}$ or $E_{b(\lambda_1-\lambda_2)}$ using CHM E1–14A3 since the integration is numerical.

Sources differ on values for constants. This could yield small discrepancies between published tables and HP-65 outputs.

Reference:

Robert Siegel and John R. Howell, *Thermal Radiation Heat Transfer*, Volume 1, National Aeronautics and Space Administration, 1968.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter *Thermal Radiation Con-*				
	stants CHM E1-14A1				
2	Store constants				
	For English units (Btu, μm,				
	hr, ft, °R)		A		1.713×10^{-9}
	For SI units (W, μm, cm, K)		B		5.669×10^{-12}
3	For experimental Stefan-Boltz-				
	mann constant instead of				
	theoretical constant		C		1.731×10^{-9} or 5.729×10^{-12}
4	If you want black body rad-				
	iation for a particular interval				
	$\Delta\lambda$, go to step 7. If you wish to				
	calculate λ_{max}, T, $E_{b(0-\infty)}$ or				
	$E_{b\lambda}$, enter *Black Body Radiat-*				
	ion, CHM E1-14A2				
5	Input absolute temperature and				
	calculate the corresponding				
	λ_{max} (If you only want				
	$E_{b(0-\infty)}$ go to step 6)	T	A		λ_{max} (μm)
	Input λ and calculate tem-				
	perature for which λ is max-				
	imum	λ(μm)	B		T
6	Calculate black body total				
	emissive power		C		$E_{b(0-\infty)}$
	Calculate black body emis-				
	sive power at λ		D		$E_{b\lambda}$
7	Enter *Black Body Radiation*				
	For Spectrum Interval, CHM E1-				
	14A3 Any values input in step 5				
	are still stored and need not be				

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
	input again				
8	Input both of the following:				
	Lower value of wavelength	λ_1 (μm)	A		λ_1 (μm)
	Absolute temperature of				
	body	T	B		T
9	Calculate:				
	Emissive power from 0 to λ_1		C		$E_{b(0-\lambda_1)}$
	Emissive power from λ_1 to				
	λ_2	λ_2	D		$E_{b(\lambda_1-\lambda_2)}$
	(λ_2 replaces λ_1 in storage)				
	Total emissive power		E		$E_{(0-\infty)}$
10	For new case go to step 4. All				
	variables input will remain				
	unchanged except for λ_2				
	replacing λ_1 as noted in step 9.				

Example 1:

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 2400 K? What is the percentage at 2500 K?

Keystrokes **See Displayed**

Using card CHM E1–14A1

B ——→ 5.669×10^{-12} W/cm^2-K^4

Using card CHM E1–14A3

.4 A 2400 B .7 D E ÷ 100 × DSP • 2 → 2.64%

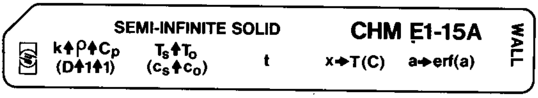
.4 A 2500 B .7 D E ÷ 100 × ——→ 3.34%

Example 2:

If the human eye was designed to work most efficiently in sunlight and the visible spectrum runs from about 0.4 to 0.7 microns, what is the sun's temperature in degrees Rankine? Assume that the sun is a black body. Using the temperature calculated, find the fraction of the sun's total emissive power which falls in the visible range. Find the percentage of the sun's radiation which has a wavelength less than 0.4 microns.

Keystrokes	**See Displayed**
Using card CHM E1–14A1	
[A] ⟶	1.713×10^{-9} Btu/hr-ft^2-°R^4
Using card CHM E1–14A2	
Compute mean of visible range.	
.4 [↑] .7 [+] 2 [÷] ⟶	5.500×10^{-1} μm
Compute temperature of sun.	
[B] ⟶	9.484×10^3 °R
Using card CHM E1–14A3	
Compute percentage of power in visible range.	
[B] .4 [A] .7 [D] [E] [÷] 100 [×] [DSP] [•] [2] ⟶	33.70%
Compute percentage of power under 0.4 μm.	
.4 [A] [C] [E] [÷] 100 [×] ⟶	8.43%

TEMPERATURE OR CONCENTRATION PROFILE FOR A SEMI-INFINITE SOLID



Many physical situations in heat and mass transfer may be solved within engineering tolerances by assuming an infinite geometry.

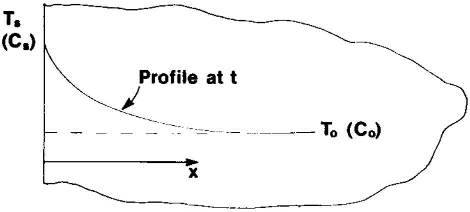


Figure 1.

In Figure 1 an infinitely thick wall initially at temperature T_0 or concentration C_0 is subject to a constant surface potential T_s or C_s. At a later time t, the internal profile will have been altered by the transport of heat or mass. This program computes values of temperature T or concentration C at time t for specified distances x from the outer surface.

Equations:

$$T = (T_0 - T_s)\,\mathrm{erf}\left(\frac{x}{2\sqrt{\frac{k}{\rho c_p}\,t}}\right) + T_s \quad *$$

where

k is thermal conductivity of the material;

ρ is the density of the material;

c_p is the specific heat of the material;

$k/\rho c_p$ is also known as the diffusivity of heat α.

Similarly, for mass transfer

$$C = (C_0 - C_s)\,\mathrm{erf}\left(\frac{x}{2\sqrt{Dt}}\right) + C_s \quad *$$

where

D is the mass diffusivity.

*erf is the error function.

Remarks:

This solution is exact for infinite configurations with constant cross sectional areas. However, finite geometries where the argument of the error function is greater than two will yield little or no error. This means transfer in finite bodies such as plates may be predicted until the effects of the step are felt on the far side. Also, geometries such as cylinders may be studied if the depth of penetration is small compared to the radius.

The routine used by this program will resolve error functions with arguments less than 4.5. For larger arguments, the value of the error function is set to 1.0.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	To compute the error function				
	of an argument go to step 8.				
3	Input:				
	Conductivity	k	↑		k
	then density	ρ	↑		ρ
	then specific heat	c_p	A		α
	or heat (or mass) diffusivity	α (D)	↑		α (D)
	then 1.00	1	↑		1.00
	then 1.00	1	A		α (D)
4	Input:				
	Surface temperature (con-				
	centration)	T_s (C_s)	↑		T_s (C_s)
	then initial temperature				
	(concentration)	T_0 (C_0)	B		T_s (C_s)
5	Input time	t	C		t
6	Input distance from surface				
	and calculate temperature				
	or concentration	x	D		T (C)
7	For new case go to step 2, 3, or				
	4 and change inputs. For new				
	time go to step 5. For new x go				
	to step 6.				
8	Input argument and compute				
	error function	a	E		erf(a)

Example 1:

A large steel transmission shaft is case hardened by diffusion of carbon. The initial carbon concentration is 0.10% and the surface concentration is brought to 1.20% almost instantly. What is the carbon concentration at 1.0 mm (1×10^{-3} m) after 15 hours (54000 seconds), if the diffusivity of carbon in steel is taken to be 1.6×10^{-11} m^2/s?

Keystrokes	See Displayed
1.6 [EEX] [CHS] 11 [↑] 1 [↑] 1 [A] 1.2 [↑] .1 [B] 54000	
[C] [EEX] [CHS] 3 [D] ⟶	0.59%

Example 2:

A furnace wall is at a constant 55°F. When the furnace is turned on the inside wall temperature is raised to 2000°F. How long will it take to raise the outside wall temperature 1°F?

k = 0.67 Btu/hr-ft-°F

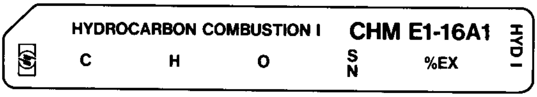
Thickness = 1.5 feet

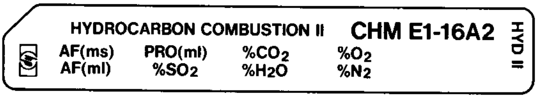
c = 0.2 Btu/lb °F

ρ = 150 lb/ft^3

Keystrokes	See Displayed
An iterative solution is required since t is not a program output. Guess 5.0 hours for t.	
.67 [↑] 150 [↑] .2 [A] 2000 [↑] 55 [B] 5 [C] 1.5 [D] ⟶	57.92°F
Guess 4.0	
Noting that x is stored in register 8.	
4.0 [C] [RCL] [8] [D] ⟶	55.75°F
Guess 4.2	
4.2 [C] [RCL] [8] [D] ⟶	56.04°F
Guess 4.18	
4.18 [C] [RCL] [8] [D] ⟶	56.01°F
Noting that t is stored in register 7.	
[RCL] [7] [f] [→D.MS] ⟶	≈4 hr. 10 min.

HYDROCARBON COMBUSTION





Given the atomic composition of a hydrocarbon fuel and the desired amount of excess air, the air-fuel ratio on a mass and mole basis is found. The number of moles of products is also calculated along with the volume percents of sulfur dioxide, carbon dioxide, water vapor, oxygen and nitrogen. Complete combustion is assumed.

Equations:

$$\text{Air} = 1 + \frac{\%\ \text{Excess Air}}{100}$$

$$O_2 = C + S + \frac{H}{4} - \frac{O}{2}$$

$$\text{AF(mole)} = O_2\ (4.762)\ \text{Air}$$

$$\text{AF(mass)} = \frac{1.8094\ \text{AF(mole)}}{0.7507C + 0.063H + 2.004S + 0.875N + 0}$$

$$M = O_2\ [4.762\ \text{Air}] + \frac{H}{4} + \frac{O}{2} + \frac{N}{2}$$

$$\text{Volume}\ \%CO_2 = \frac{100C}{M}$$

$$\text{Volume}\ \%SO_2 = \frac{100S}{M}$$

$$\text{Volume } \%H_2O = \frac{100H}{2M}$$

$$\text{Volume } \%O_2 = \frac{100(\text{Air} - 1)\, O_2}{M}$$

$$\text{Volume } \%N_2 = \frac{(100)\left[(3.762)\text{ Air } O_2 + \frac{N}{2}\right]}{M}$$

where

C, S, N, H and O refer to number of carbon, sulfur, nitrogen, hydrogen and oxygen atoms respectively per hypothetical fuel molecule.

AF stands for air-fuel ratio.

M stands for total moles of product.

Remarks:

% Excess air $\geqslant 0$.

Complete Combustion is assumed.

The volume percent values assume that no water vapor has been condensed out.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter *Hydrocarbon Combustion*				
	I, CHM E1-16A1				
2	Input all of the following (even				
	if zero):				
	Carbon atoms per molecule	C	A		C
	Hydrogen atoms per mole-				
	cule	H	B		H
	Oxygen atoms per molecule	O	C		O
	Sulfur atoms per molecule,	S	D		S
	then, Nitrogen atoms per				
	molecule	N	D		N
3	Input percent excess air	% excess	E		% excess
4	Enter *Hydrocarbon Combust-*				
	ion II, CHM E1-16A2				
5	Compute the following:				
	Air fuel ratio on a mass				
	basis, *then*		A		AF, mass
	Air fuel ratio on a mole basis		A		Af, mole
	Total moles of product, *then*		B		prod, mole
	Percent SO_2		B		% SO_2
	Percent CO_2, *then*		C		% CO_2
	Percent H_2O		C		% H_2O
	Percent O_2, *then*		D		% O_2
	Percent N_2		D		% N_2
6	For new case go to step 1.				

Example 1:

Octane C_8H_{18} is burned in 40% excess air. What is the air-fuel ratio on a mass basis and what are the volume percents of the products?

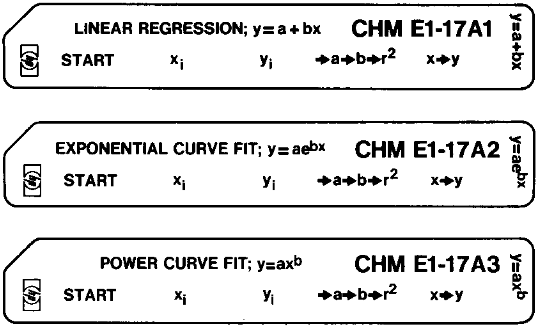
Keystrokes	**See Displayed**
Using card CHM E1–16A1	
8 [A] 18 [B] 0 [C] [D] [D] 40 [E] →	40.00
Using card CHM E1–16A2	
[A] →	21.12 (lb air/lb fuel)
[C] →	9.11% CO_2
[C] →	10.25% H_2O
[D] →	5.69% O_2
[D] →	74.95% N_2

Example 2:

A gas is composed of 70% C_4H_{10}, 20% CH_4 and 10% N_2 by volume. If the gas is burned with no excess air, what is the composition of the products of combustion assuming complete combustion?

Keystrokes	**See Displayed**
Using card CHM E1–16A1	
.7 [↑] 4 [×] .2 [↑] 1 [×] [+] [A] .7 [↑] 10 [×] .2 [↑] 4 [×]	
[+] [B] 0 [C] 0 [D] .1 [↑] 2 [×] [D] 0 [E] →	0.00
Using card CHM E1–16A2	
[C] →	11.71% CO_2
[C] →	15.22% H_2O
[D] →	0.00% O_2
[D] →	73.07% N_2

CURVE FITTING



These cards can be used to fit experimental data to:

straight lines

$$y = a + bx$$

exponential curves

$$y = ae^{bx} \qquad (a > 0)$$

and power curves

$$y = ax^b \qquad (a > 0)$$

A coefficient of determination r^2 ($0 \leqslant r^2 \leqslant 1.0$) is also calculated giving an estimate of goodness of fit. Values of r^2 close to 1.00 indicate a good fit. Values of r^2 close to zero indicate a poor fit.

Equations:

Linear regression

$$b = \frac{\Sigma x_i y_i - \dfrac{\Sigma x_i \Sigma y_i}{n}}{\Sigma x_i^2 - \dfrac{(\Sigma x_i)^2}{n}}$$

$$a = \left[\frac{\Sigma y_i}{n} - b\,\frac{\Sigma x_i}{n}\right]$$

$$r^2 = \frac{\left[\Sigma x_i y_i - \frac{\Sigma x_i \Sigma y_i}{n}\right]^2}{\left[\Sigma x_i^2 - \frac{(\Sigma x_i)^2}{n}\right]\left[\Sigma y_i^2 - \frac{(\Sigma y_i)^2}{n}\right]}$$

Exponential curve fit

$$b = \frac{\Sigma x_i \ln y_i - \frac{1}{n}(\Sigma x_i)(\Sigma \ln y_i)}{\Sigma x_i^2 - \frac{1}{n}(\Sigma x_i)^2}$$

$$a = \exp\left[\frac{\Sigma \ln y_i}{n} - b\,\frac{\Sigma x_i}{n}\right]$$

$$r^2 = \frac{\left[\Sigma x_i \ln y_i - \frac{1}{n}\Sigma x_i \Sigma \ln y_i\right]^2}{\left[\Sigma x_i^2 - \frac{(\Sigma x_i)^2}{n}\right]\left[\Sigma(\ln y_i)^2 - \frac{(\Sigma \ln y_i)^2}{n}\right]}$$

Power curve fit

$$b = \frac{\Sigma(\ln x_i)(\ln y_i) - \frac{(\Sigma \ln x_i)(\Sigma \ln y_i)}{n}}{\Sigma(\ln x_i)^2 - \frac{(\Sigma \ln x_i)^2}{n}}$$

$$a = \exp\left[\frac{\Sigma \ln y_i}{n} - b\,\frac{\Sigma \ln x_i}{n}\right]$$

$$r^2 = \frac{\left[\Sigma(\ln x_i)(\ln y_i) - \frac{(\Sigma \ln x_i)(\Sigma \ln y_i)}{n}\right]^2}{\left[\Sigma(\ln x_i)^2 - \frac{(\Sigma \ln x_i)^2}{n}\right]\left[\Sigma(\ln y_i)^2 - \frac{(\Sigma \ln y_i)^2}{n}\right]}$$

Remarks:

Negative and zero x_i values will cause flashing zeros in *Power Curve Fit*, CHM E1–17A3.

Negative and zero y_i values will cause flashing zeros in *Exponential Curve Fit*, CHM E1–17A2 and *Power Curve Fit*, CHM E1–17A3.

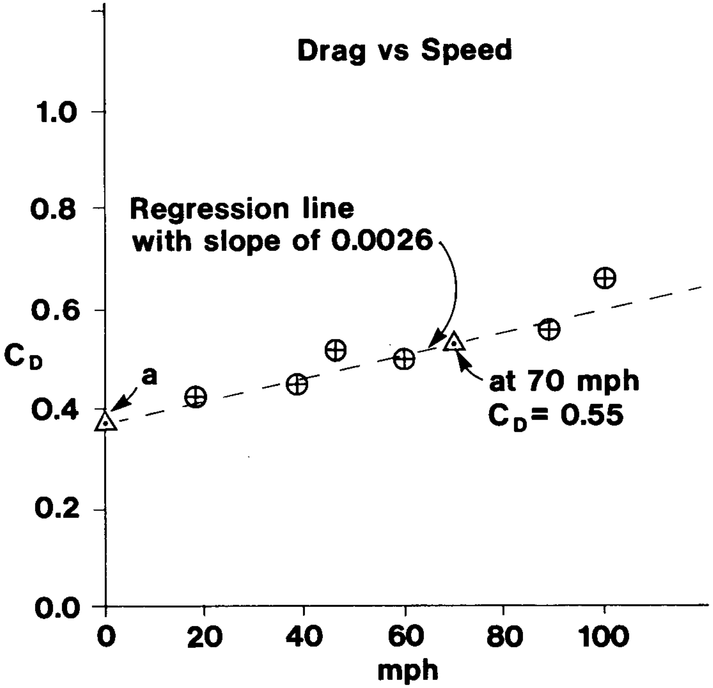
Values of r^2 slightly larger than one may be observed due to round off error.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter appropriate data fitting				
	card				
2	Initialize		A		
3	Input x value	x_i	B		x_i*
4	Input corresponding y value	y_i	C		y_i
5	Go to step 2 until all data points				
	have been input				
6	Calculate a		D		a
7	Optional: display b		D		b
8	Optional: display r^2		D		r^2
9	Based on the curve fit, project				
	a y value based on x	x	E		y
10	For another projected value go				
	to step 9. For additional data				
	values go to step 3. For a new				
	case go to step 2.				

* On power curve fit x_i is not displayed.

Example 1:

A test on an experimental automobile body shape resulted in the following data plot. Run a linear regression on the circled points and find a projected value of C_D at 70 mph.



Keystrokes	**See Displayed**
Using card CHM E1–17A1	
A 18 B .42 C 38 B .44 C 46 B .52 C 60 B .5 C 90 B .56 C 100 B .66 C D →	0.37 (a)
D DSP • 4 →	0.0026 (b)
D →	0.8664 (r^2)
70 E →	0.5459 (C_D)

Example 2:

A chemical reaction yields the following concentrations of species A as a function of time.

t	A
0	0.60
1	0.47
2	0.38
3	0.30
4	0.25

Run an exponential regression on the data. Determine a, b, and r^2 and find a projected value of A at t = 7.0.

Keystrokes	**See Displayed**
Using card CHM E1–17A2	
[A] 0 [B] .6 [C] 1 [B] .47 [C] 2 [B] .38 [C] 3 [B] .3 [C] 4 [B] .25 [C] [D] →	0.59 (a)
[D] →	–0.22 (b)
[D] →	1.00 (r^2)
7 [E] →	0.13

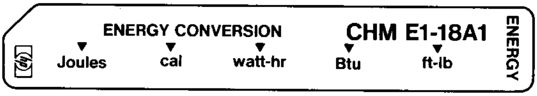
Example 3:

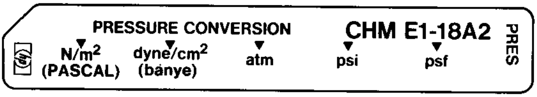
Pressure-volume data for a compression process is shown below. Run a power curve fit to determine the polytropic constant n. What is the pressure when v is 15?

V	P
10	210
30	40
50	12
70	9
90	6.8

Keystrokes	See Displayed
Using card CHM E1–17A3	
A 10 B 210 C 30 B 40 C 50 B 12 C 70 B	
9 C 90 B 6.8 C D →	8599.81 (a)
D →	–1.62 (b or –n)
D →	0.99 (r^2)
15 E →	108.35

UNIT CONVERSIONS





These cards convert interchangeably between commonly used units of pressure and energy.

Equations:

Energy conversion

1 calorie (thermochemical) = 4.184 joules*

1 watt-hour = 3600 joules*

1 Btu = 1055 joules

1 foot pound = 1.355818 joules

Pressure conversion

1 dyne/centimeter^2 = 1 barye = 0.1 newton/meter^2 = 0.1 Pascal*

1 atmosphere = 101325 newton/meter^2 *

1 pound/inch^2 = 6894.7572 newton/meter^2

1 pound/foot^2 = 47.88 newton/meter^2

*by definition

Remarks:

Zero is an invalid input.

Reference:

Mechtly, *The International System of Units, Physical Constants and Conversion Factors, Revised,* NASA SP-7012, 1969.

ENERGY CONVERSION

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter *Energy Conversions,*		[ ] [ ]	
	CHM E1-18A1		[ ] [ ]	
2	Input one of the following:		[ ] [ ]	
	Energy in joules	joules	[A] [ ]	0.00
	Energy in calories	cal	[B] [ ]	0.00
	Energy in watt-hours	watt-hr	[C] [ ]	0.00
	Energy in British thermal		[ ] [ ]	
	units	Btu	[D] [ ]	0.00
	Energy in foot-pounds	ft-lb	[E] [ ]	0.00
3	Convert to one of the following:		[ ] [ ]	
	Energy in joules	0.00	[A] [ ]	joules
	Energy in calories	0.00	[B] [ ]	cal
	Energy in watt-hours	0.00	[C] [ ]	watt-hr
	Energy in British thermal		[ ] [ ]	
	units	0.00	[D] [ ]	Btu
	Energy in foot-pounds	0.00	[E] [ ]	ft-lb
4	For another conversion of the		[ ] [ ]	
	same input, key zero and go to		[ ] [ ]	
	step 3.		[ ] [ ]	
5	For a new case go to step 2		[ ] [ ]	

PRESSURE CONVERSION

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter *Pressure Conversions,*		[ ] [ ]	
	CHM E1-18A2		[ ] [ ]	
2	Input one of the following:		[ ] [ ]	
	Pressure in newtons per		[ ] [ ]	
	square meter	N/m^2	[A] [ ]	0.00
	Pressure in dynes per square		[ ] [ ]	
	centimeter	$dyne/cm^2$	[B] [ ]	0.00
	Pressure in atmospheres	atm	[C] [ ]	0.00
	Pressure in pounds per		[ ] [ ]	
	square inch	psi	[D] [ ]	0.00
	Pressure in pounds per		[ ] [ ]	
	square foot	psf	[E] [ ]	0.00
3	Convert to one of the following:		[ ] [ ]	
	Pressure in Newtons per		[ ] [ ]	
	square meter	0.00	[A] [ ]	N/m^2
	Pressure in dynes per square		[ ] [ ]	
	centimeter	0.00	[B] [ ]	$dyne/cm^2$
	Pressure in atmospheres	0.00	[C] [ ]	atm
	Pressure in pounds per		[ ] [ ]	
	square inch	0.00	[D] [ ]	psi
	Pressure in pounds per		[ ] [ ]	
	square foot	0.00	[E] [ ]	psf
4	For another conversion of the		[ ] [ ]	
	same input, key zero and go to		[ ] [ ]	
	step 3.		[ ] [ ]	
5	For a new case go to step 2.		[ ] [ ]	

Example 1:

Convert 1.5 atmospheres to psi.

Keystrokes	**See Displayed**
Using card CHM E1–18A2	
1.5 C D ⟶	22.04 psi
Convert 4000 psf to nt/m^2 and atmospheres.	
4000 E A ⟶	191520.00 (nt/m^2)
0 C ⟶	1.89 atm

Example 2:

Convert 12.7 joules to ft-lb and watt-hr.

Keystokes	**See Displayed**
Using card CHM1–18A1	
12.7 A E ⟶	9.37 ft-lbs
0 C DSP 2 ⟶	3.53×10^{-3} (watt-hr)

REGISTER ALLOCATION

CARD	#s	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9
Ideal	CHM E1–1A	P	V	R	T			n		Used
Kwng-P	CHM E1–2A1	P	v	R	T	a	b	Used		
Kwng-T	CHM E1–2A2	P	v	R	T	a	b		RT/(v – b)	Used
Kwng-v	CHM E1–2A3	P	v	R	T	a	b	Used	RT/(v – b)	Used
Poly	CHM E1–3A		n	n – 1	1/(n – 1)	P_2/P_1				Used
Flow I	CHM E1–4A1	M^2	k	k – 1	1/(k – 1)					Used
Flow II	CHM E1–4A2	M^2	k	k – 1	1/(k – 1)		A/A^*	(k – 1)/(k + 1)	Used	Used
Shock	CHM E1–5A1	M_x^2	k	k – 1	1/(k – 1)	M_y^2	Ty/Tx	Py/Px	2/(k – 1)	Used
Re	CHM E1–6A1	Re			ρ	μ		v	x	Used
Nu, Bi	CHM E1–6A2		Nu(Bi)			$h(k_c)$	$k(D_{ab})$		x	Used
St, Le	CHM E1–6A3		St(Le)		ρ	$h(k_c)$	c_p	$v(D_{ab})$		Used
Pr	CHM E1–6A4			Pr	c_p		k	μ		Used
Sc	CHM E1–6A5			Sc	ρ		D_{ab}	μ		Used
Fan	CHM E1–7A1	Re	1.737			$1/\sqrt{f}$, f	D_{eq}/ϵ			Used
Cond	CHM E1–7A2	Re	v	L/D_{eq}	$\Delta P/\rho$	f		v	K_T	Used
Eng-E	CHM E1–8A1				ρ	778.16	g	144	ΣE	Used
Eng-Si	CHM E1–8A2				ρ		g		ΣE	Used
von	CHM E1–9A		$St(k_c/v)$	Pr(Sc)	Used	f	f/2		Used	Used
HE-*E*	CHM E1–10A1	T_{hin}	T_{cin}	C_c	C_h	*E*	q			Used
HE-q	CHM E1–10A2	T_{hin}	T_{cin}	C_c	C_h	*E*	q	C_{min}		Used
HE CNT	CHM E1–10A3			C_c	C_h	*E*		C_{min}	AU	Used

HE par	CHM E1–10A4			C_c	C_h	E		C_{min}	AU	Used
HE P-C	CHM E1–10A5			C_c	C_h	E	$\sqrt{1+\left(\frac{C_{min}}{C_{max}}\right)^2}$	$1+\frac{C_{min}}{C_{max}}$	AU	Used
HE CRS	CHM E1–10A6			C_c	C_h	E	C_{min}	C_{max}/C_{min}	AU	Used
Cyl & Wl	CHM E1–11A				U		1 or π	Used	ΣR	
Fin	CHM E1–12A	t/2	k	h	L	η_f	N_{ave}	x		Used
Gr	CHM E1–13A1	Gr				ΔT	k	$g\beta\rho^2/\mu^2$	x	Used
Plate V	CHM E1–13A2	Gr	Nu	Pr		ΔT	k		x	Used
Plate H	CHM E1–13A3	Gr	Nu	Pr		ΔT	k		x	Used
Rad Cn	CHM E1–14A1	c_1	c_2	c_3	σ					
BB Rad	CHM E1–14A2	c_1	c_2	c_3	σ	T	λ			
Spec	CHM E1–14A3	c_1	c_2	c_3	σ	T	λ	sum	kc_2/T	Used
Wall	CHM E1–15A	Partial sum	$2a^2$	2n + 1	$T_o(C_o)$	$T_s(C_s)$	α	t	x	Used
Hyd I	CHM E1–16A1	C	H	O	S	air	O_2	prod	AF(mole)	N
Hyd II	CHM E1–16A2	C	H	O	S	air	O_2	prod	AF(mole)	N
y = a + bx	CHM E1–17A1	x_i,b	y_i,a	Σx	Σx^2	Σy	Σy^2	Σxy	–n	
$y = ae^{bx}$	CHM E1–17A2	x_i,b	y_i,a	Σx	Σx^2	$\Sigma \ln y$	$\Sigma (\ln y)^2$	$\Sigma x \ln y$	–n	
$y = ax^b$	CHM E1–17A3	x_i,b	y_i,a	$\Sigma \ln x$	$\Sigma (\ln x)^2$	$\Sigma \ln y$	$\Sigma (\ln y)^2$	$\Sigma(\ln x)(\ln y)$	–n	
Energy	CHM E1–18A1								joule	Used
Press	CHM E1–18A2								Nt/m^2	Used

Program Listings

IDEAL GAS EQUATION OF STATE

KEYS	CODE
LBL	23
A	11
STO 1	33 01
0	00
g x≠y	35 21
0	00
RTN	24
RCL 7	34 07
RCL 3	34 03
RCL 4	34 04
x	71
x	71
RCL 2	34 02
÷	81
STO 1	33 01
RTN	24
LBL	23
B	12
STO 2	33 02
0	00
g x≠y	35 21
0	00
RTN	24
RCL 7	34 07
RCL 3	34 03
RCL 4	34 04
x	71
x	71
RCL 1	34 01
÷	81
STO 2	33 02
RTN	24
LBL	23
C	13
STO 7	33 07

KEYS	CODE
0	00
g x≠y	35 21
0	00
RTN	24
RCL 1	34 01
RCL 2	34 02
x	71
RCL 3	34 03
RCL 4	34 04
x	71
÷	81
STO 7	33 07
RTN	24
LBL	23
D	14
STO 3	33 03
0	00
g x≠y	35 21
0	00
RTN	24
RCL 1	34 01
RCL 2	34 02
x	71
RCL 7	34 07
RCL 4	34 04
x	71
÷	81
STO 3	33 03
RTN	24
LBL	23
E	15
STO 4	33 04
0	00
g x≠y	35 21
0	00

KEYS	CODE
RTN	24
RCL 1	34 01
RCL 2	34 02
x	71
RCL 7	34 07
RCL 3	34 03
x	71
÷	81
STO 4	33 04
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	P	R_4	T	R_7	n
R_2	V	R_5		R_8	
R_3	R	R_6		R_9	Used

REDLICH-KWONG, PRESSURE

KEYS	CODE
LBL	23
A	11
STO 3	33 03
g x⇄y	35 07
STO 5	33 05
x	71
STO 7	33 07
g x⇄y	35 07
÷	81
•	83
0	00
8	08
6	06
7	07
x	71
STO 6	33 06
4	04
•	83
9	09
3	03
4	04
x	71
RCL 7	34 07
x	71
RCL 5	34 05
f	31
$\sqrt{x}$	09
x	71
STO 5	33 05
RCL 3	34 03
RTN	24
LBL	23
B	12
STO 4	33 04
RTN	24

KEYS	CODE
LBL	23
C	13
STO 2	33 02
RTN	24
LBL	23
D	14
RCL 3	34 03
RCL 4	34 04
x	71
RCL 2	34 02
RCL 6	34 06
—	51
÷	81
RCL 5	34 05
RCL 4	34 04
f	31
$\sqrt{x}$	09
÷	81
RCL 2	34 02
÷	81
g LST X	35 00
RCL 6	34 06
+	61
÷	81
—	51
STO 1	33 01
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

KEYS	CODE
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	P	R_4	T	R_7	Used
R_2	v	R_5	a	R_8	
R_3	R	R_6	b	R_9	

REDLICH-KWONG, TEMPERATURE

KEYS	CODE
LBL	23
A	11
STO 3	33 03
g x⇄y	35 07
STO 5	33 05
x	71
STO 7	33 07
g x⇄y	35 07
÷	81
•	83
0	00
8	08
6	06
7	07
x	71
STO 6	33 06
4	04
•	83
9	09
3	03
4	04
x	71
RCL 7	34 07
x	71
RCL 5	34 05
f	31
√x	09
x	71
STO 5	33 05
RCL 3	34 03
RTN	24
LBL	23
B	12
STO 2	33 02
RTN	24

KEYS	CODE
LBL	23
C	13
STO 1	33 01
RTN	24
LBL	23
D	14
RCL 1	34 01
RCL 2	34 02
x	71
RCL 3	34 03
÷	81
STO 4	33 04
LBL	23
1	01
RCL 3	34 03
RCL 4	34 04
x	71
RCL 2	34 02
RCL 6	34 06
–	51
÷	81
STO 8	33 08
RCL 1	34 01
–	51
RCL 5	34 05
RCL 4	34 04
f	31
√x	09
÷	81
RCL 2	34 02
÷	81
g LST X	35 00
RCL 6	34 06
+	61
÷	81

KEYS	CODE
–	51
g LST X	35 00
2	02
÷	81
RCL 8	34 08
+	61
RCL 4	34 04
÷	81
÷	81
STO	33
–	51
4	04
RCL 4	34 04
÷	81
g	35
ABS	06
EEX	43
CHS	42
4	04
g x≤y	35 22
GTO	22
1	01
RCL 4	34 04
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1 P	R_4 T	R_7
R_2 v	R_5 a	R_8 RT/(v−b)
R_3 R	R_6 b	R_9 Used

REDLICH-KWONG, VOLUME

KEYS	CODE
STO 3	33 03
g x⇄y	35 07
STO 5	33 05
x	71
STO 7	33 07
g x⇄y	35 07
÷	81
•	83
0	00
8	08
6	06
7	07
x	71
STO 6	33 06
4	04
•	83
9	09
3	03
4	04
x	71
RCL 7	34 07
x	71
RCL 5	34 05
f	31
$\sqrt{x}$	09
x	71
STO 5	33 05
RCL 3	34 03
RTN	24
LBL	23
E	15
RCL 2	34 02
÷	81
g LST X	35 00
RCL 6	34 06

KEYS	CODE
+	61
÷	81
RTN	24
LBL	23
B	12
STO 4	33 04
g x⇄y	35 07
STO 1	33 01
RTN	24
LBL	23
C	13
RCL 3	34 03
RCL 4	34 04
x	71
RCL 1	34 01
÷	81
STO 2	33 02
LBL	23
1	01
RCL 3	34 03
RCL 4	34 04
x	71
RCL 2	34 02
RCL 6	34 06
—	51
STO 7	33 07
÷	81
STO 8	33 08
RCL 1	34 01
—	51
RCL 5	34 05
RCL 4	34 04
f	31
$\sqrt{x}$	09
÷	81

KEYS	CODE
E	15
—	51
g LST X	35 00
E	15
RCL 2	34 02
↑	41
+	61
RCL 6	34 06
+	61
x	71
RCL 8	34 08
RCL 7	34 07
÷	81
—	51
÷	81
STO	33
—	51
2	02
RCL 2	34 02
÷	81
g	35
ABS	06
EEX	43
CHS	42
4	04
g x≤y	35 22
GTO	22
1	01
RCL 2	34 02
RTN	24

R_1	P	R_4	T	R_7	Used
R_2	v	R_5	a	R_8	RT/(v−b)
R_3	R	R_6	b	R_9	Used

POLYTROPIC PROCESS

KEYS	CODE
LBL	23
A	11
STO 2	33 02
1	01
−	51
STO 3	33 03
g	35
$^1/x$	04
STO 4	33 04
RCL 2	34 02
RTN	24
LBL	23
B	12
0	00
g x=y	35 23
RCL 5	34 05
RTN	24
g R↓	35 08
STO 5	33 05
0	00
RTN	24
LBL	23
C	13
0	00
g x=y	35 23
GTO	22
1	01
g R↓	35 08
RCL 2	34 02
CHS	42
g	35
y^x	05
STO 5	33 05
0	00
RTN	24

KEYS	CODE
LBL	23
1	01
RCL 5	34 05
RCL 2	34 02
CHS	42
g	35
$^1/x$	04
g	35
y^x	05
RTN	24
LBL	23
D	14
0	00
g x=y	35 23
GTO	22
2	02
g R↓	35 08
RCL 2	34 02
RCL 4	34 04
x	71
g	35
y^x	05
STO 5	33 05
0	00
RTN	24
LBL	23
2	02
RCL 5	34 05
RCL 3	34 03
RCL 2	34 02
÷	81
g	35
y^x	05
RTN	24
LBL	23

KEYS	CODE
E	15
0	00
g x=y	35 23
GTO	22
3	03
g R↓	35 08
RCL 2	34 02
g	35
y^x	05
STO 5	33 05
0	00
RTN	24
LBL	23
3	03
RCL 5	34 05
RCL 2	34 02
g	35
$^1/x$	04
g	35
y^x	05
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1		R_4	$1/(n-1)$	R_7	
R_2	n	R_5	P_2/P_1	R_8	
R_3	$n-1$	R_6		R_9	Used

ISENTROPIC FLOW I

KEYS	CODE
STO 2	33 02
1	01
–	51
STO 3	33 03
g	35
1/x	04
STO 4	33 04
RCL 2	34 02
RTN	24
LBL	23
B	12
↑	41
x	71
0	00
g x=y	35 23
GTO	22
1	01
g R↓	35 08
STO 1	33 01
0	00
RTN	24
LBL	23
1	01
RCL 1	34 01
f	31
√x	09
RTN	24
LBL	23
C	13
0	00
g x=y	35 23
GTO	22
1	01
CLX	44
2	02

KEYS	CODE
g x⇄y	35 07
÷	81
2	02
–	51
RCL 3	34 03
÷	81
STO 1	33 01
0	00
RTN	24
LBL	23
1	01
2	02
RCL 1	34 01
RCL 3	34 03
x	71
2	02
+	61
÷	81
RTN	24
LBL	23
D	14
0	00
g x=y	35 23
GTO	22
1	01
CLX	44
RCL 3	34 03
RCL 2	34 02
÷	81
g	35
y^x	05
GTO	22
C	13
LBL	23
1	01

KEYS	CODE
C	13
RCL 2	34 02
RCL 3	34 03
÷	81
g	35
y^x	05
RTN	24
LBL	23
E	15
0	00
g x=y	35 23
GTO	22
1	01
CLX	44
RCL 3	34 03
g	35
y^x	05
GTO	22
C	13
LBL	23
1	01
C	13
RCL 4	34 04
g	35
y^x	05
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	M^2	R_4	$1/(k-1)$	R_7	
R_2	k	R_5		R_8	
R_3	$k-1$	R_6		R_9	Used

ISENTROPIC FLOW II

KEYS	CODE
STO 2	33 02
1	01
–	51
STO 3	33 03
g	35
$^1/x$	04
STO 4	33 04
RCL 2	34 02
RTN	24
LBL	23
B	12
3	03
CHS	42
g $x \rightleftarrows y$	35 07
0	00
g $x=y$	35 23
GTO	22
D	14
LBL	23
1	01
g R↓	35 08
↑	41
STO 6	33 06
f^{-1}	32
INT	83
f	31
$\sqrt{x}$	09
+	61
g $x \rightleftarrows y$	35 07
g	35
y^x	05
STO 1	33 01
LBL	23
2	02
RCL 6	34 06

KEYS	CODE
D	14
÷	81
1	01
–	51
•	83
5	05
RCL 8	34 08
÷	81
•	83
5	05
RCL 1	34 01
÷	81
–	51
÷	81
STO	33
+	61
1	01
RCL 1	34 01
÷	81
g	35
ABS	06
EEX	43
CHS	42
4	04
g $x \leq y$	35 22
GTO	22
2	02
0	00
RTN	24
LBL	23
C	13
3	03
g $x \rightleftarrows y$	35 07
0	00
g $x \neq y$	35 21

KEYS	CODE
GTO	22
1	01
LBL	23
D	14
2	02
RCL 2	34 02
1	01
+	61
÷	81
RCL 3	34 03
g LST X	35 00
÷	81
STO 7	33 07
RCL 1	34 01
x	71
+	61
STO 8	33 08
RCL 7	34 07
2	02
x	71
g	35
$^1/x$	04
g	35
y^x	05
RCL 1	34 01
f	31
$\sqrt{x}$	09
÷	81
RTN	24
g NOP	35 01

R_1	M^2	R_4	$1/(k-1)$	R_7	$(k-1)/(k+1)$
R_2	k	R_5		R_8	Used
R_3	$k-1$	R_6	A/A*	R_9	Used

ONE DIMENSIONAL NORMAL SHOCKS

KEYS	CODE
STO 2	33 02
1	01
–	51
STO 3	33 03
g	35
$1/x$	04
STO 4	33 04
RCL 2	34 02
RTN	24
LBL	23
B	12
0	00
g x≠y	35 21
GTO	22
2	02
RCL 1	34 01
f	31
$\sqrt{x}$	09
RTN	24
LBL	23
2	02
g R↓	35 08
↑	41
x	71
STO 1	33 01
2	02
RCL 3	34 03
÷	81
STO 8	33 08
+	61
g LST X	35 00
RCL 2	34 02
x	71
RCL 1	34 01
x	71

KEYS	CODE
1	01
–	51
÷	81
RCL 1	34 01
g x>y	35 24
g x⇄y	35 07
g NOP	35 01
STO 5	33 05
g x⇄y	35 07
STO 1	33 01
RCL 8	34 08
÷	81
1	01
+	61
RCL 5	34 05
RCL 8	34 08
÷	81
1	01
+	61
÷	81
STO 6	33 06
RCL 1	34 01
x	71
RCL 5	34 05
÷	81
f	31
$\sqrt{x}$	09
STO 7	33 07
0	00
RTN	24
LBL	23
C	13
0	00
g x≠y	35 21
GTO	22

KEYS	CODE
2	02
RCL 5	34 05
f	31
$\sqrt{x}$	09
RTN	24
LBL	23
D	14
RCL 6	34 06
RTN	24
LBL	23
D	14
RCL 7	34 07
RCL 6	34 06
÷	81
RTN	24
LBL	23
E	15
RCL 7	34 07
RTN	24
LBL	23
E	15
RCL 7	34 07
RCL 6	34 06
RCL 2	34 02
RCL 3	34 03
÷	81
g	35
y^x	05
÷	81
RTN	24

R_1	M_x^2	R_4	$1/(k-1)$	R_7	Py/Px
R_2	k	R_5	M_y^2	R_8	$2/k - 1$
R_3	$k - 1$	R_6	Ty/Tx	R_9	Used

REYNOLDS NUMBER

KEYS	CODE
LBL	23
A	11
STO 8	33 08
0	00
g x≠y	35 21
0	00
RTN	24
RCL 1	34 01
RCL 5	34 05
x	71
RCL 7	34 07
÷	81
RCL 4	34 04
÷	81
STO 8	33 08
RTN	24
LBL	23
B	12
STO 7	33 07
0	00
g x≠y	35 21
0	00
RTN	24
RCL 1	34 01
RCL 8	34 08
÷	81
RCL 4	34 04
÷	81
RCL 5	34 05
x	71
STO 7	33 07
RTN	24
LBL	23
C	13
STO 4	33 04

KEYS	CODE
0	00
g x≠y	35 21
0	00
RTN	24
RCL 1	34 01
RCL 8	34 08
÷	81
RCL 7	34 07
÷	81
RCL 5	34 05
x	71
STO 4	33 04
RTN	24
LBL	23
D	14
STO 5	33 05
0	00
g x≠y	35 21
0	00
RTN	24
RCL 8	34 08
RCL 7	34 07
x	71
RCL 4	34 04
x	71
RCL 1	34 01
÷	81
STO 5	33 05
RTN	24
LBL	23
E	15
STO 1	33 01
0	00
g x≠y	35 21
0	00

KEYS	CODE
RTN	24
RCL 8	34 08
RCL 7	34 07
x	71
RCL 4	34 04
x	71
RCL 5	34 05
÷	81
STO 1	33 01
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1 Re	R_4 ρ	R_7 v
R_2	R_5 μ	R_8 x
R_3	R_6	R_9 Used

NUSSELT AND BIOT NUMBERS

KEYS	CODE
LBL	23
A	11
STO 5	33 05
0	00
g x≠y	35 21
0	00
RTN	24
RCL 2	34 02
RCL 6	34 06
x	71
RCL 8	34 08
÷	81
STO 5	33 05
RTN	24
LBL	23
B	12
STO 8	33 08
0	00
g x≠y	35 21
0	00
RTN	24
RCL 2	34 02
RCL 5	34 05
÷	81
RCL 6	34 06
x	71
STO 8	33 08
RTN	24
LBL	23
C	13
STO 6	33 06
0	00
g x≠y	35 21
0	00
RTN	24

KEYS	CODE
RCL 5	34 05
RCL 8	34 08
x	71
RCL 2	34 02
÷	81
STO 6	33 06
RTN	24
LBL	23
D	14
STO 2	33 02
0	00
g x≠y	35 21
0	00
RTN	24
RCL 5	34 05
RCL 8	34 08
x	71
RCL 6	34 06
÷	81
STO 2	33 02
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

KEYS	CODE
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1		R_4		R_7	
R_2	Nu(Bi)	R_5	h(k_c)	R_8	x
R_3		R_6	k (D_{ab})	R_9	Used

STANTON AND LEWIS NUMBERS

KEYS	CODE
LBL	23
A	11
STO 5	33 05
0	00
g x≠y	35 21
0	00
RTN	24
RCL 2	34 02
RCL 4	34 04
x	71
RCL 7	34 07
x	71
RCL 6	34 06
x	71
STO 5	33 05
RTN	24
LBL	23
B	12
STO 4	33 04
0	00
g x≠y	35 21
0	00
RTN	24
RCL 5	34 05
RCL 2	34 02
÷	81
RCL 7	34 07
÷	81
RCL 6	34 06
÷	81
STO 4	33 04
RTN	24
LBL	23
C	13
STO 7	33 07

KEYS	CODE
0	00
g≠y	35 21
0	00
RTN	24
RCL 5	34 05
RCL 2	34 02
÷	81
RCL 4	34 04
÷	81
RCL 6	34 06
÷	81
STO 7	33 07
RTN	24
LBL	23
D	14
STO 6	33 06
0	00
g x≠y	35 21
0	00
RTN	24
RCL 5	34 05
RCL 2	34 02
÷	81
RCL 4	34 04
÷	81
RCL 7	34 07
÷	81
STO 6	33 06
RTN	24
LBL	23
E	15
STO 2	33 02
0	00
g x≠y	35 21
0	00

KEYS	CODE
RTN	24
RCL 5	34 05
RCL 4	34 04
RCL 7	34 07
RCL 6	34 06
x	71
x	71
÷	81
STO 2	33 02
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1		R_4	ρ	R_7	$v(D_{ab})$
R_2	St(Le)	R_5	$h(k_c)$	R_8	
R_3		R_6	c_p	R_9	Used

PRANDTL NUMBER

KEYS	CODE
LBL	23
A	11
STO 7	33 07
0	00
g x≠y	35 21
0	00
RTN	24
RCL 3	34 03
RCL 6	34 06
x	71
RCL 4	34 04
÷	81
STO 7	33 07
RTN	24
LBL	23
B	12
STO 4	33 04
0	00
g x≠y	35 21
0	00
RTN	24
RCL 3	34 03
RCL 7	34 07
÷	81
RCL 6	34 06
x	71
STO 4	33 04
RTN	24
LBL	23
C	13
STO 6	33 06
0	00
g x≠y	35 21
0	00
RTN	24

KEYS	CODE
RCL 7	34 07
RCL 4	34 04
x	71
RCL 3	34 03
÷	81
STO 6	33 06
RTN	24
LBL	23
D	14
STO 3	33 03
0	00
g x≠y	35 21
0	00
RTN	24
RCL 7	34 07
RCL 4	34 04
x	71
RCL 6	34 06
÷	81
STO 3	33 03
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

KEYS	CODE
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	R_4 c_p	R_7 μ
R_2	R_5	R_8
R_3 Pr	R_6 k	R_9 Used

SCHMIDT NUMBER

KEYS	CODE
LBL	23
A	11
STO 7	33 07
0	00
g x≠y	35 21
0	00
RTN	24
RCL 3	34 03
RCL 4	34 04
x	71
RCL 6	34 06
x	71
STO 7	33 07
RTN	24
LBL	23
B	12
STO 4	33 04
0	00
g x≠y	35 21
0	00
RTN	24
RCL 7	34 07
RCL 6	34 06
÷	81
RCL 3	34 03
÷	81
STO 4	33 04
RTN	24
LBL	23
C	13
STO 6	33 06
0	00
g x≠y	35 21
0	00
RTN	24

KEYS	CODE
RCL 7	34 07
RCL 4	34 04
÷	81
RCL 3	34 03
÷	81
STO 6	33 06
RTN	24
LBL	23
D	14
STO 3	33 03
0	00
g x≠y	35 21
0	00
RTN	24
RCL 7	34 07
RCL 6	34 06
÷	81
RCL 4	34 04
÷	81
STO 3	33 03
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

KEYS	CODE
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	R_4 ρ	R_7 μ
R_2	R_5	R_8
R_3 Sc	R_6 D_{ab}	R_9 Used

FANNING FRICTION FACTOR

KEYS	CODE
STO 1	33 01
RTN	24
LBL	23
B	12
STO 6	33 06
RTN	24
LBL	23
C	13
1	01
6	06
RCL 1	34 01
2	02
3	03
0	00
0	00
g x≤y	35 22
GTO	22
1	01
g R↓	35 08
÷	81
STO 5	33 05
RTN	24
LBL	23
1	01
RCL 6	34 06
f	31
LN	07
1	01
•	83
7	07
3	03
7	07
STO 2	33 02
x	71
2	02

KEYS	CODE
•	83
2	02
8	08
+	61
STO 5	33 05
↑	41
↑	41
↑	41
LBL	23
2	02
+	61
CLX	44
RCL 5	34 05
–	51
4	04
•	83
6	06
7	07
RCL 6	34 06
x	71
RCL 1	34 01
÷	81
RCL 5	34 05
x	71
1	01
+	61
STO	33
9	09
f	31
LN	07
RCL 2	34 02
x	71
–	51
RCL	34
9	09

KEYS	CODE
g	35
$^1/_x$	04
CHS	42
1	01
+	61
RCL 2	34 02
x	71
RCL 5	34 05
÷	81
1	01
+	61
÷	81
STO	33
+	61
5	05
g	35
ABS	06
EEX	43
CHS	42
6	06
g x≤y	35 22
GTO	22
2	02
RCL 5	34 05
↑	41
x	71
g	35
$^1/_x$	04
STO 5	33 05
RTN	24

R_1	Re	R_4		R_7	
R_2	1.737	R_5	$1/\sqrt{f}$, f	R_8	
R_3		R_6	D_{eq}/ϵ	R_9	Used

CONDUIT FLOW

KEYS	CODE
LBL	23
A	11
4	04
÷	81
STO 8	33 08
0	00
RTN	24
LBL	23
B	12
STO 4	33 04
0	00
g x≠y	35 21
0	00
RTN	24
RCL 2	34 02
↑	41
x	71
↑	41
+	61
RCL 5	34 05
RCL 3	34 03
x	71
RCL 8	34 08
+	61
x	71
STO 4	33 04
RTN	24
LBL	23
C	13
STO 3	33 03
0	00
g x≠y	35 21
0	00
RTN	24
RCL 4	34 04

KEYS	CODE
RCL 2	34 02
↑	41
x	71
↑	41
+	61
÷	81
RCL 8	34 08
–	51
RCL 5	34 05
÷	81
STO 3	33 03
RTN	24
LBL	23
D	14
STO 5	33 05
0	00
g x≠y	35 21
0	00
RTN	24
RCL 4	34 04
RCL 2	34 02
↑	41
x	71
↑	41
+	61
÷	81
RCL 8	34 08
–	51
RCL 3	34 03
÷	81
STO 5	33 05
RTN	24
LBL	23
E	15
STO 2	33 02

KEYS	CODE
0	00
g x≠y	35 21
0	00
RTN	24
RCL 4	34 04
RCL 5	34 05
RCL 3	34 03
x	71
RCL 8	34 08
+	61
↑	41
+	61
÷	81
f	31
$\sqrt{x}$	09
STO 2	33 02
RCL 7	34 07
0	00
g x≠y	35 21
g R↓	35 08
÷	81
STO	33
x	71
1	01
RCL 2	34 02
STO 7	33 07
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	Re	R_4	$\Delta P/\rho$	R_7	v
R_2	v	R_5	f	R_8	K_T
R_3	L/D_{eq}	R_6		R_9	Used

CONSERVATION OF ENERGY-ENGLISH

KEYS	CODE
STO 4	33 04
CLX	44
STO 8	33 08
7	07
7	07
8	08
•	83
1	01
6	06
STO 5	33 05
3	03
2	02
•	83
1	01
7	07
STO 6	33 06
RTN	24
LBL	23
B	12
↑	41
g	35
ABS	06
x	71
2	02
÷	81
0	00
g x≠y	35 21
GTO	22
1	01
RCL 8	34 08
2	02
x	71
f	31
√x	09
RTN	24

KEYS	CODE
LBL	23
C	13
↑	41
RCL 6	34 06
x	71
0	00
g x≠y	35 21
GTO	22
1	01
RCL 8	34 08
RCL 6	34 06
÷	81
RTN	24
LBL	23
D	14
↑	41
1	01
4	04
4	04
STO 7	33 07
x	71
RCL 4	34 04
÷	81
RCL 6	34 06
x	71
0	00
g x≠y	35 21
GTO	22
1	01
RCL 8	34 08
RCL 7	34 07
÷	81
RCL 4	34 04
x	71
RCL 6	34 06

KEYS	CODE
÷	81
RTN	24
LBL	23
E	15
↑	41
RCL 5	34 05
x	71
RCL 6	34 06
x	71
0	00
g x≠y	35 21
GTO	22
1	01
RCL 8	34 08
RCL 5	34 05
÷	81
RCL 6	34 06
÷	81
RTN	24
LBL	23
1	01
g R↓	35 08
STO	33
+	61
8	08
0	00
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	R_4 ρ	R_7 144
R_2	R_5 778.16	R_8 ΣE
R_3	R_6 g	R_9 Used

CONSERVATION OF ENERGY-SI

KEYS	CODE
LBL	23
A	11
STO 4	33 04
CLX	44
STO 8	33 08
9	09
•	83
8	08
0	00
6	06
6	06
5	05
STO 6	33 06
RTN	24
LBL	23
B	12
↑	41
g	35
ABS	06
x	71
2	02
÷	81
0	00
g x≠y	35 21
GTO	22
1	01
RCL 8	34 08
2	02
x	71
f	31
√x	09
RTN	24
LBL	23
C	13
↑	41

KEYS	CODE
RCL 6	34 06
x	71
0	00
g x≠y	35 21
GTO	22
1	01
RCL 8	34 08
RCL 6	34 06
÷	81
RTN	24
LBL	23
D	14
↑	41
RCL 4	34 04
÷	81
0	00
g x≠y	35 21
GTO	22
1	01
RCL 8	34 08
RCL 4	34 04
x	71
RTN	24
LBL	23
E	15
↑	41
0	00
g x=y	35 23
RCL 8	34 08
RTN	24
LBL	23
1	01
g R↓	35 08
STO	33
+	61

KEYS	CODE
8	08
0	00
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	R_4 ρ	R_7
R_2	R_5	R_8 ΣE
R_3	R_6 g	R_9 Used

von KÁRMÁN ANALOGY

KEYS	CODE
STO 3	33 03
0	00
RTN	24
LBL	23
B	12
STO 2	33 02
0	00
g x≠y	35 21
0	00
RTN	24
RCL 5	34 05
2	02
÷	81
STO 6	33 06
D	14
÷	81
STO 2	33 02
RTN	24
LBL	23
C	13
STO 5	33 05
0	00
g x≠y	35 21
0	00
RTN	24
RCL 2	34 02
RCL 3	34 03
2	02
↑	41
3	03
÷	81
g	35
y^x	05
x	71
STO 6	33 06

KEYS	CODE
LBL	23
1	01
D	14
RCL 2	34 02
x	71
STO 4	33 04
RCL 6	34 06
g x⇄y	35 07
−	51
RCL 4	34 04
RCL 2	34 02
−	51
RCL 6	34 06
÷	81
2	02
÷	81
1	01
−	51
÷	81
+	61
STO 6	33 06
−	51
g	35
ABS	06
EEX	43
CHS	42
8	08
g x≤y	35 22
GTO	22
1	01
RCL 6	34 06
2	02
x	71
STO 5	33 05
R/S	84

KEYS	CODE
LBL	23
D	14
RCL 6	34 06
RCL 3	34 03
1	01
−	51
↑	41
↑	41
5	05
x	71
6	06
÷	81
1	01
+	61
f	31
ln	07
+	61
STO 8	33 08
g x⇄y	35 07
f	31
$\sqrt{x}$	09
x	71
5	05
x	71
1	01
+	61
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1		R_4	Used	R_7	
R_2	$St(k_c/v)$	R_5	f	R_8	Used
R_3	Pr(Sc)	R_6	f/2	R_9	Used

HEAT EXCHANGER EFFECTIVENESS

KEYS	CODE
LBL	23
A	11
x	71
STO 3	33 03
g x⇄y	35 07
STO 2	33 02
RTN	24
LBL	23
B	12
x	71
STO 4	33 04
g x⇄y	35 07
STO 1	33 01
RTN	24
LBL	23
C	13
RCL 2	34 02
−	51
RCL 3	34 03
x	71
GTO	22
E	15
LBL	23
D	14
RCL 1	34 01
g x⇄y	35 07
−	51
RCL 4	34 04
x	71
LBL	23
E	15
STO 6	33 06
RCL 3	34 03
RCL 4	34 04
g x>y	35 24

KEYS	CODE
g x⇄y	35 07
g NOP	35 01
RCL 1	34 01
RCL 2	34 02
−	51
x	71
RCL 6	34 06
g x⇄y	35 07
÷	81
STO 5	33 05
RCL 1	34 01
RCL 6	34 06
RCL 4	34 04
÷	81
−	51
RCL 6	34 06
RCL 3	34 03
÷	81
RCL 2	34 02
+	61
RCL 6	34 06
RCL 5	34 05
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

KEYS	CODE
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	T_{hin}	R_4	C_h	R_7	
R_2	T_{cin}	R_5	E	R_8	
R_3	C_c	R_6	q	R_9	Used

HEAT EXCHANGER HEAT TRANSFER

KEYS	CODE
LBL	23
A	11
STO 1	33 01
g x⇄y	35 07
STO 2	33 02
RTN	24
LBL	23
B	12
x	71
STO 4	33 04
g R↓	35 08
x	71
STO 3	33 03
RTN	24
LBL	23
C	13
STO 5	33 05
RTN	24
LBL	23
D	14
RCL 3	34 03
RCL 4	34 04
g x>y	35 24
g x⇄y	35 07
g NOP	35 01
STO 7	33 07
RCL 5	34 05
x	71
RCL 1	34 01
RCL 2	34 02
−	51
x	71
g	35
ABS	06
STO 6	33 06

KEYS	CODE
RTN	24
LBL	23
E	15
D	14
RCL 3	34 03
RCL 4	34 04
g x≤y	35 22
g x⇄y	35 07
g NOP	35 01
RCL 6	34 06
g x⇄y	35 07
÷	81
RCL 2	34 02
+	61
RTN	24
LBL	23
E	15
RCL 1	34 01
RCL 6	34 06
RCL 7	34 07
÷	81
−	51
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

KEYS	CODE
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	T_{hin}	R_4	C_h	R_7	C_{min}
R_2	T_{cin}	R_5	E	R_8	
R_3	C_c	R_6	q	R_9	Used

COUNTER-FLOW HEAT EXCHANGER

KEYS	CODE
LBL	23
A	11
x	71
STO 4	33 04
g R↓	35 08
x	71
STO 3	33 03
RTN	24
LBL	23
B	12
STO 8	33 08
D	14
1	01
—	51
RCL 8	34 08
RCL 7	34 07
÷	81
x	71
f^{-1}	32
LN	07
1	01
g x⇄y	35 07
—	51
g LST X	35 00
D	14
x	71
1	01
g x⇄y	35 07
—	51
0	00
g x=y	35 23
GTO	22
1	01
g R↓	35 08
÷	81

KEYS	CODE
STO 5	33 05
RTN	24
LBL	23
1	01
RCL 8	34 08
RCL 7	34 07
÷	81
↑	41
↑	41
1	01
+	61
÷	81
STO 5	33 05
RTN	24
LBL	23
C	13
STO 5	33 05
D	14
RCL 5	34 05
g	35
1/x	04
—	51
1	01
g LST X	35 00
—	51
÷	81
f	31
LN	07
D	14
1	01
g x⇄y	35 07
—	51
0	00
g x=y	35 23
GTO	22

KEYS	CODE
2	02
g R↓	35 08
÷	81
RCL 7	34 07
x	71
STO 8	33 08
RTN	24
LBL	23
2	02
RCL 5	34 05
1	01
RCL 5	34 05
—	51
÷	81
RCL 7	34 07
x	71
STO 8	33 08
RTN	24
LBL	23
D	14
RCL 3	34 03
RCL 4	34 04
g x>y	35 24
g x⇄y	35 07
g NOP	35 01
STO 7	33 07
g x⇄y	35 07
÷	81
RTN	24
g NOP	35 01

R_1	R_4 C_h	R_7 C_{min}
R_2	R_5 E	R_8 AU
R_3 C_c	R_6	R_9 Used

PARALLEL-FLOW HEAT EXCHANGER

KEYS	CODE	KEYS	CODE	KEYS	CODE
LBL	23	+	61	g NOP	35 01
A	11	RCL 5	34 05	g NOP	35 01
x	71	x	71	g NOP	35 01
STO 4	33 04	CHS	42	g NOP	35 01
g R↓	35 08	1	01	g NOP	35 01
x	71	+	61	g NOP	35 01
STO 3	33 03	f	31	g NOP	35 01
RTN	24	LN	07	g NOP	35 01
LBL	23	CHS	42	g NOP	35 01
B	12	1	01	g NOP	35 01
STO 8	33 08	D	14	g NOP	35 01
D	14	+	61	g NOP	35 01
1	01	÷	81	g NOP	35 01
+	61	RCL 7	34 07	g NOP	35 01
RCL 8	34 08	x	71	g NOP	35 01
RCL 7	34 07	STO 8	33 08	g NOP	35 01
÷	81	RTN	24	g NOP	35 01
x	71	LBL	23	g NOP	35 01
CHS	42	D	14	g NOP	35 01
f^{-1}	32	RCL 3	34 03	g NOP	35 01
LN	07	RCL 4	34 04	g NOP	35 01
CHS	42	g x>y	35 24	g NOP	35 01
1	01	g x⇄y	35 07	g NOP	35 01
+	61	g NOP	35 01	g NOP	35 01
1	01	STO 7	33 07	g NOP	35 01
D	14	g x⇄y	35 07	g NOP	35 01
+	61	÷	81	g NOP	35 01
÷	81	↑	41	g NOP	35 01
STO 5	33 05	CLX	44	g NOP	35 01
RTN	24	g x=y	35 23	g NOP	35 01
LBL	23	1	01		
C	13	STO 7	33 07		
STO 5	33 05	g R↓	35 08		
D	14	RTN	24		
1	01	g NOP	35 01		

R_1	R_4 C_h	R_7 C_{min}
R_2	R_5 E	R_8 AU
R_3 C_c	R_6	R_9 Used

PARALLEL-COUNTER-FLOW, (SHELL MIXED, EVEN NUMBER)

KEYS	CODE
LBL	23
A	11
x	71
STO 4	33 04
g R↓	35 08
x	71
STO 3	33 03
RTN	24
LBL	23
B	12
STO 8	33 08
E	15
D	14
x	71
CHS	42
f^{-1}	32
LN	07
1	01
g x⇄y	35 07
+	61
1	01
g LST X	35 00
—	51
÷	81
RCL 6	34 06
x	71
RCL 7	34 07
+	61
2	02
g x⇄y	35 07
÷	81
STO 5	33 05
RTN	24
LBL	23
C	13

KEYS	CODE
STO 5	33 05
D	14
2	02
x	71
RCL 6	34 06
2	02
RCL 5	34 05
÷	81
+	61
RCL 7	34 07
—	51
÷	81
CHS	42
1	01
+	61
f	31
LN	07
RCL 6	34 06
÷	81
CHS	42
E	15
g LST X	35 00
↑	41
x	71
x	71
RTN	24
LBL	23
D	14
RCL 3	34 03
RCL 4	34 04
g x≤y	35 22
g x⇄y	35 07
g NOP	35 01
÷	81
↑	41

KEYS	CODE
x	71
g LST X	35 00
1	01
+	61
STO 7	33 07
CLX	44
1	01
+	61
f	31
$\sqrt{x}$	09
STO 6	33 06
RTN	24
LBL	23
E	15
RCL 3	34 03
RCL 4	34 04
g x≤y	35 22
g x⇄y	35 07
g NOP	35 01
g R↓	35 08
÷	81
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	R_4 C_h	R_7 $1+(C_{min}/C_{max})$
R_2	R_5 E	R_8 AU
R_3 C_c	R_6 $\sqrt{1+(C_{min}/C_{max})^2}$	R_9 Used

CROSS-FLOW WITH FLUIDS UNMIXED

KEYS	CODE
STO 4	33 04
g x⇄y	35 07
STO 3	33 03
LBL	23
E	15
RCL 3	34 03
RCL 4	34 04
g x>y	35 24
g x⇄y	35 07
g NOP	35 01
STO 6	33 06
÷	81
STO 7	33 07
RTN	24
LBL	23
B	12
STO 8	33 08
E	15
A	11
RCL 8	34 08
LBL	23
D	14
RCL 6	34 06
÷	81
↑	41
↑	41
•	83
2	02
2	02
g	35
y^x	05
RCL 7	34 07
x	71
÷	81
g LST X	35 00

KEYS	CODE
g x⇄y	35 07
CHS	42
f^{-1}	32
LN	07
1	01
–	51
x	71
f^{-1}	32
LN	07
CHS	42
1	01
+	61
RTN	24
STO 5	33 05
RTN	24
LBL	23
C	13
STO 5	33 05
1	01
–	51
CHS	42
f	31
LN	07
CHS	42
E	15
CLX	44
RCL 6	34 06
x	71
STO 8	33 08
LBL	23
1	01
RCL 8	34 08
D	14
RCL 8	34 08
RCL 8	34 08

KEYS	CODE
EEX	43
5	05
÷	81
–	51
D	14
–	51
g LST X	35 00
RCL 5	34 05
–	51
g x⇄y	35 07
÷	81
RCL 8	34 08
EEX	43
5	05
÷	81
x	71
STO	33
–	51
8	08
g	35
ABS	06
RCL 8	34 08
EEX	43
3	03
÷	81
g x≤y	35 22
GTO	22
1	01
RCL 8	34 08
RTN	24

R_1		R_4	C_h	R_7	C_{max}/C_{min}
R_2		R_5	E	R_8	AU
R_3	C_c	R_6	C_{min}	R_9	Used

COMPOSITE CYLINDERS AND WALLS

KEYS	CODE
LBL	23
A	11
g	35
π	02
STO 6	33 06
CLX	44
STO 8	33 08
g R↓	35 08
g x⇄y	35 07
STO 7	33 07
g x⇄y	35 07
GTO	22
A	11
LBL	23
1	01
RTN	24
LBL	23
A	11
x	71
g	35
1/x	04
STO	33
+	61
8	08
GTO	22
1	01
LBL	23
B	12
g	35
1/x	04
g x⇄y	35 07
RCL 7	34 07
g x⇄y	35 07
STO 7	33 07
÷	81

KEYS	CODE
f	31
LN	07
x	71
2	02
÷	81
STO	33
–	51
8	08
GTO	22
1	01
LBL	23
C	13
RCL 8	34 08
g	35
1/x	04
RCL 6	34 06
x	71
STO 4	33 04
RTN	24
LBL	23
D	14
1	01
g x⇄y	35 07
LBL	23
E	15
1	01
STO 6	33 06
CLX	44
STO 8	33 08
g R↓	35 08
GTO	22
E	15
LBL	23
2	02
RTN	24

KEYS	CODE
LBL	23
E	15
g x⇄y	35 07
÷	81
LBL	23
D	14
g	35
1/x	04
STO	33
+	61
8	08
GTO	22
2	02
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	R_4 U	R_7 Used
R_2	R_5	R_8 ΣR
R_3	R_6 1 or π	R_9

STRAIGHT FIN EFFICIENCY

KEYS	CODE
LBL	23
A	11
STO 2	33 02
g x⇄y	35 07
STO 3	33 03
RTN	24
LBL	23
B	12
STO 4	33 04
g R↓	35 08
2	02
÷	81
STO 1	33 01
RTN	24
LBL	23
C	13
RCL 4	34 04
RCL 1	34 01
+	61
f	31
√x	09
g LST X	35 00
x	71
RCL 3	34 03
RCL 2	34 02
÷	81
RCL 1	34 01
÷	81
RCL 4	34 04
÷	81
f	31
√x	09
x	71
STO 7	33 07
f^{-1}	32

KEYS	CODE
LN	07
f^{-1}	32
TAN	06
↑	41
+	61
9	09
0	00
–	51
f	31
SIN	04
RCL 7	34 07
÷	81
STO 5	33 05
RTN	24
LBL	23
D	14
STO 6	33 06
RCL 1	34 01
↑	41
+	61
x	71
1	01
g x≤y	35 22
0	00
÷	81
RCL 6	34 06
RTN	24
LBL	23
E	15
RCL 4	34 04
RCL 1	34 01
+	61
↑	41
+	61
RCL 6	34 06

KEYS	CODE
x	71
RCL 5	34 05
x	71
RCL 1	34 01
↑	41
+	61
RCL 6	34 06
x	71
CHS	42
1	01
+	61
+	61
x	71
RCL 3	34 03
x	71
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	t/2	R_4	L	R_7	x
R_2	k	R_5	η_f	R_8	
R_3	h	R_6	N_{ave}	R_9	Used

GRASHOF NUMBER

KEYS	CODE
LBL	23
A	11
STO 1	33 01
0	00
g x≠y	35 21
0	00
RTN	24
RCL 5	34 05
RCL 7	34 07
x	71
RCL 8	34 08
↑	41
↑	41
x	71
x	71
x	71
STO 1	33 01
RTN	24
LBL	23
B	12
STO 8	33 08
0	00
g x≠y	35 21
0	00
RTN	24
RCL 1	34 01
RCL 7	34 07
÷	81
RCL 5	34 05
÷	81
3	03
g	35
$^1/x$	04
g	35
y^x	05

KEYS	CODE
STO 8	33 08
RTN	24
LBL	23
C	13
STO 5	33 05
0	00
g x≠y	35 21
0	00
RTN	24
RCL 1	34 01
RCL 7	34 07
÷	81
RCL 8	34 08
↑	41
↑	41
x	71
x	71
÷	81
STO 5	33 05
RTN	24
LBL	23
D	14
STO 7	33 07
0	00
g x≠y	35 21
0	00
RTN	24
RCL 1	34 01
RCL 8	34 08
↑	41
↑	41
x	71
x	71
÷	81
RCL 5	34 05

KEYS	CODE
÷	81
STO 7	33 07
RTN	24
LBL	23
E	15
STO 6	33 06
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	Gr	R_4		R_7	$g\beta\rho^2/\mu^2$
R_2		R_5	ΔT	R_8	x
R_3		R_6	k	R_9	Used

VERTICAL WALLS, CYLINDERS, HORIZONTAL CYLINDERS

KEYS	CODE
LBL	23
A	11
STO 1	33 01
RTN	24
LBL	23
B	12
STO 3	33 03
RTN	24
LBL	23
C	13
RCL 1	34 01
RCL 3	34 03
x	71
3	03
EEX	43
9	09
g x⇄y	35 07
g x>y	35 24
GTO	22
1	01
•	83
2	02
5	05
g	35
y^x	05
•	83
5	05
5	05
5	05
x	71
STO 2	33 02
RTN	24
LBL	23
1	01
•	83

KEYS	CODE
4	04
g	35
y^x	05
•	83
0	00
2	02
1	01
x	71
STO 2	33 02
RTN	24
LBL	23
D	14
RCL 3	34 03
RCL 1	34 01
x	71
EEX	43
4	04
g x>y	35 24
0	00
÷	81
EEX	43
5	05
x	71
g x⇄y	35 07
g x>y	35 24
0	00
÷	81
•	83
2	02
5	05
g	35
y^x	05
•	83
5	05
3	03

KEYS	CODE
x	71
STO 2	33 02
RTN	24
LBL	23
E	15
RCL 2	34 02
RCL 6	34 06
x	71
RCL 8	34 08
÷	81
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1 Gr	R_4	R_7
R_2 Nu	R_5 ΔT	R_8 x
R_3 Pr	R_6 k	R_9 Used

HORIZONTAL PLATES

KEYS	CODE
LBL	23
A	11
STO 1	33 01
RTN	24
LBL	23
B	12
STO 3	33 03
RTN	24
LBL	23
C	13
RCL 1	34 01
RCL 3	34 03
x	71
2	02
EEX	43
7	07
g x⇄y	35 07
g x>y	35 24
GTO	22
1	01
EEX	43
5	05
g x>y	35 24
0	00
÷	81
g R↓	35 08
•	83
2	02
5	05
g	35
y^x	05
•	83
5	05
4	04
x	71

KEYS	CODE
STO 2	33 02
RTN	24
LBL	23
1	01
3	03
EEX	43
1	01
0	00
g x≤y	35 22
0	00
÷	81
g R↓	35 08
3	03
g	35
1/x	04
g	35
y^x	05
•	83
1	01
4	04
x	71
STO 2	33 02
RTN	24
LBL	23
D	14
RCL 1	34 01
RCL 3	34 03
x	71
3	03
EEX	43
5	05
g x>y	35 24
0	00
÷	81
CLX	44

KEYS	CODE
EEX	43
1	01
0	00
g x⇄y	35 07
g x>y	35 24
0	00
÷	81
•	83
2	02
5	05
g	35
y^x	05
•	83
2	02
7	07
x	71
STO 2	33 02
RTN	24
LBL	23
E	15
RCL 2	34 02
RCL 6	34 06
x	71
RCL 8	34 08
÷	81
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1 Gr	R_4	R_7
R_2 Nu	R_5 ΔT	R_8 x
R_3 Pr	R_6 k	R_9 Used

THERMAL RADIATION CONSTANTS

KEYS	CODE
DSP	21
3	03
1	01
8	08
8	08
8	08
7	07
9	09
8	08
2	02
STO 1	33 01
2	02
5	05
8	08
9	09
8	08
•	83
4	04
STO 2	33 02
5	05
2	02
1	01
6	06
STO 3	33 03
•	83
1	01
7	07
1	01
3	03
1	01
2	02
EEX	43
CHS	42
8	08
STO 4	33 04

KEYS	CODE
RTN	24
LBL	23
B	12
DSP	21
3	03
5	05
9	09
5	05
4	04
•	83
4	04
STO 1	33 01
1	01
4	04
3	03
8	08
8	08
STO 2	33 02
2	02
8	08
9	09
7	07
•	83
8	08
STO 3	33 03
5	05
•	83
6	06
6	06
9	09
3	03
EEX	43
CHS	42
1	01
2	02

KEYS	CODE
STO 4	33 04
RTN	24
LBL	23
C	13
RCL 4	34 04
1	01
•	83
0	00
1	01
0	00
5	05
x	71
STO 4	33 04
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1 c_1	R_4 σ	R_7
R_2 c_2	R_5	R_8
R_3 c_3	R_6	R_9

BLACK BODY RADIATION

KEYS	CODE
LBL	23
A	11
STO 5	33 05
RCL 3	34 03
g x⇄y	35 07
÷	81
RTN	24
LBL	23
B	12
STO 6	33 06
RCL 3	34 03
g x⇄y	35 07
÷	81
RTN	24
LBL	23
C	13
RCL 5	34 05
↑	41
x	71
↑	41
x	71
RCL 4	34 04
x	71
RTN	24
LBL	23
D	14
RCL 1	34 01
2	02
x	71
g	35
π	02
x	71
RCL 6	34 06
5	05
g	35

KEYS	CODE
y^x	05
÷	81
RCL 2	34 02
RCL 6	34 06
÷	81
RCL 5	34 05
÷	81
f^{-1}	32
LN	07
1	01
–	51
÷	81
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

KEYS	CODE
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	c_1	R_4	σ	R_7	
R_2	c_2	R_5	T	R_8	
R_3	c_3	R_6	λ	R_9	

BLACK BODY RADIATION FOR SPECTRUM INTERVALS

KEYS	CODE
STO 6	33 06
RTN	24
LBL	23
B	12
STO 5	33 05
RTN	24
LBL	23
C	13
0	00
STO 8	33 08
STO 7	33 07
LBL	23
1	01
g R↓	35 08
CLX	44
RCL 8	34 08
RCL 2	34 02
RCL 5	34 05
÷	81
—	51
STO 8	33 08
3	03
g x⇄y	35 07
÷	81
RCL 6	34 06
RCL 6	34 06
x	71
÷	81
1	01
g LST X	35 00
÷	81
RCL 6	34 06
÷	81
—	51
6	06

KEYS	CODE
RCL 6	34 06
÷	81
RCL 8	34 08
f^{-1}	32
$\sqrt{x}$	09
÷	81
—	51
6	06
RCL 8	34 08
f^{-1}	32
$\sqrt{x}$	09
÷	81
RCL 8	34 08
÷	81
+	61
RCL 8	34 08
RCL 6	34 06
÷	81
f^{-1}	32
LN	07
x	71
RCL 8	34 08
÷	81
STO	33
+	61
7	07
RCL 7	34 07
÷	81
EEX	43
CHS	42
5	05
g x≤y	35 22
GTO	22
1	01
g R↓	35 08

KEYS	CODE
CLX	44
RCL 7	34 07
↑	41
+	61
g	35
π	02
x	71
RCL 1	34 01
x	71
RTN	24
LBL	23
D	14
↑	41
↑	41
C	13
g x⇄y	35 07
STO 6	33 06
C	13
—	51
CHS	42
RTN	24
LBL	23
E	15
RCL 5	34 05
4	04
g	35
y^x	05
RCL 4	34 04
x	71
RTN	24

R_1	c_1	R_4	σ	R_7	sum
R_2	c_2	R_5	T	R_8	kc_2/T
R_3	c_3	R_6	λ	R_9	Used

SEMI-INFINITE SOLID

KEYS	CODE
LBL	23
A	11
x	71
÷	81
STO 6	33 06
RTN	24
LBL	23
B	12
STO 4	33 04
g x⇄y	35 07
STO 5	33 05
RTN	24
LBL	23
C	13
STO 7	33 07
RTN	24
LBL	23
D	14
STO 8	33 08
2	02
÷	81
RCL 6	34 06
RCL 7	34 07
x	71
f	31
$\sqrt{x}$	09
÷	81
E	15
RCL 4	34 04
RCL 5	34 05
−	51
x	71
RCL 5	34 05
+	61
RTN	24

KEYS	CODE
LBL	23
E	15
STO 1	33 01
4	04
•	83
5	05
g x≤y	35 22
1	01
RTN	24
g R↓	35 08
↑	41
x	71
2	02
x	71
STO 2	33 02
1	01
STO 3	33 03
RCL 1	34 01
LBL	23
1	01
RCL 2	34 02
RCL 3	34 03
2	02
+	61
STO 3	33 03
÷	81
RCL 1	34 01
x	71
STO 1	33 01
+	61
g x≠y	35 21
GTO	22
1	01
2	02
x	71

KEYS	CODE
g	35
π	02
f	31
$\sqrt{x}$	09
÷	81
RCL 2	34 02
2	02
÷	81
f^{-1}	32
LN	07
÷	81
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	Partial sum	R_4	$T_o(C_o)$	R_7	t
R_2	$2a^2$	R_5	$T_s(C_s)$	R_8	x
R_3	2n + 1	R_6	α	R_9	Used

HYDROCARBON COMBUSTION I

KEYS	CODE
LBL	23
A	11
STO 1	33 01
RTN	24
LBL	23
B	12
STO 2	33 02
RTN	24
LBL	23
C	13
STO 3	33 03
RTN	24
LBL	23
D	14
STO 4	33 04
0	00
STO	33
9	09
g x⇄y	35 07
RTN	24
LBL	23
D	14
STO	33
9	09
RTN	24
LBL	23
E	15
↑	41
EEX	43
2	02
÷	81
1	01
+	61
STO 5	33 05
RCL 1	34 01

KEYS	CODE
RCL 4	34 04
+	61
RCL 2	34 02
4	04
÷	81
+	61
RCL 3	34 03
2	02
÷	81
–	51
STO 6	33 06
x	71
4	04
•	83
7	07
6	06
2	02
x	71
STO 8	33 08
RCL 2	34 02
4	04
÷	81
+	61
RCL 3	34 03
2	02
÷	81
+	61
RCL	34
9	09
2	02
÷	81
+	61
STO 7	33 07
RCL 5	34 05
1	01

KEYS	CODE
–	51
EEX	43
2	02
x	71
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	C	R_4	S	R_7	prod
R_2	H	R_5	air	R_8	AF (mole)
R_3	O	R_6	O_2	R_9	N

HYDROCARBON COMBUSTION II

KEYS	CODE
LBL	23
A	11
RCL 8	34 08
1	01
•	83
8	08
0	00
9	09
4	04
x	71
RCL 1	34 01
•	83
7	07
5	05
0	00
7	07
x	71
RCL 2	34 02
•	83
0	00
6	06
3	03
x	71
+	61
RCL 3	34 03
+	61
2	02
•	83
0	00
0	00
4	04
RCL 4	34 04
x	71
+	61
•	83

KEYS	CODE
8	08
7	07
5	05
RCL	34
9	09
x	71
+	61
÷	81
RTN	24
LBL	23
A	11
RCL 8	34 08
RTN	24
LBL	23
B	12
RCL 7	34 07
RTN	24
LBL	23
B	12
RCL 4	34 04
E	15
RTN	24
LBL	23
C	13
RCL 1	34 01
E	15
RTN	24
LBL	23
C	13
RCL 2	34 02
2	02
÷	81
E	15
RTN	24
LBL	23

KEYS	CODE
D	14
RCL 5	34 05
1	01
–	51
RCL 6	34 06
x	71
E	15
RTN	24
LBL	23
D	14
RCL 8	34 08
RCL 5	34 05
RCL 6	34 06
x	71
–	51
RCL	34
9	09
2	02
÷	81
+	61
LBL	23
E	15
RCL 7	34 07
÷	81
EEX	43
2	02
x	71
RTN	24
g NOP	35 01
g NOP	35 01

R_1	C	R_4	S	R_7	prod
R_2	H	R_5	air	R_8	AF (mole)
R_3	O	R_6	O_2	R_9	N

LINEAR REGRESSION; y = a + bx

KEYS	CODE
f	31
REG	43
RTN	24
LBL	23
B	12
STO 1	33 01
g	35
DSZ	83
STO	33
+	61
3	03
↑	41
x	71
STO	33
+	61
4	04
RCL 1	34 01
RTN	24
LBL	23
C	13
STO 2	33 02
STO	33
+	61
5	05
↑	41
x	71
STO	33
+	61
6	06
g LST X	35 00
RCL 1	34 01
x	71
STO	33
+	61
7	07

KEYS	CODE
RCL 2	34 02
RTN	24
LBL	23
D	14
RCL 7	34 07
RCL 3	34 03
RCL 5	34 05
x	71
RCL 8	34 08
÷	81
+	61
↑	41
↑	41
RCL 3	34 03
↑	41
x	71
RCL 8	34 08
÷	81
RCL 4	34 04
+	61
÷	81
STO 1	33 01
x	71
RCL 5	34 05
↑	41
x	71
RCL 8	34 08
÷	81
RCL 6	34 06
+	61
÷	81
RCL 3	34 03
RCL 8	34 08
÷	81
RCL 1	34 01

KEYS	CODE
x	71
RCL 5	34 05
RCL 8	34 08
CHS	42
÷	81
+	61
STO 2	33 02
RTN	24
LBL	23
D	14
CLX	44
RCL 1	34 01
RTN	24
LBL	23
D	14
g R↑	35 09
RTN	24
LBL	23
E	15
RCL 1	34 01
x	71
RCL 2	34 02
+	61
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	x_i,b	R_4	Σx^2	R_7	Σxy
R_2	y_i,a	R_5	Σy	R_8	−n
R_3	Σx	R_6	Σy^2	R_9	

EXPONENTIAL CURVE FIT; $y = ae^{bx}$

KEYS	CODE
f	31
REG	43
RTN	24
LBL	23
B	12
STO 1	33 01
g	35
DSZ	83
STO	33
+	61
3	03
↑	41
x	71
STO	33
+	61
4	04
RCL 1	34 01
RTN	24
LBL	23
C	13
STO 2	33 02
f	31
LN	07
STO	33
+	61
5	05
↑	41
x	71
STO	33
+	61
6	06
g LST X	35 00
RCL 1	34 01
x	71
STO	33

KEYS	CODE
+	61
7	07
RCL 2	34 02
RTN	24
LBL	23
D	14
RCL 7	34 07
RCL 3	34 03
RCL 5	34 05
x	71
RCL 8	34 08
÷	81
+	61
↑	41
↑	41
RCL 3	34 03
↑	41
x	71
RCL 8	34 08
÷	81
RCL 4	34 04
+	61
÷	81
STO 1	33 01
x	71
RCL 5	34 05
↑	41
x	71
RCL 8	34 08
÷	81
RCL 6	34 06
+	61
÷	81
RCL 3	34 03
RCL 8	34 08

KEYS	CODE
÷	81
RCL 1	34 01
x	71
RCL 5	34 05
RCL 8	34 08
CHS	42
÷	81
+	61
f^{-1}	32
LN	07
STO 2	33 02
RTN	24
LBL	23
D	14
CLX	44
RCL 1	34 01
RTN	24
LBL	23
D	14
g R↑	35 09
RTN	24
LBL	23
E	15
RCL 1	34 01
x	71
f^{-1}	32
LN	07
RCL 2	34 02
x	71
RTN	24

R_1	x_i,b	R_4	Σx^2	R_7	$\Sigma x \ln y$
R_2	y_i,a	R_5	$\Sigma \ln y$	R_8	−n
R_3	Σx	R_6	$\Sigma (\ln y)^2$	R_9	

POWER CURVE FIT; $y = ax^b$

KEYS	CODE
f	31
REG	43
RTN	24
LBL	23
B	12
g	35
DSZ	83
f	31
LN	07
STO 1	33 01
STO	33
+	61
3	03
↑	41
x	71
STO	33
+	61
4	04
RTN	24
LBL	23
C	13
STO 2	33 02
f	31
LN	07
STO	33
+	61
5	05
↑	41
x	71
STO	33
+	61
6	06
g LST X	35 00
RCL 1	34 01
x	71

KEYS	CODE
STO	33
+	61
7	07
RCL 2	34 02
RTN	24
LBL	23
D	14
RCL 7	34 07
RCL 3	34 03
RCL 5	34 05
x	71
RCL 8	34 08
÷	81
+	61
↑	41
↑	41
RCL 3	34 03
↑	41
x	71
RCL 8	34 08
÷	81
RCL 4	34 04
+	61
÷	81
STO 1	33 01
x	71
RCL 5	34 05
↑	41
x	71
RCL 8	34 08
÷	81
RCL 6	34 06
+	61
÷	81
RCL 3	34 03

KEYS	CODE
RCL 8	34 08
÷	81
RCL 1	34 01
x	71
RCL 5	34 05
RCL 8	34 08
CHS	42
÷	81
+	61
f^{-1}	32
LN	07
STO 2	33 02
RTN	24
LBL	23
D	14
RCL 1	34 01
RTN	24
LBL	23
D	14
g R↑	35 09
RTN	24
LBL	23
E	15
RCL 1	34 01
g	35
y^x	05
RCL 2	34 02
x	71
RTN	24
g NOP	35 01

R_1	x_i,b	R_4	$\Sigma (\ln x)^2$	R_7	$\Sigma(\ln x)(\ln y)$
R_2	y_i,a	R_5	$\Sigma \ln y$	R_8	−n
R_3	$\Sigma \ln x$	R_6	$\Sigma (\ln y)^2$	R_9	

ENERGY CONVERSION

KEYS	CODE
LBL	23
C	13
3	03
6	06
0	00
0	00
x	71
0	00
g x=y	35 23
GTO	22
1	01
g R↓	35 08
STO 8	33 08
0	00
RTN	24
LBL	23
1	01
RCL 8	34 08
g LST X	35 00
÷	81
RTN	24
LBL	23
B	12
4	04
•	83
1	01
8	08
4	04
x	71
0	00
g x=y	35 23
GTO	22
1	01
g R↓	35 08
STO 8	33 08

KEYS	CODE
0	00
RTN	24
LBL	23
A	11
0	00
g x=y	35 23
RCL 8	34 08
RTN	24
g R↓	35 08
STO 8	33 08
0	00
RTN	24
LBL	23
D	14
1	01
0	00
5	05
5	05
x	71
0	00
g x=y	35 23
GTO	22
1	01
g R↓	35 08
STO 8	33 08
0	00
RTN	24
LBL	23
E	15
1	01
•	83
3	03
5	05
5	05
8	08

KEYS	CODE
1	01
8	08
x	71
0	00
g x=y	35 23
GTO	22
1	01
g R↓	35 08
STO 8	33 08
0	00
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	R_4	R_7
R_2	R_5	R_8 joule
R_3	R_6	R_9 Used

PRESSURE CONVERSION

KEYS	CODE
LBL	23
C	13
1	01
0	00
1	01
3	03
2	02
5	05
x	71
0	00
g x=y	35 23
GTO	22
1	01
g R↓	35 08
STO 8	33 08
0	00
RTN	24
LBL	23
1	01
RCL 8	34 08
g LST X	35 00
÷	81
RTN	24
LBL	23
B	12
•	83
1	01
x	71
0	00
g x=y	35 23
GTO	22
1	01
g R↓	35 08
STO 8	33 08
0	00

KEYS	CODE
RTN	24
LBL	23
A	11
0	00
g x=y	35 23
RCL 8	34 08
RTN	24
g R↓	35 08
STO 8	33 08
0	00
RTN	24
LBL	23
D	14
6	06
8	08
9	09
4	04
•	83
7	07
5	05
7	07
2	02
x	71
0	00
g x=y	35 23
GTO	22
1	01
g R↓	35 08
STO 8	33 08
0	00
RTN	24
LBL	23
E	15
4	04
7	07

KEYS	CODE
•	83
8	08
8	08
x	71
0	00
g x=y	35 23
GTO	22
1	01
g R↓	35 08
STO 8	33 08
0	00
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	R_4	R_7
R_2	R_5	R_8 Nt/m^2
R_3	R_6	R_9 Used

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