HEWLETT-PACKARD

HP-67/HP-97

Users' Library Solutions

Physics

INTRODUCTION

In an effort to provide continued value to it's customers, Hewlett-Packard is introducing a unique service for the HP fully programmable calculator user. This service is designed to save you time and programming effort. As users are aware, Programmable Calculators are capable of delivering tremendous problem solving potential in terms of power and flexibility, but the real genie in the bottle is program solutions. HP's introduction of the first handheld programmable calculator in 1974 immediately led to a request for program **solutions** — hence the beginning of the HP-65 Users' Library. In order to save HP calculator customers time, users wrote their own programs and sent them to the Library for the benefit of other program users. In a short period of time over 5,000 programs were accepted and made available. This overwhelming response indicated the value of the program library and a Users' Library was then established for the HP-67/97 users.

To extend the value of the Users' Library, Hewlett-Packard is introducing a unique service—a service designed to save you time and money. The Users' Library has collected the best programs in the most popular categories from the HP-67/97 and HP-65 Libraries. These programs have been packaged into a series of low-cost books, resulting in substantial savings for our valued HP-67/97 users.

We feel this new software service will extend the capabilities of our programmable calculators and provide a great benefit to our HP-67/97 users.

A WORD ABOUT PROGRAM USAGE

Each program contained herein is reproduced on the standard forms used by the Users' Library. Magnetic cards are not included. The Program Description I page gives a basic description of the program. The Program Description II page provides a sample problem and the keystrokes used to solve it. The User Instructions page contains a description of the keystrokes used to solve problems in general and the options which are available to the user. The Program Listing I and Program Listing II pages list the program steps necessary to operate the calculator. The comments, listed next to the steps, describe the reason for a step or group of steps. Other pertinent information about data register contents, uses of labels and flags and the initial calculator status mode is also found on these pages. Following the directions in your HP-67 or HP-97 **Owners' Handbook and Programming Guide**, "Loading a Program" (page 134, HP-67; page 119, HP-97), key in the program from the Program Listing I and Program Listing II pages. A number at the top of the Program Listing indicates on which calculator the program was written (HP-67 or HP-97). If the calculator indicated differs from the calculator you will be using, consult Appendix E of your **Owner's Handbook** for the corresponding keycodes and keystrokes converting HP-67 to HP-97 keycodes and vice versa. No program conversion is necessary. The HP-67 and HP-97 are totally compatible, but some differences do occur in the keycodes used to represent some of the functions.

A program loaded into the HP-67 or HP-97 is not permanent—once the calculator is turned off, the program will not be retained. You can, however, permanently save any program by recording it on a blank magnetic card, several of which were provided in the Standard Pac that was shipped with your calculator. Consult your **Owner's Handbook** for full instructions. A few points to remember:

> The Set Status section indicates the status of flags, angular mode, and display setting. After keying in your program, review the status section and set the conditions as indicated before using or permanently recording the program.
>
> REMEMBER! To save the program permanently, **clip** the corners of the magnetic card once you have recorded the program. This simple step will protect the magnetic card and keep the program from being inadvertently erased.

As a part of HP's continuing effort to provide value to our customers, we hope you will enjoy our newest concept.

TABLE OF CONTENTS

Program Description I

Program Title Black Body Thermal Radiation

Contributor's Name Hewlett-Packard
Address 1000 N. E. Circle Blvd.
City Corvallis State Oregon Zip Code 97330

Program Description, Equations, Variables

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.

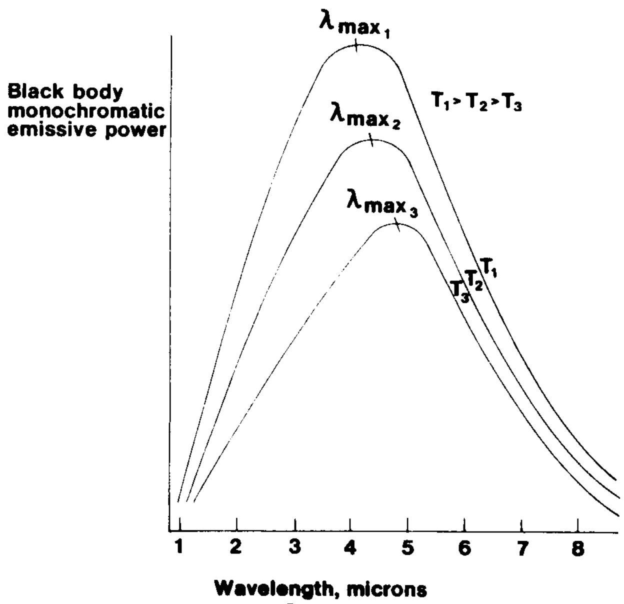


Figure 1.

(continued next page)

Operating Limits and Warnings

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

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

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.

This program calculates the wavelength of maximum emissive power for a given temperature, the temperature for which a given wavelength would be the wavelength of maximum emissive power, the total emissive power over all wavelengths, the emissive power at a particlular wavelength, the emissive power form zero to a specified wavelength, and the emissive power between specified wavelengths.

Equations:

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

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

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

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

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

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

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

Program Description II

Sketch(es)

Sample Problem(s) 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:	Outputs:
[f] [B]	5.669×10^{-12} W/cm^2-K^4
2400 [A] .4 [B] .7 [f] [E] [C] [÷] 100 [x]	2.641%
2500 [A] .7 [f] [E] [C] [÷] 100 [x]	3.337%

Example 2:

If the human eye was designed to work most efficinetly is 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:	Outputs:
[f] [A]	1.713×10^{-9} Btu/hr-ft^2-°R^4
Compute mean of visible range.	
.4 [+] .7 [+] 2 [÷]	550.0×10^{-3} µm
Compute temperature of sun.	
[B]	9.484×10^3 °R

(continued)

Reference(s)

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

Compute percentage of power in visible range.

[A] .4 [B] .7 [E][E] [C] [÷] 100 [x]------------------→ 33.70 x 10^0 %

Compute percentage of power under 0.4 microns.

[E] [C] [÷] 100 [x]--------------------------------→ **8.433%**

User Instructions

Black Body Thermal Radiation

1					2
Eng		SI	Exp σ		$\lambda' \to E_{b(\lambda-\lambda')}$
$T \to \lambda max$	$\lambda \to T(\lambda max)$		$\to E_b\ (0-\infty)$	$\to E_{b\lambda}$	$E_{b(0-\lambda)}$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Load side 1 and side 2.				
2	Store constants:				
	For English units (Btu, μm, hr, ft, °R)		f	A	1.713×10^{-9}
	For SI units (W, μm, cm, K)		f	B	5.669×10^{-12}
3	For experimental Stefan-Boltzman constant				
	instead of theoretical value press		f	C	1.731×10^{-9}
					or 5.729×10^{-12}
4	Calculate any or all of the following (T and				
	λ need only be input once):				
	Calculate λ_{max} for a given T;	T	A		λ_{max}
	Calculate T such that λ is λ_{max} for T;	λ	B		$T(\lambda_{max})$
	Calculate total emissive power;	T	A	C	$E_{b(0-\infty)}$
	Calculate the emissive power at λ;	T	A		λ_{max}
		λ	B	D	$E_{b\lambda}$
	Calculate the emissive power between zero				
	and λ;	T	A		λ_{max}
		λ	B	E	$E_{b(0-\lambda)}$
	Calculate the emissive power between λ				
	and λ'.	T	A		λ_{max}
		λ	B		$T(\lambda_{max})$
		λ'	f	E	$E_{b(\lambda-\lambda')}$
5	For a new case, go to steps 2, 3, or 4.				

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLa	21 16 11	
002	1	01	Store English constants.
003	8	08	
004	8	08	
005	8	08	
006	7	07	
007	9	09	
008	8	08	
009	2	02	
010	STO1	35 01	
011	2	02	
012	5	05	
013	8	08	
014	9	09	
015	8	08	
016	.	-62	
017	4	04	
018	STO2	35 02	
019	5	05	
020	2	02	
021	1	01	
022	6	06	
023	STO3	35 03	
024	.	-62	
025	1	01	
026	7	07	
027	1	01	
028	3	03	
029	1	01	
030	2	02	
031	EEX	-23	
032	CHS	-22	
033	8	08	
034	STO4	35 04	
035	RTN	24	
036	*LBLb	21 16 12	
037	5	05	Store SI constants.
038	9	09	
039	5	05	
040	4	04	
041	.	-62	
042	4	04	
043	STO1	35 01	
044	1	01	
045	4	04	
046	3	03	
047	8	08	
048	8	08	
049	STO2	35 02	
050	2	02	
051	8	08	
052	9	09	
053	7	07	
054	.	-62	
055	8	08	
056	STO3	35 03	

STEP	KEY ENTRY	KEY CODE	COMMENTS
057	5	05	
058	.	-62	
059	6	06	
060	6	06	
061	9	09	
062	3	03	
063	EEX	-23	
064	CHS	-22	
065	1	01	
066	2	02	
067	STO4	35 04	
068	RTN	24	
069	*LBLc	21 16 13	Convert to experimental σ.
070	1	01	
071	.	-62	
072	0	00	
073	1	01	
074	0	00	
075	5	05	
076	ST×4	35-35 04	
077	RCL4	36 04	
078	RTN	24	Store T and calculate λ_{max}.
079	*LBLA	21 11	
080	STO5	35 05	
081	RCL3	36 03	
082	X⇄Y	-41	
083	÷	-24	
084	RTN	24	
085	*LBLB	21 12	
086	STO6	35 06	Store λ and calculate T for which λ would be λ_{max}.
087	RCL3	36 03	
088	X⇄Y	-41	
089	÷	-24	
090	RTN	24	
091	*LBLC	21 13	Calculate $E_{b(0-\infty)}$.
092	RCL5	36 05	
093	X²	53	
094	X²	53	
095	RCL4	36 04	
096	×	-35	
097	RTN	24	
098	*LBLD	21 14	
099	RCL1	36 01	Calculate $E_{b\lambda}$.
100	ENT↑	-21	
101	+	-55	
102	Pi	16-24	
103	×	-35	
104	RCL6	36 06	
105	5	05	
106	Y^x	31	
107	÷	-24	
108	RCL2	36 02	
109	RCL6	36 06	
110	÷	-24	
111	RCL5	36 05	
112	÷	-24	

REGISTERS

0	1	2	3	4	5	6	7	8	9
λ	c_1	c_2	c_3	σ	T	λ, λ'	sum	kc_2/T	
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

97 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
113	e^x	33	
114	1	01	
115	-	-45	
116	÷	-24	
117	RTN	24	
118	*LBLE	21 15	Calculate $E_{b(0-\lambda)}$.
119	0	00	
120	STO8	35 08	
121	STO7	35 07	
122	*LBL1	21 01	
123	R↓	-31	
124	CLX	-51	
125	RCL8	36 08	
126	RCL2	36 02	
127	RCL5	36 05	
128	÷	-24	
129	-	-45	
130	STO8	35 08	
131	3	03	
132	X⇄Y	-41	
133	÷	-24	
134	RCL6	36 06	
135	X^2	53	
136	÷	-24	
137	LSTX	16-63	
138	1/X	52	
139	RCL6	36 06	
140	÷	-24	
141	-	-45	
142	6	06	
143	RCL6	36 06	
144	÷	-24	
145	RCL8	36 08	
146	X^2	53	
147	÷	-24	
148	-	-45	
149	6	06	
150	RCL8	36 08	
151	X^2	53	
152	÷	-24	
153	RCL8	36 08	
154	÷	-24	
155	+	-55	
156	RCL8	36 08	
157	RCL6	36 06	
158	÷	-24	
159	e^x	33	
160	×	-35	
161	RCL8	36 08	
162	÷	-24	
163	ST+7	35-55 07	
164	RCL7	36 07	
165	÷	-24	
166	EEX	-23	
167	CHS	-22	
168	5	05	

STEP	KEY ENTRY	KEY CODE	COMMENTS
169	X≤Y?	16-35	
170	GTO1	22 01	
171	R↓	-31	
172	CLX	-51	
173	RCL7	36 07	
174	ENT↑	-21	
175	+	-55	
176	Pi	16-24	
177	×	-35	
178	RCL1	36 01	
179	×	-35	
180	RTN	24	
181	*LBLe	21 16 15	Calculate $E_{b(\lambda-\lambda')}$.
182	ENT↑	-21	
183	ENT↑	-21	
184	GSBE	23 15	
185	X⇄Y	-41	
186	RCL6	36 06	
187	STO0	35 00	
188	R↓	-31	
189	STO6	35 06	
190	GSBE	23 15	
191	-	-45	
192	ABS	16 31	
193	RCL0	36 00	
194	STO6	35 06	
195	R↓	-31	
196	RTN	24	

LABELS

A $T \rightarrow \lambda_{max}$	B $\lambda \rightarrow T(\lambda_{max})$	C $\rightarrow E_{b(0-\infty)}$	D $\rightarrow E_{b\ \lambda}$	E $\rightarrow E_{b(0-\lambda)}$
a Eng	b SI	c Exp σ	d	e $\lambda' \rightarrow E_{b(\lambda-\lambda')}$
0	1 $E_{b(0-\lambda)}$	2	3	4
5	6	7	8	9

FLAGS

0	
1	
2	
3	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☑	DEG	☑	FIX	☐
1	☐	☑	GRAD	☐	SCI	☐
2	☐	☑	RAD	☐	ENG	☑
3	☐	☑			n	3

Program Description I

Program Title Black Hole Characteristics

Contributor's Name Geoff Kidd
Address 1514 Oxford St #301
City Berkeley State CA Zip Code 94709

Program Description, Equations, Variables

A black hole of mass (M) in grams has a Schwarzchild radius (Rs) in centimeters of:

$R_s = \frac{2GM}{C^2} = (M) \cdot 1.484986855 \times 10^{-28}$ where G is the universal gravitational constant and C is the speed of light.

The lifetime of a black hole (t_L) in seconds is given by:

$t_L = M^3 \cdot (10^{-28})$.

The temperature of a black hole (K) in degrees Kelvin is

$K = 10^{26}/M$

Operating Limits and Warnings M must be greater than zero

Underflow occurs for R_s when $M < 6.734066343 \times 10^{-72}$

t_L $M < 2.154434653 \times 10^{-24}$

Overflow occurs for K when $M < 1.000000001 \times 10^{-74}$

t_L $M > 2.154434650 \times 10^{33}$

M $R_s > 1.484986854 \times 10^{72}$

Program Description II

Sketch(es)

Sample Problem(s)

1.) The sun has a mass 1.99×10^{33} gm. What would be the temperature, Schwarzchild radius, and lifetime of a black hole of that mass?

2.) Given a Schwarzchild radius of 6.96×10^{10} cm, what is the mass of the black hole? What is the temperature?

Solution(s)

1.) 1.99 [EEX] 33 [D] --> 1.9900×10^{33}
[A] --> 2.9551×10^{5} R_s
[B] --> 5.0251×10^{-8} K
[C] --> 7.8806×10^{71} t_L

2.) 6.96 [EEX] 10 [A] --> 6.9600×10^{10}
[D] --> 4.6869×10^{38} M
[B] --> 2.1336×10^{-13} K

Reference(s) Harwit, Martin <u>Astrophysical Concepts</u> Wiley, New York

User Instructions

BLACK HOLE CHARACTERISTICS

R_S	K	t_L	M

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1.	Enter program			
2.	Enter mass	M	D	M
	or Schwarzchild radius	R_S	A	R_S
	or temperature	K	B	K
	or lifetime	t_L	C	t_L
3.	Compute mass		D	M
	or Schwarzchild radius		A	R_S
	or temperature		B	K
	or lifetime		C	t_L
	For a different variable, go to 3			
	For a new case, go to 2			
	Before any computations, at least one of the four variables must have been entered or results will be unpredictable			
	Note: a new value <u>entered</u> for R_S, t_L or K causes the mass stored in memory to be recalculated.			

67 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	f LBL A	31 25 11	Schwarzschild Radius
	h F? 3	35 71 03	
	GTO 0	22 00	
	1	01	
	.	83	
	4	04	R_s =
	8	08	
	4	04	$M \cdot 1.484986855 \times 10^{-28}$
	9	09	
010	8	08	
	6	06	
	8	08	
	5	05	
	5	05	
	EEX	43	
	2	02	
	8	08	
	CHS	42	
	RCL 3	34 03	
020	×	71	
	STO 0	33 00	
	h RTN	35 22	
	f LBL 0	31 25 00	If entered value of R_s, compute new mass
	STO 0	33 00	
	6	06	
	.	83	
	7	07	
	3	03	$M = R_s \cdot 6.734066344 \times 10^{27}$
	4	04	
030	0	00	
	6	06	
	6	06	
	3	03	
	4	04	
	4	04	
	EEX	43	
	2	02	
	7	07	
	×	71	
040	STO 3	33 03	
	RCL 0	34 00	
	h RTN	35 22	
	f LBL B	31 25 12	Temperature
	h F? 3	35 71 03	
	GTO 0	22 00	$K = 10^{26}/M$
	EEX	43	
	2	02	
	6	06	
	RCL 3	34 03	
050	÷	81	
	STO 1	33 01	
	h RTN	35 22	
	f LBL 0	31 25 00	If entered value of K, compute new Mass
	STO 1	33 01	
	EEX	43	
	2	02	
	6	06	$M = \frac{10^{26}}{K}$
	h x⇄y	35 52	
	÷	81	
060	STO 3	33 03	
	RCL 1	34 01	
	h RTN	35 22	
	f LBL C	31 25 13	Lifetime
	h F? 3	35 71 03	
	GTO 0	22 00	$t_L = M^3 \cdot 10^{-28}$
	EEX	43	
	CHS	42	
	2	02	
	8	08	
070	RCL 3	34 03	
	ENT↑	41	
	3	03	
	h y^x	35 63	
	×	71	
	STO 2	33 02	
	h RTN	35 22	
	f LBL 0	31 25 00	If entered value of t_L, compute new mass
	STO 2	33 02	
	EEX	43	
080	2	02	
	8	08	
	×	71	$M = \sqrt[3]{t_L \cdot 10^{28}}$
	3	03	
	h 1/x	35 62	
	h y^x	35 63	
	STO 3	33 03	
	RCL 2	34 02	
	h RTN	35 22	
	f LBL D	31 25 14	Mass
090	h F? 3	35 71 03	
	GTO 0	22 00	If new value not entered, display old. Else store value entered.
	RCL 3	34 03	
	h RTN	35 22	
	f LBL 0	31 25 00	
	STO 3	33 03	
	h RTN	35 22	
	R/S	84	
		↓	Flags 0-4 off, Deg mode, SCI, DSP 4 are initial values
100			
			Labels used: A, B, C, D, 0
110			

REGISTERS

0	1	2	3	4	5	6	7	8	9
R_s	K	t_L	M						

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title SPECIAL RELATIVITY CONVERSIONS

Contributor's Name Ctein
Address 298 Vista Grande
City Daly City **State** Ca **Zip Code** 94014

Program Description, Equations, Variables This program provides relativistic conversions between the following quantities: rest mass (m); velocity (v, in units of c=1); energy (E), and momentum (P). Given any two it is possible to find the two unknowns by the following equations:

(I)-- $E = m/SQRT(1-v^2)$ // (II)-- $E=SQRT(P^2+m^2)$ // (III)-- $E=P/v$

(IV)-- $P=vE$ // (V)-- $P=SQRT(E^2-m^2)$ // (VI)-- $v=P/E$ // (VII) $m=SQRT(E^2-P^2)$

Data may be entered in any order and recalled at any time. The program scans the registers and, after determining if there is enough data to solve for the unknown, selects the appropriate subset of equations. If insufficient data , then the program displays Error. The following selection patterns are used:

TO FIND:	v	m	E	P
GIVEN:	m,E use V,VI	v,E use IV,VII	v,m use I	v,E use IV
	m,P use II, VI	v,P use III,VII	v,P use III	v,m use I,IV
	E,P use VI	E,P use VII	m,P use II	m,E use V

Because of the complexity of this program, a chart is provided on the next page which diagrams the access patterns used by each labeled subsection. Boxes are used to represent direct jumps, and circles represent subroutine calls. The user is advised to review this carefully before modifying this program.

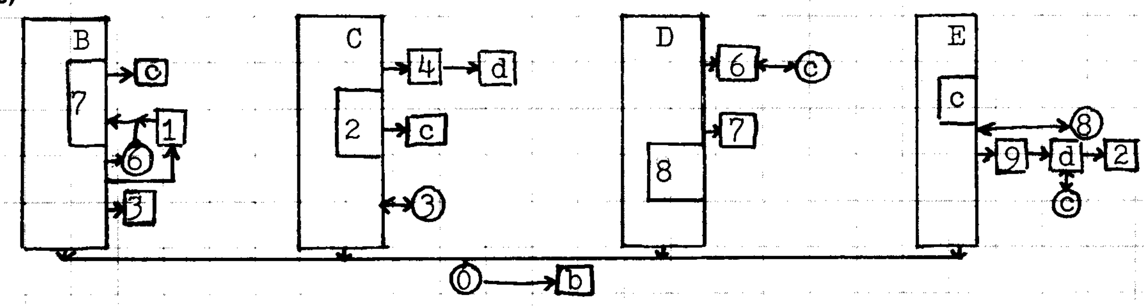
Operating Limits and Warnings

all data must be positive. Velocity must be less than 1. ERROR message will be displayed if a real solution does not exist or the input data is outside these limits.

Program Description II

Special Relativity

Sketch(es)



Sample Problem(s)

1) Find the velocity and momentum of an electron (m=.511 MeV) with a total energy of 1.0 MeV.

2) Given an E of 500 MeV and a P of 498 MeV/c, what is the particle's mass and velocity.

3) At .9c, and electron has an energy of 1.1723 MeV. Find its rest mass and momentum.

4) An electron is traveling at .3c. Find its momentum and energy.

Solution(s)

1) A , .511, C, 1, D, B, v=.8596c; E, P=.8596MeV/c.

2) A , 500, D, 498, E, B, v=.996c; C, m= 44.6766MeV

3) A , .9, B, 1.1723, D, C, m=.511MeV; E, P=1.0551MeV/c

4) A , .3, B, .511, C, D, E=.5357MeV; E, P=.1607 MeV/c

Reference(s) HP-65 library program #308 by this author.

User Instructions

SPECIAL RELATIVITY CONVERSIONS

1 ◀ RESET | VELOCITY | MASS | ENERGY | MOMENTUM ▶ 2

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Load Side one of card				
2	Reset registers	------	A		
3	TO ENTER A VARIABLE:				
	velocity	v	B		v
	mass	m	C		m
	energy	E	D		E
	momentum	P	E		P
4	TO FIND A VARIABLES VALUE:				
	velocity	none	B		v
	mass	none	C		m
	energy	none	D		E
	momentum	none	E		P
	GO TO STEP 2 FOR EACH NEW SET OF KNOWN VARIABLES				

FLAGS	
0	------
1	------
2	------
3	data?

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n 4	

LABELS

A reset	B velocity	C mass	D energy	E momentum
a ------	b store 'x'	c 0 'error	d eq. V, VII	e ------
0 I or Ø?	1 find v; $\bar{m}$	2 eq. V, VII	3 $\sqrt{(1-x^2/y^2)}$	4 find m; $\bar{v}$
5 ------	6 eq. II	7 eq. VI	8 $\sqrt{(1-v^2)}$	9 find P; $\bar{v}$

67 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBL A	31 25 11	RESET
	CL REG	31 43	
	CF 3	35 61 03	
	R/S	84	----------------
	*LBL B	31 25 12	FIND/STORE v
	1	01	
	GSB 0	31 22 00	store new v
	RCL 2	34 02	m
	x=0?	31 51	if m is unknown
010	GTO 1	22 01	then go to 1
	RCL 3	34 03	E
	x≠0?	31 61	if E,m are known
	GTO 3	22 03	then go to 3
	GSB 6	31 22 06	eq.II gives E
	ENTER	41	
	*LBL 7	31 25 07	----------------
	R↓	35 53	
	RCL 4	34 04	P
	x↔y	35 52	E
020	/	81	eq. VI gives v
	GTO c	22 31 13	check out P
	*LBL C	31 25 13	FIND/STORE m
	2	02	
	GSB 0	31 22 00	store new m
	x=0?	31 51	if v is unknown
	GTO 4	22 04	then go to 4
	RCL 3	34 03	E
	x	71	eq.IV gives P
	LST x	35 82	E
030	x≠0?	31 61	if E is known,
	GTO 2	22 02	go to 2
	RCL 4	34 04	P
	ENTER	41	
	ENTER	41	
	RCL 1	34 01	v
	/	81	eq.III gives E
	*LBL 2	31 25 02	eq. V or VII
	ENTER	41	
	R↓	35 53	SQRT(x^2-y^2)
040	GSB 3	31 22 03	
	R↑	35 54	
	x	71	eq.VII gives m
	GTO c	22 31 13	check for valid
	*LBL 3	31 25 03	results
	/	81	find
	asin	32 62	SQRT(1-y^2/x^2)
	cos	31 63	
	RTN	35 22	
	*LBL D	31 25 14	FIND/STORE E
050	3	03	
	GSB 0	31 22 00	store new E
	x=0?	31 51	if v is unknown
	GTO 6	22 06	then go to 6.
	RCL 2	34 02	if m is unknown
	x=0?	31 51	then go to 7.
	GTO 7	22 07	

STEP	KEY ENTRY	KEY CODE	COMMENTS
	*LBL 8	31 25 08	v in X
	x↔y	35 52	
	asin	32 62	SQRT(1-v^2)
060	cos	31 63	
	/	81	eq.I gives E
	RTN	35 22	
	*LBL E	31 25 15	FIND/STORE P
	4	04	
	GSB 0	31 22 00	store new P
	x=0?	31 51	if v is unknown
	GTO 9	22 09	then go to 9.
	RCL 2	34 02	if m,v known,
	x≠0?	31 61	then eq.I gives
070	GSB 8	31 22 08	E.
	RCL 3	34 03	If R_3 contains
	x=0?	31 51	E(i.e.≠0), then
	R↓	35 53	this takes prior-
	RCL 1	34 01	ity.
	x	71	eq.IV gives P
	*LBL c	32 25 13	if variable or
	x=0?	31 51	result is not
	/	81	legitimate,end.
	RTN	35 22	check/store'x'
080	*LBL 0	31 25 00	store (i)
	ST I	35 33	if data has been
	F? 3	35 71 03	entered,go to b
	GTO b	22 31 12	check contents
	RCL(i)	34 24	of register'x'
	x≠0?	31 61	and display if
	R/S	84	good. Otherwise
	RCL 1	34 01	RCL v and return
	RTN	35 22	STORE NEW "x"
	*LBL b	32 25 12	in register defi
090	R↓	35 53	ned by (i)
	STO(i)	33 24	
	R/S	84	
	*LBL 1	31 25 01	FIND v;m UNKNOWN
	RCL 3	34 03	E
	ENTER	41	
	GTO 7	22 07	eq.VI gives v
	*LBL 4	31 25 04	FIND m;v UNKNOWN
	RCL 4	34 04	P
	GTO d	22 31 14	go to d
100	*LBL 6	31 25 06	EQ. II
	RCL 2	34 02	m
	GSB c	32 22 13	check validity
	RCL 4	34 04	P
	GSB c	32 22 13	check validity
	R→P	32 72	E=SQRT(m^2+P^2)
	RTN	35 22	
	*LBL 9	31 25 09	FIND P:v UNKNOWN
	RCL 2	34 02	m
	*LBL d	32 25 14	------------
110	GSB c	32 22 13	check validity
	RCL 3	34 03	E
	GTO 2	22 02	eq.V orVII

REGISTERS

0	1	2	3	4	5	6	7	8	9
	velocity	mass	energy	momentum					

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I
					used

Program Description I

Program Title Three Dimensional Special Relativity

Contributor's Name William C. Wickes

Address Princeton University, Department of Physics

City Princeton **State** N.J. **Zip Code** 08540

Program Description, Equations, Variables

1. Given the components of any 4-vector, in particular $x'^{\mu} = (x', y', z', ct')$ or $p'^{\mu} = (p'^{x}, p'^{y}, p'^{z}, \frac{E'}{c})$, calculate the components x^{μ} or p^{μ} in a frame in which the original frame is moving with velocity $\vec{\beta} = (\beta^{x}, \beta^{y}, \beta^{z},)$.

   $\vec{p}$ = momentum

   E = total energy

   $\vec{\beta} = \vec{v}/c$ $\vec{v}$ = velocity

2. For any $\vec{\beta}$, calculate the time-dilation/length contraction factor γ.

3. For a 4-vector Δx^{μ} connecting any two space-time events, calculate the invariant interval $c\Delta\tau$.

Formulae:

$$\Delta\vec{x} = \Delta\vec{x}' + \vec{\beta}[(\gamma-1)\frac{\vec{\beta}\cdot\vec{x}'}{\beta^2} + \gamma c\Delta t']$$

$$\Delta t = \gamma(t + \vec{\beta}\cdot\vec{x}/c^2)$$

$$\gamma = [1-\beta^2]^{-1/2}$$

$$\beta = |\vec{\beta}| = [\beta^{x^2}+\beta^{y^2}+\beta^{z^2}]^{1/2}$$

$$|\Delta\vec{x}| = [\Delta x^2+\Delta y^2+\Delta z^2]^{1/2}$$

$$c^2\Delta\tau^2 = c^2\Delta t^2 - |\Delta\vec{x}|^2$$

The coordinate frames are assumed to be synchronized so that the event (0,0,0,0) has the same coordinates in both frames.

Operating Limits and Warnings For a spacelike interval, $c^2\Delta\tau^2 < 0$, the calculator will display " - $|c\Delta\tau|$"

Program Description II

Sketch(es)

Sample Problem(s) An observer moving relative to the Earth with velocity $\vec{\beta}=(.4,.5,.6)$ measures the coordinates of an event as $x'^{\mu} = (1,2,3,4)$.

a) Give the coordinates relative to the Earth frame.

b) What is the interval between the event and the origin (0,0,0,0)

Solution(s) (If necessary) Set dimensions = 3: 3[E] --------------3.00

Enter $\vec{\beta}$: .4[↑] .5[↑] .6[A] ------------ .88*** $|\vec{\beta}|$

2.09 γ

Enter x'^{μ}: 1[↑] 2[↑] 3[↑] 4[B] -------- 1.00 x'

Calculate_ $c\Delta\tau$ [D] -------- 1.41 $c\Delta\tau$

Calculate x^{μ}: [C] --------15.01*** t

10.71*** z

8.43*** y

6.14*** x

Reference(s) J.D. Jackson, Classical Electrodynamics (J. Wiley & Sons, NY 1962)

User Instructions

3-Dimensional Special Relativity

	A	B	C	D	E
(shifted)	$\gamma \to \lvert\beta\rvert$				
1 ◀ ▶ 2	$\vec{\beta} \to \gamma$	x'^{μ}	$\to x^{\mu}$	$c\Delta\tau$	N

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	KEYS	OUTPUT DATA/UNITS
1.	Set number space dimensions N	1,2,or 3		E	N
	(default is N=3)				
2.	Enter $\vec{\beta}$ (if N=3)	β^x	↑		
	(if N>1)	β^y	↑		
		β^z	A		β***
					γ
3.	Enter x^{μ}. (if N=3)	x	↑		
	(if N>1)	y	↑		
		z	↑		
		ct	B		x
4.	Compute x^{μ}		C		x***(if N=3)
					y***(if N>1)
					z***
					ct
5.	Compute $c\Delta\tau$		D		$\pm \lvert c\Delta\tau\rvert$
	Result is positive if $c\Delta\tau$				
	negative if $c\Delta\tau$				
6.	To calculate the speed β corresponding to a				
	dilation factor γ	γ	f	A	β

67 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	LBL D	31 25 14	
	RCL 6	34 06	
	F? 0	35 71 00	
	GTO 4	22 04	
	RCL 4	34 04	
	R→P	32 72	
	F? 1	35 71 01	Compute Σx_i^2
	GTO 4	22 04	
	RCL 5	34 05	
010	R→P	32 72	
	LBL 4	31 25 04	
	x^2	32 54	
	RCL 7	34 07	
	x^2	32 54	
	−	51	$c^2t^2 - x^2$
	CHS	42	
	x<0	31 71	
	SF 0	35 51 02	SPACELIKE? SF0
	ABS	35 64	
020	$\sqrt{x}$	31 54	
	F? 2	35 71 02	
	CHS	42	− for SPACELIKE
	RTN	35 22	
	LBL a	32 25 11	Calculate β from γ
	STO B	33 12	
	x^2	32 54	
	1/x	35 62	
	1	01	
	−	51	
030	CHS	42	
	$\sqrt{x}$	31 54	
	STO A	33 11	
	RTN	35 22	
	LBL e	32 25 15	
	RCL 6	34 06	Compute $\vec{\beta}\cdot\vec{x}'$
	RCL 3	34 03	
	×	71	$= \sum_i \beta^i x'^i$
	F0?	35 71 00	
	RTN	35 22	
040	RCL 1	34 01	
	RCL 4	34 04	
	×	71	
	+	61	
	F? 1	35 71 01	
	RTN	35 22	
	RCL 2	34 02	
	RCL 5	34 05	
	×	71	
	+	61	
050	RTN	35 22	
	LBL A	31 25 11	Compute γ
	STO 3	33 03	
	F? 0	35 71 00	
	GTO 6	22 06	
	x⇄y	35 52	
	R→P	32 72	

STEP	KEY ENTRY	KEY CODE	COMMENTS
	LST x	35 82	
	STO 1	33 01	
	x⇄y	35 52	
060	F? 1	35 71 01	
	GTO 6	22 06	
	R↑	35 54	
	STO 2	33 02	
	R→P	32 72	$\lvert\vec{\beta}\rvert$
	LBL 6	31 25 06	
	STO A	33 11	
	COS^{-1}	32 63	} $\sqrt{1-\beta^2}$
	SIN	31 62	
	1/x	35 62	
070	STO B	33 12	γ
	RCL A	34 11	
	-x-	31 84	DISPLAY β
	x⇄y	35 52	
	RTN	35 22	γ
	LBL B	31 25 12	
	STO 7	33 07	
	R↓	35 53	
	STO 6	33 06	STO $\vec{\beta}$
	R↓	35 53	
080	STO 4	33 04	
	R↓	35 53	
	STO 5	33 05	
	RTN	35 22	
	LBL C	31 25 13	$x'^\mu \rightarrow x^\mu$
	GSB e	32 22 15	$\vec{\beta}\cdot\vec{x}'$
	RCL A	34 11	
	x^2	32 54	
	÷	81	
	RCL B	34 12	
090	1	01	
	−	51	
	×	71	
	RCL B	34 12	
	RCL 7	34 07	
	×	71	
	+	61	
	STO C	33 13	
	3	03	
	STO 0	33 00	USE R0 AS COUNTER
100	ST I	35 33	
	LBL 0	31 25 00	compute one component each cycle
	RCL 0	34 00	
	ST I	35 33	
	RCL C	34 13	
	RCL (i)	34 24	
	×	71	
	RC I	35 34	
	3	03	
	+	61	
110	ST I	35 33	
	CLx	44	
	RCL (i)	34 24	

REGISTERS

0	1	2	3	4	5	6	7	8	9
counter	β^y	β^x	β^z	y	x	z	ct		

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
				y'	x'	z'	ct'		

A	B	C	D	E	I
β	γ				USED

67 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
	+	61	
	P⇄S	31 42	
	STO (i)	33 24	
	P⇄S	31 42	
	2	02	
	F? 0	35 71 00	One cycle for N=1
	STO − 0	33 51 00	
120	.	83	
	5	05	
	F? 1	35 71 01	Two cycles for N=2
	STO − 0	33 51 00	
	0	00	
	ST I	35 33	
	DSZ (i)	32 33	
	GTO 0	22 00	
	RCL 7	34 07	Compute ct
	GSB e	32 22 15	
130	+	61	
	RCL B	34 12	
	×	71	
	P⇄S	31 42	
	STO 7	33 07	
	-x-	31 84	
	RCL 6	34 06	
	-x-	31 84	
	F? 0	35 71 00	
	GTO 5	22 05	
140	RCL 4	34 04	DISPLAY RESULTS
	-x-	31 84	
	F? 1	35 71 01	
	GTO 5	22 05	
	RCL 5	34 05	
	LBL 5	31 25 05	
	P⇄S	31 42	
	RTN	35 22	
	LBL E	31 25 15	
	ST I	35 33	
150	GTO (i)	22 24	Set appropriate flags for N=1, 2, or 3
	LBL 1	31 25 01	
	CF 1	35 61 01	
	SF 0	35 51 00	
	RTN	35 22	
	LBL 2	31 25 02	
	CF 0	35 61 00	
	SF 1	35 51 01	
	RTN	35 22	
	LBL 3	31 25 03	
160	CF 0	35 61 00	
	CF 1	35 61 01	
	RTN	35 22	

LABELS

A 51 $\vec{\beta} \to \gamma$	B 075 x'^{μ}	C 084 $\to x^{\mu}$	D 001 $c\Delta t$	E 148 N
a 024 $\gamma \to \beta$	b	c	d	e 034 $\vec{\beta}, \vec{x}'$
0 101	1 151	2 155	3 159	4 011
5 145	6 65	7	8	9

FLAGS

0	N = 1
1	N = 2
2	USED
3	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☐	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	2

Program Description I

Program Title Einsteins Twin Paradox

Contributor's Name David M. Weingold

Address % Synergy Research P.O. Box 372

City Woodmere **State** N.Y. **Zip Code** 11598

Program Description, Equations, Variables

The program is arranged to calculate subjective and real time differential between an observer on Earth and the pilot of a vehicle accelerating near the speed of light. If you imagine twins at age 21. One becomes an astronaut and volunteers for the first interstellar flight. He takes off and travels at a ponderous speed of say 2.994444444*10**8 meters per second. In this situation it is accurate enough to call C the speed of light, 3*10**8. The astronaut travels for what he measures to be a year well past the sun at which time he fires retro and navigational engines, and turns around and heads toward Earth; the journey naturally takes another year. He is now 23 years old but when he steps from the ship his twin is over 37 years old! That over 16 years had passed on Earth. The explanation as to why this happened involves very complicated non Euclidian geometry and relativistic considerations of accelerating frame of reference too complicated for this discussion, it sufficies to say that in the event of tremendous accelerations such as the turning around of a space craft traveling near the speed of light that the order of magnitude of energy involved is extremely large and the consideration of it as it interelates to space as time is conceived as a fourth physical

Operating Limits and Warnings

Program Description I

Program Title Einsteins Twin Paradox

Contributor's Name David M. Weingold

Address % Synergy Research P.O. Box 372

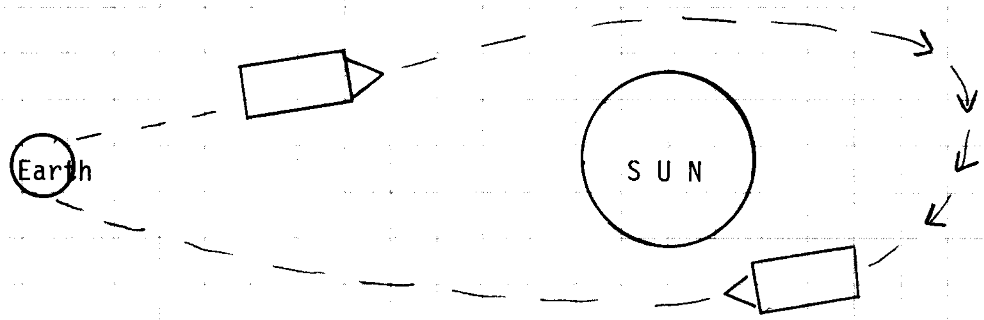
City Woodmere **State** New York **Zip Code** 11598

Program Description, Equations, Variables dimension of space, the Universe is then conceived as a giant four dimensional sphere with a three dimensional surface. The space craft in its turning travels relative to the Earth, not as far along that fourth dimension and hence the differential between the twins age. The equations for this case are quite simple and adequate for this case. They consist primarily of the Lorentz transform i.e., $\sqrt{(1 - \frac{v^2}{c^2})}$, where v is the velocity of the space craft relative to the Earth, and c is the universal constant, 3×10^8 meters per second, the speed of light. The program inputs consist of speed of space craft in meters per second, time passed on Earth, time passed on board the craft, and the ages of the twins before the flights. With input T_E, time passed on Earth, the equation $T_S = T_E\sqrt{(1 - \frac{v^2}{c^2})}$ gives T_S, ["time passed on board"] ship during journey. Input T_S, time passed on board ship, and the equation: $T_E = \frac{T_S}{\sqrt{1 - \frac{v^2}{c^2}}}$ gives you T_E, ["time passed on Earth"] during journey. The label A clears and initiates the program. Lbl B is the input for average velocity of the craft. Lbl C is the input for time passed on earth in years and outputs time passed on board ship by hitting fC Lbl D input time passed on board ship fD give appropriate time passed on earth the E's give ages.

Operating Limits and Warnings Be certain that you enter the speed of the space craft in meters per second. All time and age entries must be in years. Outputs will be in years. Do not try to make the space travel at the speed of light, ≈ (3.00×10^8 meters/second) as this will only show an error as should be and is implied by the theory of relativity.

Program Description II

Sketch(es)



Sample Problem(s) Suppose two twins, age thrity, take part in this experiment the velocity of the ship will average 2.999111111x10^8, if the twin on board travels a total of one year how much time will have passed on Earth? And given that 25 years passes on earth before return of the ship, how much time passed on board? What was the age differential in both cases?

Solution(s)

```
Load side 1 and side 2
[A] ---------------------------------> -9.00 x 10^16
2.999111111 [EEX] 8 [B]
1 [D] [f] [D] ------------------------> 41.08 years passed on Earth
30 [E] -------------------------------> 71    twin on Earth's age
Age differential is 40 years (71-31)
[A]
2.999111111 [EEX] 8 [B]
25 [C] [f] [C] ----------------------->   .6085 years passed in space
30 [f] [E] ---------------------------> 30.6085 twin on board's age
Age differential is 24.3015 (55-30.6085)
```

REFERENCE (S) Introduction to Special Relativity by James H. Smith (chp. 6) W.A. Benjam Inc., New York, Amsterdam 1965.

User Instructions

Einstien Twin Paradox	mtrs./sec.	[f][C]→(T_S)yrs	[f][D]→(T_E)yrs	[f][E] space twins age	
INT	speed of craft	(T_E)years	(T_S)years	age of Earth twin	
[A]	[B]	[C]	[D]	[E]	

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1.	Run tape				
2.	Hit [A] initiate clear registers set display		A		9.000+16
3.	Enter ship average velocity in meters/sec	2.999+8	B		8.994+16
4.	Enter time passed on ship in years	1	D		3.155+07
5.	Calculate time passed on Earth in years		f	D	3.873+01
6.	Calculate how old Earth man is upon end	30	E		6.874+01
7.	Enter time passed on Earth in years	25	C		7.889+08
8.	Calculate time passed on ship in years		f	C	6.454-01
9.	Find age of space twin at end of journey	30	f	E	3.064+01

Always enter time in years, and speed in mtrs. per second, to go to new case i.e., new speed or different amounts of time or ages*. Hit [A], and then continue from step #3 with new values.

If time passed outputs are decimals, multiplying by 365.25 converts to days

* The ages used in the [E] and [f] [E] subroutines need not be the same, our two "participants" need not be twins.

Time passed outputs, or age outputs can all be viewed in fixed mode by hitting fix key. i.e., 3.873+01→38.73, or 6.873+01→68.73

LABELS

A	B	C	D	E
Initiate	Avg Ship Vel Ent	T. passed on Earth Ent	T. passed in space Ent	Earth Twin F. age
a $\sqrt{1-\frac{v^2}{c^2}}$ routine	b	c Earth T. to ship T.	d Space T. to Earth T.	e Space twin F. age
0	1	2	3	4
5	6	7	8	9

FLAGS: 0, 1, 2, 3

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☐
1	☐	☒	GRAD	☐	SCI	☒
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	9

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	iniTiate STore constants Clear Registers Find c^2 and Store in RA.
002	CLRG	16-53	
003	SCI	-12	
004	DSP9	-63 09	
005	CLX	-51	
006	3	03	
007	6	06	
008	0	00	
009	0	00	
010	STO0	35 00	
011	2	02	
012	4	04	
013	STO1	35 01	
014	3	03	
015	6	06	
016	5	05	
017	.	-62	
018	2	02	
019	5	05	
020	STO2	35 02	
021	3	03	
022	EEX	-23	
023	8	08	
024	X	53	
025	STOA	35 11	
026	RTN	24	
027	*LBLB	21 12	Enter ship Avg. Velocity Square and STore in RB
028	X^2	53	
029	STOB	35 12	
030	RTN	24	
031	*LBLC	21 13	EnTer Time Passed ON Earth in years convert To Seconds STore in RC
032	RCL0	36 00	
033	x	-35	
034	RCL1	36 01	
035	x	-35	
036	RCL2	36 02	
037	x	-35	
038	STOC	35 13	
039	RTN	24	
040	*LBLc	21 16 13	Calculate $T_s = T_E\sqrt{1-\frac{v^2}{c^2}}$ STore R3 Space and Print
041	RCLC	36 13	
042	GSB0	23 00	
043	x	-35	
044	RCL0	36 00	
045	÷	-24	
046	RCL1	36 01	
047	÷	-24	
048	RCL2	36 02	
049	÷	-24	
050	STO3	35 03	
051	PSE	16 51	
052	SPC	16-11	
053	PRTX	-14	
054	RTN	24	
055	*LBLD	21 14	Enter Time Passed in Space convert from Years To Seconds STore in RD
056	RCL0	36 00	
057	x	-35	
058	RCL1	36 01	
059	x	-35	
060	RCL2	36 02	
061	x	-35	
062	STOD	35 14	
063	RTN	24	
064	*LBLd	21 16 14	Calculate $T_E = \frac{T_s}{\sqrt{1-\frac{v^2}{c^2}}}$ STore in R4
065	RCLD	36 14	
066	GSB0	23 00	
067	÷	-24	
068	RCL0	36 00	
069	÷	-24	
070	RCL1	36 01	
071	÷	-24	
072	RCL2	36 02	
073	÷	-24	
074	STO4	35 04	
075	PSE	16 51	
076	SPC	16-11	
077	PRTX	-14	
078	RTN	24	
079	*LBL0	21 00	$\sqrt{1-\frac{v^2}{c^2}}$ subroutine
080	RCLB	36 12	
081	RCLA	36 11	
082	÷	-24	
083	CHS	-22	
084	1	01	
085	+	-55	
086	√X	54	
087	RTN	24	
088	*LBLE	21 15	Calculate Earth Twin Final Age
089	RCL4	36 04	
090	+	-55	
091	PSE	16 51	
092	SPC	16-11	
093	PRTX	-14	
094	RTN	24	
095	*LBLe	21 16 15	Calculate Space Twin Final age
096	RCL3	36 03	
097	+	-55	
098	PSE	16 51	
099	SPC	16-11	
100	PRTX	-14	
101	RTN	24	
	R/S	51	

REGISTERS

0	1	2	3	4	5	6	7	8	9
3600	24	365.25	T_s	T_E					

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I
c^2	v^2	time passed Earth in sec.	time passed rocket in sec.		

Program Description I

Program Title Delta-V - Orbit Simulator

Contributor's Name Harold T. Coderre
Address 414 1915 Hall
City Princeton State New Jersey Zip Code 08540

Program Description, Equations, Variables This program calculates orbit parameters from initial position and velocity data both for elliptical and hyperbolic orbits in a plane. It is also possible to move the point of interest to anywhere along the orbit and then recalculate orbit parameters. Equations Used:

Energy: $E = \frac{1}{2} V_i^2 - \frac{GM}{R_i}$

Angular Momentum: $\ell = vr\sin(\alpha_i - \theta_i)$

Eccentricity: $\epsilon = \sqrt{1 + \frac{2E\ell^2}{(GM)^2}}$

$R_0 = \frac{\ell^2}{GM}$

$\theta' = \theta_i + \cos^{-1}\left(\frac{\frac{R_0}{R_i} - 1}{\epsilon}\right)$

$R_{min} = R_0/1+\epsilon$

Semimajor Axes: $a = R_0/(1-\epsilon^2)$

Semiminor Axes: $b = a\sqrt{1-\epsilon^2}$

Period: $T = 2\pi\sqrt{\frac{a^3}{GM}}$

Given θ_{new}:

$R_{new} = R_0/(1+\epsilon\cos(\theta_{new} - \theta'))$

$V_{new} = \sqrt{2(E + \frac{GM}{R_{new}})}$

$\alpha_{new} = \theta_{new} + \sin^{-1}\left(\frac{\ell}{V_{new} R_{new}}\right)$

For a change in Velocity

$\vec{V}_{new} = \vec{V}_{old} + \vec{\Delta V}$

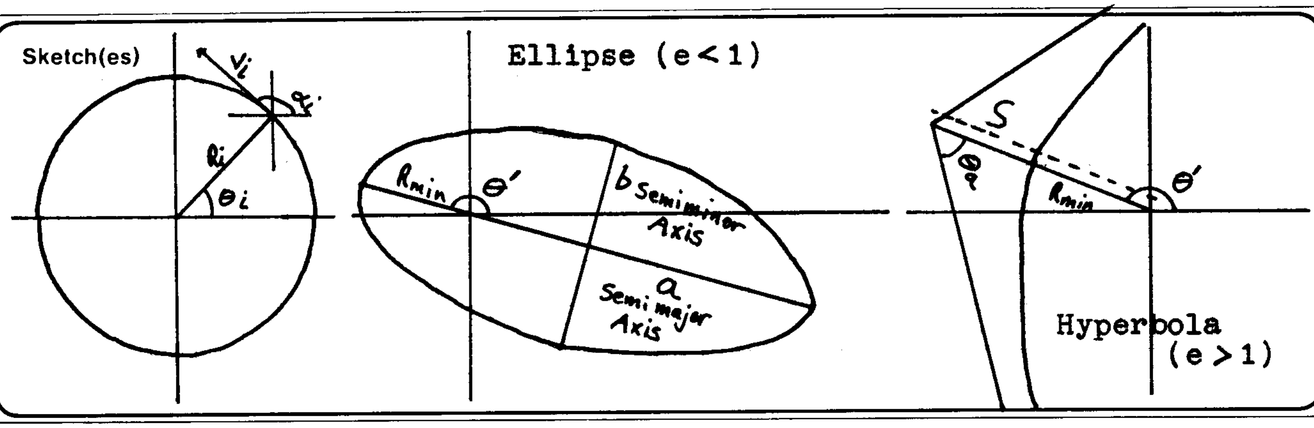
Distance to Asymptote Vertex $S = R_{min}/(1 - \frac{1}{\epsilon})$

Angle between Asymptotes and Radius Vector $\theta_a = \cos^{-1}(\frac{1}{\epsilon})$

Operating Limits and Warnings All angles should be $0 \leq \theta \leq 360$. If $\hat{\theta}$ (A) gives a negative radius for a hyperbolic orbit ($e > 1$) the orbit does not exist for the inputted θ. This program becomes ill-conditioned and inaccurate near degenerate conics (Circles, Parabolas and Straight lines). For added realism: avoid all orbits where R_{min} < radius of the attracting body ($6.400 * 10^6$ m for the Earth).

Program Description II

Sketch(es)



Sample Problem(s) Execute a transfer from Low Earth Orbit to Geosynchronous

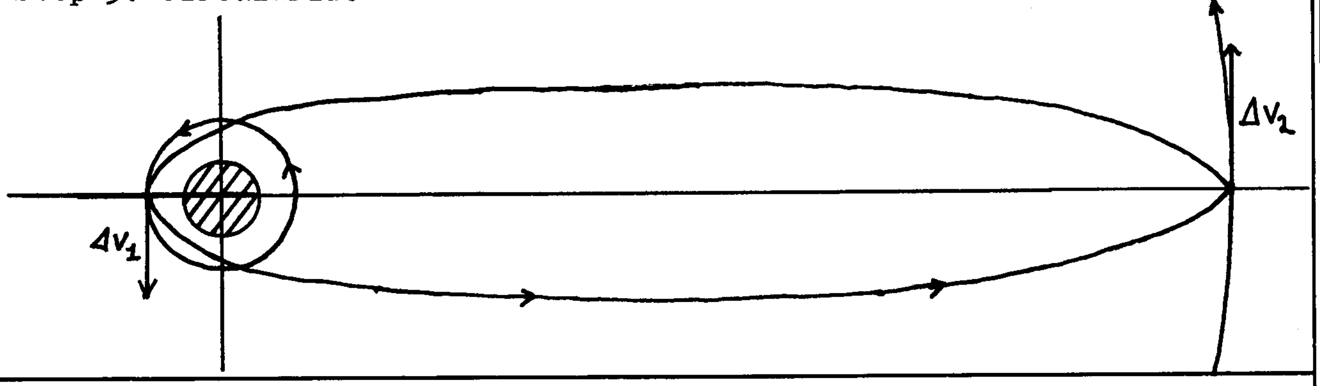
Step 1: Initialize $R_i = 7.1E6$ $\theta_i = 0$ $V_i = 7.4E3$ $\alpha_i = 90$

Step 2: Position Satellite at Perigee

Step 3: Accelerate to Synchronous Transfer

Step 4: Position Satellite at new Apogee

Step 5: Circularize



Solution(s) Keystrokes: (all underlined numbers are machine output)

Step 1: 7.10E6 ENT 0 [f][A]
7.40E3 ENT 90 [f][B]

Step 2: [D] 180.0 [A] 6.7462E6

Step 3: 2312 [RCL] [3] [B] 270.0

Step 4: [D] 180.0 180 [+] [A] 4.228688E7

Step 5: 1455 [RCL] [3] [B] 90.0 [C] 3.505809E-3 [E] 4.213916E7
[R/S] 23.90148 [H→H.MS] 23.54053 *******

Reference(s) Goldstein: Classical Mechanics Chapt 3

User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Load side 1 and side 2				
2	Initialize Utility Registers	3600	STO	5	
		360	STO	D	
		180	STO	B	
3	Compute G * M +	6.6732E-11	ENTER↑		
	(Mass of attracting body (Kg)) ⟶	M	*	STO 4	G * M
4	Enter initial position	R_i	ENTER↑		
		θ_i	f	A	R_i
5	Enter initial velocity	V_i	ENTER↑		
		α_i	f	B	V_i
6	(Optional) Calculate the eccentricity		C		ϵ
7	Calculate θ′ and R_{min} (program will pause to display ε)		D		θ′
			x⇄y		R_{min}
8	(Step 8 must always be preceded by Step 7)				
	For e<1: Calculate semimajor and		E		a
	seminor Axes		x⇄y		b
	Calculate the Period T		R/S		T (Hrs)
	For e≥1: Calculate S		E		S
	Calculate θ_a		R/S		θ_a
	(if e=1 program will return 0 for S)				
9	Position the Satellite at a given θ	θ	A		R_{new}
	Find new Speed		RCL	2	V_{new}
	Find new Velocity Bearing		RCL	3	α_{new}
10	Introduce a change in Velocity	ΔV	ENTER		
		α_Δ	B		α_{new}
11	Now go back to step 6 or 7 and recalculate the orbit				
	Note on dimensions: All inputted distances and velocities should be in meters and meters/sec. The Program will also output in these units.				
	+For the Earth G * M = 3.98991 * 10^{14}				

Note: All quantities listed below are per kilogram

Program Listing I

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STEP	KEY ENTRY	KEY CODE	COMMENTS
001	LBL a	32 25 11	
	STO 1	33 01	
	x⇌y	35 52	
	STO 0	33 00	
	RTN	35 22	
	LBL b	32 25 12	
	STO 3	33 03	
	x⇌y	35 52	
	STO 2	33 02	
010	SF 1	35 51 01	
	RTN	35 22	
	LBL C	31 25 13	
	RCL 2	34 02	
	X**2	32 54	
	2	02	
	÷	81	
	RCL 4	34 04	
	RCL 0	34 00	
	÷	81	
020	-	51	
	STO 6	33 06	→ENERGY
	RCL 3	34 03	
	RCL 1	34 01	
	-	51	
	SIN	31 62	
	RCL 0	34 00	
	*	71	
	RCL 2	34 02	
	*	71	
030	STO 7	33 07	→ANGULAR MOMENTUM
	X**2	32 54	
	2	02	
	*	71	
	RCL 6	34 06	
	*	71	
	RCL 4	34 04	
	X**2	32 54	
	÷	81	
	1	01	
040	+	61	
	√X	31 54	
	STO 8	33 08	→ECCENTRICITY
	1	01	
	CLF 0	35 61 00	
	x≤y	32 71	
	STF 0	35 51 00	
	RCL 1	34 01	
	RCL 7	34 07	
	X**2	32 54	
050	RCL 4	34 04	
	÷	81	
	STO 9	33 09	→R_o
	RCL 0	34 00	
	÷	81	
	1	01	
	-	51	

STEP	KEY ENTRY	KEY CODE	COMMENTS
	RCL 8	34 08	
	÷	81	
	GSB d	32 22 14	
060	COS-1	32 63	
	RCL 3	34 03	
	RCL 1	34 01	
	-	51	
	COS	31 63	
	LST X	35 82	
	SIN	31 62	
	*	71	
	x<0	31 71	
	GTO 7	22 07	
070	R↓	35 53	
	CHS	42	
	R↑	35 54	
	LBL 7	31 25 07	
	R↓	35 53	
	+	61	
	GSB e	32 22 15	
	STO A	33 11	→θ'
	CLF 1	35 61 01	
	RCL 8	34 08	
080	RTN	35 22	
	LBL D	31 25 14	
	TF 1	35 71 01	
	GSB C	31 22 13	
	RCL 8	34 08	
	Pause	35 72	
	1	01	
	+	61	
	1/X	35 62	
	RCL 9	34 09	
090	*	71	→R_{min}
	STO C	33 13	
	RCL A	34 11	
	RTN	35 22	
	LBL E	31 25 15	
	TF 0	35 71 00	
	GTO 2	22 02	ellipse section
	RCL 9	34 09	
	1	01	
	RCL 8	34 08	
100	X**2	32 54	
	-	51	
	÷	81	
	STO E	33 15	→Semimajor Axis
	LST X	35 82	
	√X	31 54	
	*	71	→Semiminor Axis
	RCL E	34 15	
	R/S	84	
	RCL E	34 15	
110	X**2	32 54	
	LST X	35 82	
	*	71	

REGISTERS

0	1	2	3	4	5	6	7	8	9
Dist	BEARING	Speed	Speed Bearing	G * M	3600	Energy	A. M.	e	R_o

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I
θ'	180	R_{min}	360	a	

67 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
	RCL 4	34 04	
	÷	81	
	√x	31 54	
	2	02	
	*	71	
	π	35 73	
	*	71	
120	RCL 5	34 05	
	÷	81	→Period (Hrs)
	RTN	35 22	
	LBL 2	31 25 02	Hyperbola Section
	RCL C	34 13	
	1	01	
	RCL 8	34 08	
	1/X	35 62	
	-	51	
	x≠0	31 61	Output Zero for a Parabola
130	GTO 3	22 03	
	RTN	35 22	
	LBL 3	31 25 03	
	÷	81	
	R/S	84	→S
	RCL 8	34 08	
	1/X	35 62	
	COS^{-1}	32 63	$\rightarrow \theta_a$
	RTN	35 22	
	LBL A	31 25 11	
140	STO 1	33 01	
	RCL A	34 11	
	-	51	
	COS	31 63	
	RCL 8	34 08	
	*	71	
	1	01	
	+	61	
	RCL 9	34 09	
	÷	81	
150	1/X	35 62	
	STO 0	33 00	$\rightarrow R_{new}$
	RCL 4	34 04	
	x⇄y	35 52	
	÷	81	
	RCL 6	34 06	
	+	61	
	2	02	
	*	71	
	√x	31 54	
160	STO 2	33 02	$\rightarrow V_{new}$
	RCL 7	34 07	
	RCL 0	34 00	
	RCL 2	34 02	
	*	71	
	÷	81	
	GSB d	32 22 14	
	SIN^{-1}	32 62	
	RCL 7	34 07	
	RCL 1	34 01	
170	RCL A	34 11	
	-	51	
	SIN	31 62	
	*	71	
	x>0	31 81	
	GTO 4	22 04	
	CLX	44	
	RCL B	34 12	
	-	51	
	CHS	42	
180	R↑	35 54	
	LBL 4	31 25 04	
	R↓	35 53	
	RCL 1	34 01	
	+	61	
	GSB e	32 22 15	
	STO 3	33 03	$\rightarrow \alpha_{new}$
	RCL 0	34 00	
	RTN	35 22	
	LBL B	31 25 12	
190	x⇄y	35 52	
	→R	31 72	
	RCL 3	34 03	
	RCL 2	34 02	
	→R	31 72	
	x⇄y	35 52	
	R↓	35 53	
	+	61	
	R↓	35 53	
	+	61	
200	R↑	35 54	
	→P	32 72	
	STO 2	33 02	
	x⇄y	35 52	
	GSB e	32 22 15	
	STO 3	33 03	
	SF 1	35 51 01	
	RTN	35 22	
	LBL e	32 25 15	
	RCL D	34 14	
210	÷	81	
	FRAC	32 83	
	1	01	
	+	61	
	FRAC	32 83	
	RCL D	34 14	
	*	71	
	RTN	35 22	
	LBL d	32 25 14	
	INT	31 83	
220	x≠0	31 61	
	RTN	35 22	
	CLX	44	
	LST X	35 82	
	RTN	35 22	

LABELS

A $\hat{\theta}$	B $\Delta\vec{V}$	C $\in$	D θ, R_{min}	E Graph
a $\vec{R}_1$	b $\vec{V}_1$	c	d Adjust	e Mod 360
0	1	2 -used-	3 -used-	4 -used-
5	6	7 -used-	8	9

FLAGS

0	e≥1
1	Find e
2	
3	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☐
1	☐	☒	GRAD	☐	SCI	☒
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n 6	

Program Description I

Program Title EQUATIONS OF PARTICLE MOTION

Contributor's Name ERIK GOETZE

Address 1613 CAMULOS AVE.

City GLENDALE State CALIF Zip Code 91208

Program Description, Equations, Variables HERE ALL VARIABLES ARE IN y, BUT ALL y's COULD BE REPLACED WITH x's.

nr1 $y = \frac{1}{2}(V_{yo} + V_y)t$

nr2 $y = V_{yo}t + \frac{1}{2}a_y t^2$

nr3 $y = \frac{V_y^2 - V_{yo}^2}{2a_y}$

nr4 $t = \frac{V_y - V_{yo}}{a_y}$

nr5 $t = \frac{2y}{V_{yo} + V_y}$

nr6 $t = \left(-V_{yo} \pm \sqrt{V_{yo}^2 + 2a_y y}\right)/a_y$

nr7 $V_y = V_{yo} + a_y t$

nr8 $V_y = \frac{2y}{t} - V_{yo}$

nr9 $V_y = \sqrt{V_{yo}^2 + 2a_y y}$

nr10 $V_{yo} = V_y - A_y t$

nr11 $V_{yo} = \frac{2y}{t} - V_y$

nr12 $V_{yo} = \frac{y}{t} - \frac{a_y t}{2}$

nr13 $V_{yo} = \sqrt{V_y^2 - 2a_y y}$

nr14 $a_y = \frac{V_y - V_{yo}}{t}$

nr15 $a_y = 2\left(\frac{y - V_{yo}t}{t^2}\right)$

nr16 $a_y = \frac{V_y^2 - V_{yo}^2}{2y}$

y = DISTANCE COVERED BY PARTICLE IN TIME t

t = TIME IN WHICH PARTICLE MOVES

V_y = VELOCITY AT TIME t

V_{yo} = VELOCITY AT TIME 0

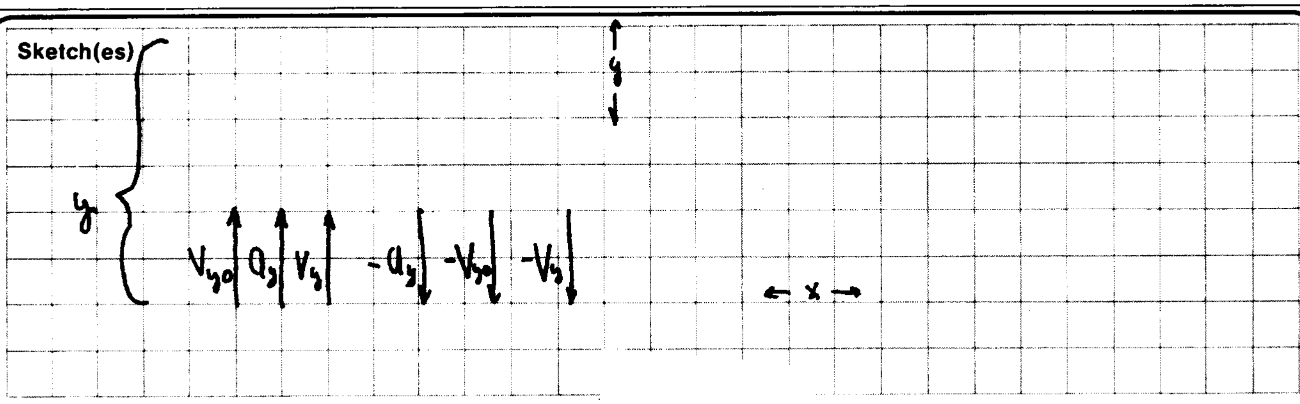
a_y = ACCELERATION (AVERAGE OVER TIME t) THAT PARTICLE IS EXPERIENCING IN TIME t

PROGRAM, GIVEN ANY THREE OUT OF THE ABOVE FIVE, WILL SOLVE THE ABOVE EQUATIONS FOR THE OTHER TWO.

Operating Limits and Warnings IF YOU ARE SOLVING FOR V-INITIAL, YOU MUST STORE THE VALUE YOU GET BY PRESSING [D] BEFORE SOLVING FOR THE OTHER UNKNOWN. THIS IS BECAUSE V_{yo} IS IN ALL THE OTHER EQUATIONS. IF THE DISPLAY COMES UP Error WHEN YOU ARE SOLVING FOR t, YOU HAVE AN IMAGINARY ROOT, SIMPLY SWITCH TO PROGRAM MODE, PRESS [SST] AND SWITCH BACK TO RUN AND PRESS [R/S]

Program Description II

Sketch(es)



Sample Problem(s) TEST
EACH EQTN. GIVEN
ON PREVIOUS SHEET.

```
    Clear everything  GSBe

Initial vel.    256.00 GSBD
Final vel.       17.00 GSBC
Time (seconds)    8.60 GSBB
Solve for y       1.00 GSBd
               1173.90  ***
                       GSBe
                159.00 GSBD
                  4.80 GSBB
      g down ↓   -9.80 GSBE
Solve for dist.   1.00 GSBd
                650.30  ***
                       GSBe
                 12.00 GSBC
                 19.00 GSBD
                 -9.80 GSBE
                  1.00 GSBd
                 11.07  ***
Solve for time         GSBe
                 29.00 GSBD
                  0.00 GSBC
                -32.30 GSBE
                  2.00 GSBd
                  0.90  ***
                  0.00 GSBe
                 47.00 GSBA
                 28.00 GSBD
                  7.00 GSBC
                  2.00 GSBd
                  2.69  ***
                       GSBe
```

```
                 88.00 GSBD
                -32.30 GSBE
                 12.00 GSBA
Quad roots        2.00 GSBd
     pause →      5.31  ***
                  0.14  ***
Solve for Vg           GSBe
                 15.00 GSBD
                 -9.80 GSBE
                  2.50 GSBB
                  3.00 GSBd
                 -9.50  ***
                       GSBe
                  7.00 GSBA
                  1.80 GSBB
                 12.00 GSBD
                  3.00 GSBd
                 -4.22  ***
                       GSBe
                 -9.80 GSBE
                  5.00 GSBA
                 23.00 GSBD
                  3.00 GSBd
                 20.76  ***
Solve for Vy0          GSBe
                 19.00 GSBC
                 -9.80 GSBE
                   .38 GSBB
                  4.00 GSBd
                 22.72  ***
                       GSBe
                 14.80 GSBA
                  2.71 GSBB
                  0.00 GSBC
                  4.00 GSBd
                 10.92  ***
                       GSBe
```

```
                118.00 GSBA
                 4.965 GSBB
                -32.30 GSBE
                  4.00 GSBd
                103.95  ***
                       GSBe
                 33.00 GSBC
                -32.30 GSBE
                 15.70 GSBA
                  4.00 GSBd
                 45.86  ***
Solve for a            GSBe
                 24.70 GSBC
                 44.30 GSBD
                  2.00 GSBB
                  5.00 GSBd
     y down ↓    -9.80  ***
                       GSBe
                  3.00 GSBA
                 16.00 GSBD
                  2.50 GSBB
                  5.00 GSBd
                -13.44  ***
                       GSBe
                 17.00 GSBC
                 39.00 GSBD
                  9.00 GSBA
                  5.00 GSBd
                -68.44  ***
```

Reference(s) PHYSICS BY RESNICK AND HALLIDAY CHAP 3 PAGE 49

User Instructions

PHYSICS (ANY THREE INPUT)			SOLVE n	RESET
NR 1 DISTANCE	nr 2 TIME	nr 3 V FINAL	nr 4 V INITIAL	nr 5 ACCELERATION

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	LOAD SIDE 1 AND 2				
2	RESET		f	e	0.00
3	INPUT DISTANCE TRAVELLED	X DIS.	A		0.00
	(IF YOU DONT KNOW THIS, GOTO STEP 4)				
4	INPUT AMOUNT OF TIME	X TIME	B		0.00
	(IF YOU DONT KNOW THIS, GOTO STEP 5)				
5	INPUT VELOCITY AT TIME t	X DIS/TIME	C		0.00
	(IF YOU DONT KNOW THIS, GOTO STEP 6)				
6	INPUT VELOCITY AT TIME ZERO	X DIS/TIME	D		0.00
	(IF YOU DONT KNOW THIS, GOTO STEP 7				
7	INPUT ACCELERATION	X $DIS/TIME^2$	E		0.00
	(IF YOU DONT KNOW THIS, GOTO STEP 8				
8	INPUT NUMBER OF VARIABLE YOU DONT				
	KNOW. (REFER TO CARD LABEL) *	X	ENTER		
9	SOLVE FOR THIS VARIABLE		f	d	n.nn
10	SOLVE FOR 2nd UNKNOWN	Y	f	d	m.mm
11	FOR NEW CASE, GOTO STEP 2				
*	WHEN $V_{INITIAL}$ IS UNKNOWN, SOLVE				
	FOR IT FIRST, THEN STORE ITS VALUE				
	BY PRESSING [D] BEFORE SOLVING				
	FOR THE OTHER UNKNOWN				

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	NR OF REG DIS IS STORED AT
002	1	01	
003	CF0	16 22 00	
004	GTO0	22 00	
005	*LBLB	21 12	NR OF REG TIME IS STORED AT
006	2	02	
007	CF1	16 22 01	
008	GTO0	22 00	
009	*LBLC	21 13	V FINAL NR REG
010	3	03	
011	CF2	16 22 02	
012	GTO0	22 00	
013	*LBLD	21 14	V INITIAL NR REG
014	4	04	
015	GTO0	22 00	ACC. NR REG
016	*LBLE	21 15	
017	5	05	
018	*LBL0	21 00	
019	STOI	35 46	
020	R↓	-31	
021	STO(i)	35 45	STORE NR. IN REG
022	RCL3	36 03	CALCULATE $\frac{V_y^2 - V_{y0}^2}{2}$
023	X²	53	
024	RCL4	36 04	
025	X²	53	
026	-	-45	
027	2	02	
028	÷	-24	
029	STO0	35 00	
030	CLX	-51	
031	RTN	24	
032	*LBL1	21 01	
033	F1?	16 23 01	DONT HAVE TIME
034	GTO9	22 09	
035	F2?	16 23 02	DONT HAVE V_{FINAL}
036	GTO8	22 08	
037	RCL4	36 04	CALCULATE y USING FORMULA NR 1
038	RCL3	36 03	
039	+	-55	
040	RCL2	36 02	
041	x	-35	
042	2	02	
043	÷	-24	
044	RTN	24	
045	*LBL8	21 08	CALCULATE y USING FORMULA NR 2
046	RCL4	36 04	
047	RCL2	36 02	
048	x	-35	
049	RCL2	36 02	
050	X²	53	
051	RCL5	36 05	
052	x	-35	
053	2	02	
054	÷	-24	
055	+	-55	
056	RTN	24	

STEP	KEY ENTRY	KEY CODE	COMMENTS
057	*LBL9	21 09	CALCULATE y USING FORMULA NR 3
058	RCL0	36 00	
059	RCL5	36 05	
060	÷	-24	
061	RTN	24	
062	*LBL2	21 02	
063	RCL5	36 05	
064	P⇄S	16-24	
065	X=Y?	16-33	NO Acc
066	GTO6	22 06	
067	F0?	16 23 00	NO y
068	GTO7	22 07	
069	RCL4	36 04	QUAD ROUT EVALUATION FOR t USING FORMULA NR 6
070	X²	53	
071	RCL5	36 05	
072	RCL1	36 01	
073	2	02	
074	x	-35	
075	x	-35	
076	+	-55	
077	√X	54	
078	STO9	35 09	
079	RCL4	36 04	
080	CHS	-22	
081	+	-55	
082	LSTX	16-63	
083	RCL9	36 09	
084	-	-45	
085	RCL5	36 05	
086	÷	-24	
087	PSE	16 51	
088	LSTX	16-63	
089	X⇄Y	-41	
090	R↓	-31	
091	÷	-24	
092	RTN	24	
093	*LBL7	21 07	CALCULATE T USING FORMULA NR 4
094	RCL3	36 03	
095	RCL4	36 04	
096	-	-45	
097	RCL5	36 05	
098	÷	-24	
099	RTN	24	
100	*LBL6	21 06	CALCULATE T USING FORMULA NR 5
101	RCL1	36 01	
102	2	02	
103	x	-35	
104	RCL3	36 03	
105	RCL4	36 04	
106	+	-55	
107	÷	-24	
108	RTN	24	
109	*LBL3	21 03	
110	F0?	16 23 00	NO y
111	GTO9	22 09	
112	F1?	16 23 01	

REGISTERS

0	1	2	3	4	5	6	7	8	9
$\frac{V_y^2 - V_{y0}^2}{2}$	DIST.	TIME	V_{FINAL}	$V_{INITIAL}$	ACCELER.				$\sqrt{b^2-4ac}$

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I
					nr OF LABEL + REG

97 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
113	GTOa	22 16 11	NO t
114	RCL1	36 01	CALCULATE V_F USING FORMULA NR 8
115	2	02	
116	x	-35	
117	RCL2	36 02	
118	÷	-24	
119	RCL4	36 04	
120	-	-45	
121	RTN	24	
122	*LBL9	21 09	CALCULATE V_F USING FORMULA NR 7
123	RCL4	36 04	
124	RCL5	36 05	
125	RCL2	36 02	
126	x	-35	
127	+	-55	
128	RTN	24	
129	*LBLa	21 16 11	CALCULATE V_F USING FORMULA NR 9
130	RCL4	36 04	
131	X²	53	
132	RCL1	36 01	
133	RCL5	36 05	
134	2	02	
135	x	-35	
136	x	-35	
137	+	-55	
138	√X	54	
139	RTN	24	
140	*LBL4	21 04	
141	F0?	16 23 00	NO y
142	GTOb	22 16 12	
143	F1?	16 23 01	NO t
144	GTOc	22 16 13	
145	RCL5	36 05	
146	Pi	16-24	
147	X=Y?	16-33	NO Acc
148	GTO8	22 08	
149	RCL1	36 01	CALCULATE V_{yo} USING FORMULA NR 12
150	RCL2	36 02	
151	÷	-24	
152	RCL5	36 05	
153	RCL2	36 02	
154	x	-35	
155	2	02	
156	÷	-24	
157	-	-45	
158	RTN	24	
159	*LBLb	21 16 12	CALCULATE V_{yo} USING FORMULA NR 10
160	RCL3	36 03	
161	RCL5	36 05	
162	RCL2	36 02	
163	x	-35	
164	-	-45	
165	RTN	24	
166	*LBLc	21 16 13	
167	RCL3	36 03	
168	X²	53	

STEP	KEY ENTRY	KEY CODE	COMMENTS
169	RCL5	36 05	CALCULATE V_{yo} USING FORMULA NR 13
170	RCL1	36 01	
171	2	02	
172	x	-35	
173	x	-35	
174	-	-45	
175	√X	54	
176	RTN	24	
177	*LBL8	21 08	CALCULATE V_{yo} USING FORMULA NR 11
178	RCL1	36 01	
179	2	02	
180	x	-35	
181	RCL2	36 02	
182	÷	-24	
183	RCL3	36 03	
184	-	-45	
185	RTN	24	
186	*LBL5	21 05	
187	F0?	16 23 00	NO y
188	GTO7	22 07	
189	F1?	16 23 01	NO t
190	GTO6	22 06	
191	RCL1	36 01	CALCULATE a USING FORMULA NR 15
192	RCL4	36 04	
193	RCL2	36 02	
194	x	-35	
195	-	-45	
196	RCL2	36 02	
197	X²	53	
198	÷	-24	
199	2	02	
200	x	-35	
201	RTN	24	
202	*LBL7	21 07	CALCULATE a USING FORMULA NR 14
203	RCL3	36 03	
204	RCL4	36 04	
205	-	-45	
206	RCL2	36 02	
207	÷	-24	
208	RTN	24	
209	*LBL6	21 06	CALCULATE a USING FORMULA NR 16
210	RCL0	36 00	
211	RCL1	36 01	
212	÷	-24	
213	RTN	24	
214	*LBLe	21 16 15	RESET BY SETTING FLAGS, π IN R_5
215	SF0	16 21 00	
216	SF1	16 21 01	
217	SF2	16 21 02	
218	Pi	16-24	
219	STO5	35 05	
220	0	00	
221	RTN	24	
222	*LBLd	21 16 14	CALCULATE VARIABLE i IN ROUTINE i
223	STOI	35 46	
224	GTOi	22 45	

LABELS

					FLAGS
A STORE DIS	B STORE TIME	C STORE V_F	D STORE V_{IN}	E STORE Acc	0 SET IF DIS HASN'T ENTERED
a USED	b USED	c USED	d SOLVE	e RESET	1 SET IF TIME HASN'T ENTERED
0 STORAGE	1 CALC DIS	2 CALC TIME	3 CALC V_F	4 CALC V_{INIT}	2 SET IF V_F HASN'T ENTERED
5 CALC Acc	6 USED	7 USED	8 USED	9 USED	3

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☒	☐	DEG	☒	FIX	☒
1	☒	☐	GRAD	☐	SCI	☐
2	☒	☐	RAD	☐	ENG	☐
3	☐	☐			n	2

Program Description I

Program Title Ballistics Trajectory Computations

Contributor's Name David M. Ivey
Address Scientific Atlanta, 3845 Pleasantdale Rd.
City Atlanta **State** Ga. **Zip Code** 30340

Program Description, Equations, Variables The Program computes remaining velocities, energies, flight times, rise and drops plus sight-in trajectories for bullets at user specified intervals. Computations technically apply to ICAO conditions which are satisfactory for most shooting conditions. The methods uses a Mayevski drag formulation with different constants for the various velocity zones. The program automatically selects the correct zone. There are three programs combined on the one card. Note that data is stored on another card. LBL A: This program does the standard trajectory computations with outputs selected by two flags. LBL B: Knowing the velocities at two ranges enables one to compute the Ballistic Coefficient with Label B. LBL C: Given a "sight-in" range, this program calculates the actual bullet path. Label C represents the advanced capability of this program set.

Operating Limits and Warnings Be sure to use ballistics coefficient based on Ingall's Tables (presently all American bullets are). This system works best when the coefficient C_b is greater than 0.150 and velocities are above that of sound. Most importantly however, use range intervals no greater than 100yds, shorter intervals give better accuracy. Typically about 3% error occurs with this program relative to numeric integration techniques at 1000yds.

BALLISTICS TRAJECTORY COMPUTATIONS D. Ivey

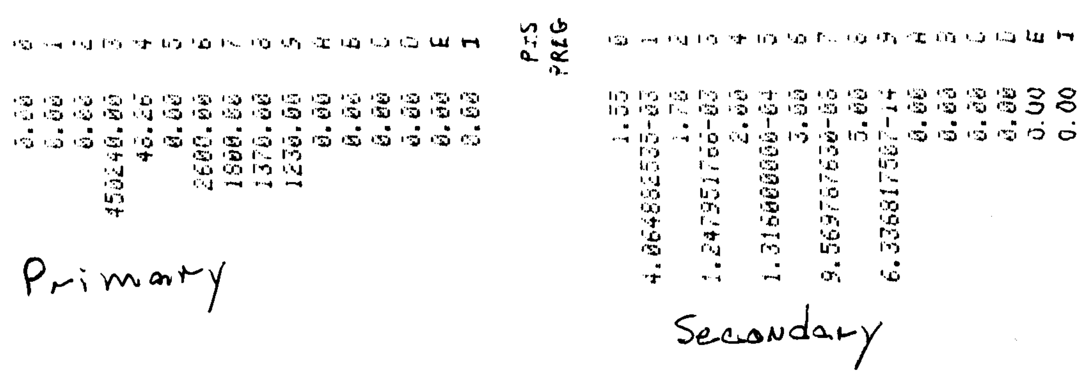
Zone Data

The drag is computed according to the formula Av^n, where A and n are constants particular to a certain velocity zone. The constants A and n for each zone as well as the limits for a zone are best stored on a magnetic card.

Mayevski Velocity Zones

Range of V	n	A
3600-2600	1.55	4.064882535[10^{-3}]
2600-1800	1.70	1.247951766[10^{-3}]
1800-1370	2.00	1.316[10^{-4}]
1370-1230	3.00	9.569787630[10^{-8}]
1230-0970	5.00	6.336817507[10^{-14}]

There are two more zones but memory space does not allow any more storage.



BALLISTICS TRAJECTORY COMPUTATIONS

D. Ivey

<u>List of equations and variables:</u>

$V_f = (V_i^2 - Z'D)^{\frac{1}{2}}$

$D = Av_i^n$

$Z' = 2\Delta x/C_b$

$t_f = 2\Delta x \sum(1/[v_i+v_f])$

$h = 48.26t_f^2$

$y_f = (4h/3)[1 + 2\sqrt{v_f/v_m}]$

$E_f = (w_b v_f^2)/450{,}240$

$C_b = (2\Delta x D)/(v_i^2 - v_f^2)$

$e_i = (x_i/x_o)(y_o+H) - y_i - H$

$x_f = x_i + \Delta x$

v_i=initial velocity ft/sec
v_f=final velocity
v_m= muzzle velocity
D = Drag
n = Mayevski constant
A = Mayevski constant
C_b= Ballistic Coefficient (Ingall's)
Δx= Range interval, ft.
t_f= flight time from v_i to v_f
h = maximum ordinate (rise)
y_f= drop at range x_f
E_f= energy of bullet at v_f
w_b= bullet weight in grains
x_o= sight in range
y_o= drop at sight in range
H = height of scope above bore
x_i= range at intermediate values
y_i= drop at intermediate values
x_m= maximum range
e_i= projectiles position at x_i

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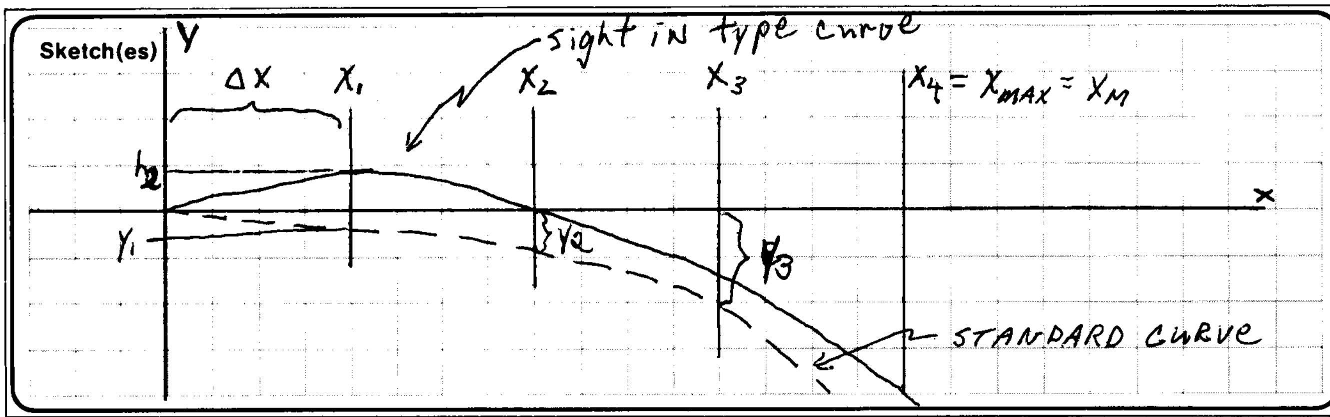
Program Description II

Sketch(es)



Sample Problem(s) LBL A problem: Compute the complete trajectory of a 30/06 cartridge where the bullet is a 165 gr. Sierra Boat Tail (C_b=0.47) at a muzzle velocity of 2800 ft/sec, in 100 yard increments out to 400 yards. Print the energy, flight time, maximum ordinate (rise) and drop.

Note: C_b is destroyed each time this program is run.

At right is the output:

Solution(s)

V_m=2800ft/sec	STO A
C_b=0.470	STO B
Δx=300ft (100yards)	STO C
X_m=1200ft (400yards)	STO D
w_b=165	STO E
Set flag one and two	
Press A	

Remarks: Thus at 400yards, we have lost 28% of our initial velocity and 48% of the energy.

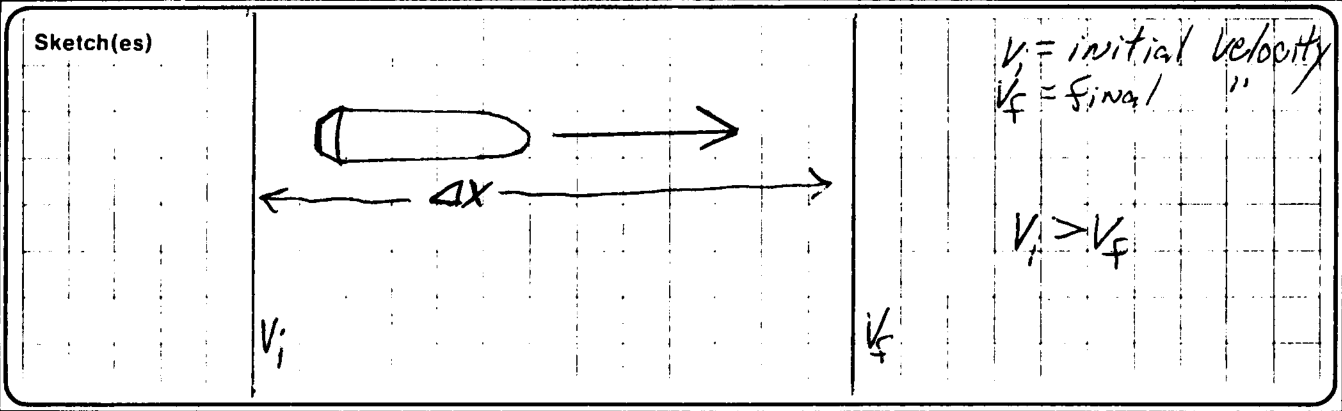
```
2800.00 STOA
    .47 STOB
 300.00 STOC
1200.00 STOD
 165.00 STOE
         SF0
         SF1
        GSBA
```

Initial Data:

```
VM - 2800.00  ***
EM - 2873.13  ***
Cb —    0.47  ***
wb    165.00  ***

Range    100.  ***

Velocity - 2588.  ***V
Energy   - 2454.  ***E
time     - 0.1114 ***t
rise     —   0.60 ***h
drop     —   2.33 ***y

    200.  ***

   2385.  ***
   2084.  ***
 0.2320   ***
   2.60   ***
   9.66   ***

    300.  ***

   2193.  ***
   1762.  ***
 0.3631   ***
   6.36   ***
  23.56   ***

    400.  ***

   2011.  ***
   1483.  ***
 0.5058   ***
  12.35   ***
  44.37   ***
```

Program Description II

Sketch(es)



Sample Problem(s) <u>LBL B Problem</u> Compute the ballistic coefficient for a 165gr. Sierra Boat Tail bullet if the initial interval velocity is 2588ft/sec. and the final interval velocity is 2385 ft/sec., assuming x=300ft.

NOTE: Due to the type of drag formulation used, different data sets yield different ballistic coefficients. This is especially true for the interval beginning at the muzzle. Several sets are shown, its best to average them.

```
2600.00 ENT↑
2588.00 GSBB
 0.4751  ***

2588.0000 ENT↑
2385.0000 GSBB
   0.4762  ***

2385.0000 ENT↑
2193.0000 GSBB
   0.4700  ***

2193.0000 ENT↑
2011.0000 GSBB
   0.4661  ***

Average [illegible]  ***
```

Solution(s) Δx=300 STO C

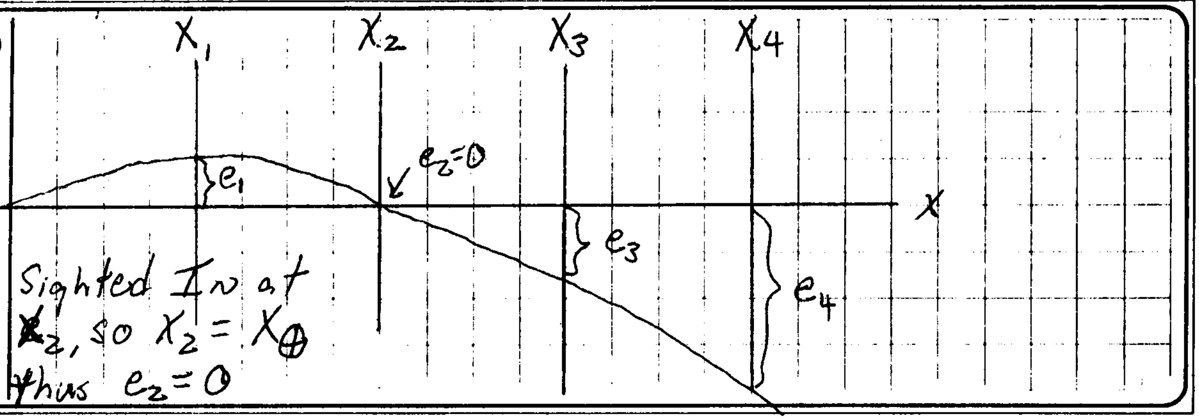
V_i ENTER V_f Press B

2588 enter 2385 B

Reference(s) This entire program set represents the first complete ballistic system without extensive numeric integration techniques with long tables. It was specifically developed for micro-computer applications. For more information regarding theoretical development or program usage, contact the author. Home phone: 404/ 448-5394 Bus: 404/ 449-2000

Program Description II

Sketch(es)



Sample Problem(s) LBL C Problem Assume we wish to sight a rifle in at 200yds with the parameters of Sample A. We want to know the bullet's position at each range increment to 400 yards. Using the data from Sample A, the drop at 200 yards is 9.86inches. Let our rifle scope be 1.5inches above the rifle bore.

```
2800.00 STOA
    .47 STOB
 300.00 STOC
1200.00 STOD
   9.86 STO4
 600.15 STOE
        GSBC

2800.00  ***
 200.00  ***
   0.47  ***

   100.  ***

   1.65  ***

   200.  ***

   0.00  ***

   300.  ***

  -7.36  ***

   400.  ***

 -23.15  ***
```

Solution(s)

```
2800 STO A*
0.470 STO B
300 STO C*
1200 STO D*
9.86 STO 4
600.15 STO E    (600=200yds in feet,       )
Press "   "     (15=1.5 inches above bore)
```

*not necessary if entered with LBL A.

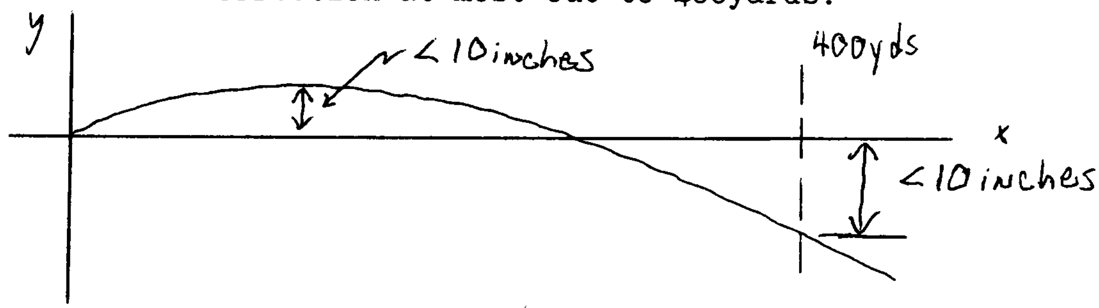
Remarks: From the output, to hit dead on at 400yds we need to hold 23.15 inches high. This program itself has great applications!

BALLISTICS TRAJECTORY COMPUTATIONS D. Ivey

Special Comment on Program C:

Programs A and C can be used togethor to determine the optium sight in range for a particular bullet/velocity combination.

Consider the 165gr. Sierra BT. What velocity and sight in range would yield a trajectory within ten inches of correction at most out to 400yards?



From the sample with Program A, 2800ft/sec sighted at 200 yards is not adequate. Suppose we try a range of 300 yards for sight in? Then, using Program C we obtain a -12.54 inches drop at 400 yards. This is out of our design specs. Probably by increasing the powder charge to get 2900ft/sec we can suceed.

This example is one way the powerful Program C can be used. Also note that with Program A one can sight in using the rise data.

User Instructions

Ballistics Trajectory Computations

F1 prints Energy

F2 prints rise, time

Regular	C_b	Sight In		

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Load both the data card and program				
	card. (Be sure to load both sides				
	also)				
2	For regular output (PRGM A)	V_m	STO	A	
		C_b	STO	B	
		x	STO	C	
		X_m	STO	D	
		w_b*	STO	E	
	To excute:		A		
	Program Outputs Initial DATA.				V_M
					E_m if F1
					C_b
					w_b
	Then the calculations:				
					Range
					velocity
					energy
					time
					rise
					drop
3	New problem, go to Step Two				
4	For Program B Enter data:	x	STO	C	
		V_i	enter		
		V_f	B		
					C_b

User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
5	For Sight In Program C				
	Store constants:	V_m	STO	A	
		C_b	STO	B	
		x	STO	C	
		X_m	STO	D	
		Xo.hh	STO	E	
		Y_o	STO	4	
	To Execute:	C			
	Outputs Calculations: (Intial Parameters)				V_m
					X_o
					C_b
	Bullet path:				Range
	E_i is in inches.				E_i

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	
002	DSP2	-63 02	
003	GSB6	23 06	Initialization and Setup.
004	SPC	16-11	
005	RCLA	36 11	
006	PRTX	-14	
007	STO2	35 02	
008	F1?	16 23 01	
009	GSB0	23 00	
010	RCLB	36 12	
011	PRTX	-14	
012	RCLE	36 15	
013	X≠0?	16-42	
014	PRTX	-14	
015	RCLC	36 13	
016	RCLB	36 12	
017	÷	-24	
018	2	02	
019	x	-35	
020	STOB	35 12	
021	*LBLa	21 16 11	
022	RCL1	36 01	Looping Label
023	RCLD	36 14	
024	X≤Y?	16-35	
025	RTN	24	
026	GSB4	23 04	
027	RCL2	36 02	
028	GSB1	23 01	
029	GSB3	23 03	
030	PRTX	-14	
031	F1?	16 23 01	
032	GSB0	23 00	
033	GSB5	23 05	
034	PRTX	-14	
035	GTOa	22 16 11	
036	*LBL3	21 03	Computes Remaining Velocity
037	RCLB	36 12	
038	x	-35	
039	CHS	-22	
040	RCL2	36 02	
041	X²	53	
042	+	-55	
043	√X	54	
044	STO5	35 05	
045	RTN	24	
046	*LBL4	21 04	
047	RCLC	36 13	Prints Range Intervals
048	SPC	16-11	
049	DSP0	-63 00	
050	ST+1	35-55 01	
051	RCL1	36 01	
052	3	03	
053	÷	-24	
054	PRTX	-14	
055	SPC	16-11	
056	RTN	24	

STEP	KEY ENTRY	KEY CODE	COMMENTS
057	*LBL5	21 05	
058	RCL2	36 02	
059	RCL5	36 05	Computes Flight time Rise and drop
060	+	-55	
061	1/X	52	
062	ST+0	35-55 00	
063	RCL5	36 05	
064	STO2	35 02	
065	RCL0	36 00	
066	RCLC	36 13	
067	x	-35	
068	2	02	
069	x	-35	
070	DSP4	-63 04	
071	F0?	16 23 00	
072	PRTX	-14	
073	X²	53	
074	4	04	
075	8	08	
076	.	-62	
077	2	02	
078	6	06	
079	x	-35	
080	DSP2	-63 02	
081	F0?	16 23 00	
082	PRTX	-14	
083	4	04	
084	x	-35	
085	3	03	
086	÷	-24	
087	RCL5	36 05	
088	RCLA	36 11	
089	÷	-24	
090	√X	54	
091	2	02	
092	x	-35	
093	1	01	
094	+	-55	
095	x	-35	
096	RTN	24	
097	*LBL0	21 00	
098	ENT↑	-21	Energy Calculations
099	RCLE	36 15	
100	RCL3	36 03	
101	÷	-24	
102	X⇄Y	-41	
103	X²	53	
104	x	-35	
105	PRTX	-14	
106	R↓	-31	
107	RTN	24	
108	*LBL1	21 01	
109	RCL6	36 06	
110	X≤Y?	16-35	
111	GTO2	22 02	
112	1	01	

REGISTERS

0	1	2	3	4	5	6	7	8	9

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

97Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
113	2	02	
114	STOI	35 46	
115	RCL2	36 02	
116	RCL7	36 07	
117	X≤Y?	16-35	
118	GTO2	22 02	
119	1	01	Selects Mayevski Drag Constants
120	4	04	
121	STOI	35 46	
122	RCL2	36 02	
123	RCL8	36 08	
124	X≤Y?	16-35	
125	GTO2	22 02	
126	1	01	
127	6	06	
128	STOI	35 46	
129	RCL2	36 02	
130	RCL9	36 09	
131	X≤Y?	16-35	
132	GTO2	22 02	
133	1	01	
134	8	08	
135	STOI	35 46	
136	*LBL2	21 02	
137	R↓	-31	
138	RCLi	36 45	
139	Y^x	31	Drag Calculation
140	ISZI	16 26 46	
141	RCLi	36 45	
142	x	-35	
143	DSZI	16 25 46	
144	RTN	24	
145	*LBLB	21 12	
146	STOA	35 11	
147	R↓	-31	
148	STO2	35 02	
149	GSB6	23 06	
150	RCLA	36 11	
151	GSB1	23 01	
152	RCLC	36 13	
153	x	-35	
154	2	02	
155	x	-35	
156	RCL2	36 02	
157	X²	53	
158	RCLA	36 11	
159	X²	53	
160	-	-45	
161	÷	-24	
162	RTN	24	
163	*LBLC	21 13	
164	CF0	16 22 00	Initial Setup
165	CF1	16 22 01	
166	GSB6	23 06	
167	RCLA	36 11	
168	SPC	16-11	

STEP	KEY ENTRY	KEY CODE	COMMENTS
169	SPC	16-11	
170	PRTX	-14	
171	STO2	35 02	
172	RCLE	36 15	
173	INT	16 34	
174	3	03	
175	÷	-24	
176	PRTX	-14	
177	RCLB	36 12	
178	PRTX	-14	
179	RCLC	36 13	
180	RCLB	36 12	
181	÷	-24	
182	2	02	
183	x	-35	
184	STOB	35 12	
185	SPC	16-11	
186	*LBLc	21 16 13	
187	RCL1	36 01	Looping For Prgm c
188	RCLD	36 14	
189	X≤Y?	16-35	
190	RTN	24	
191	GSB4	23 04	
192	RCL2	36 02	
193	GSB1	23 01	
194	GSB3	23 03	
195	GSB5	23 05	
196	RCLE	36 15	
197	FRC	16 44	
198	1	01	
199	0	00	
200	x	-35	
201	+	-55	
202	CHS	-22	
203	LSTX	16-63	
204	RCL4	36 04	
205	+	-55	
206	RCL1	36 01	
207	x	-35	
208	RCLE	36 15	
209	INT	16 34	
210	÷	-24	
211	+	-55	
212	RND	16 24	
213	PRTX	-14	
214	GTOc	22 16 13	
215	*LBL6	21 06	Registor clearance
216	0	00	
217	STO0	35 00	
218	STO1	35 01	
219	1	01	
220	0	00	
221	STOI	35 46	
222	RTN	24	
223	R/S	51	

LABELS

A	B	C	D	E
a	b	c	d	e
0	1	2	3	4
5	6	7	8	9

FLAGS

0
1
2
3

SET STATUS

FLAGS			TRIG	DISP
	ON	OFF		
0	☐	☐	DEG ☐	FIX ☐
1	☐	☐	GRAD ☐	SCI ☐
2	☐	☐	RAD ☐	ENG ☐
3	☐	☐		n ____

Program Description I

Program Title ISOTOPE OVERLAP CORRECTIONS

Contributor's Name Lawrence I. Grossman
Address 206 Crest Ave.
City Ann Arbor State MI Zip Code 48103

Program Description, Equations, Variables Program Corrects for spillover between channels when two radioactive isotopes are being counted in a liquid scintillation spectrometer. Background subtraction for each isotope is also provided. Program may be used with single isotope.

Isotopes x and y are counted in machine channels A and B, respectively.
Let a = fractional spillover of isotope y from channel B to A.
b = fractional spillover of isotope x from channel A to B.

C_x = corrected counts/min isotope x in channel A $= \frac{C_A - a\,C_B}{1-ab}$, where C_A and C_B are the observed counts/min in each channel.

$$C_y = \frac{C_B - b\,C_A}{1-ab}$$

Outputs

Total counts/min isotope x = $C_x\,(1+b) = T_x$
Total counts/min isotope y = $C_y\,(1+a) = T_y$

Operating Limits and Warnings

Program Description II

Sketch(es)

Sample Problem(s) 2 isotopes. Spillover A→B = 10%, B→A = 20%, Bk_A = 10 cpm, Bk_B = 50 cpm

For the following values of cts/min$_A$ and cts/min$_B$, calculate corrected values and totals.

sample #	A	B
1	1000	500
2	2000	1000
3	1400	2200

Solution(s) Keystrokes

Keystrokes		
[f] [A]	→ 0.00	
0.2 ENTER 10 [D]	→ 0.20	
0.1 ENTER 50 [E]	→ 0.10	
1 [f] [C]	→ 1.00	
1000 [A] 500 [B] [C]	→ 1010	(T_x)
	→ 430	(T_y)
	→ 2	(next sample)
2000 [A] 1000 [B] [C]	→ 2020	(T_x)
	→ 920	(T_y)
	→ 3	(next)
1400 [A] 2200 [B] [C]	→ 1078	(T_x)
	→ 2462	(T_y)
	→ 4	(next)
[f] [B]	→ 4108	(ΣT_x)
	→ 3812	(ΣT_y)
	→ 0	(next)

Reference(s)

User Instructions

ISOTOPE OVERLAP CORRECTIONS

1 ◀ ▶ 2

2 LABELS ?	→ΣTx, ΣTy	1st free. No.		
CPM-A	CPM-B	→ Tx, Ty	B→A ↑ Bk_A	A→B ↑ Bk_B

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Load side 1				
2	Set for two isotopes		f	A	0.00
3	Enter number of first sample	n_i	f	C	n_i
4	For single isotope, enter fractional spillover channel B→A,				
	background subtraction for channel A.	B→A ↑ BK_A	D		B→A
5	If two isotopes, enter fractional spillover channel A→B,				
	background subtraction for channel B	A→B ↑ BK_B	E		A→B
6	Enter counts/min for channel A. For 1 isotope, go to 8.	cpm_A	A		$cpm_A - BK_A$
7	Enter counts/min for channel B.	cpm_B	B		$cpm_B - BK_B$
8	Output corrected counts/min for channel A, B (if used)		C		T_x
					T_y (if used)
					next n_i
9	For next sample or pair of samples, go to 6.				
10	After last entry, obtain total of all samples of				
	isotope x and y (if used). After outputs, the flag for				
	two isotopes is cleared and the accumulation registers				
	for total of all samples are cleared.		f	B	ΣT_x
					ΣT_y
					0
11	For new set of samples, go to 2.				

67 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBL D	31 25 14	store BkA, a
	STO 0	33 00	
	R↓	35 53	
	STO 1	33 01	
	RTN	35 22	
	*LBL c	32 25 13	store first sample no.
	ST I	35 33	
	RTN	35 22	
	*LBL E	31 25 15	store BkB, b
010	STO 2	33 02	
	R↓	35 53	
	STO 3	33 03	
	RTN	35 22	
	*LBL A	31 25 11	enter counts/min for A channel, subtract BkA, store.
	RCL 0	34 00	
	−	51	
	STO 4	33 04	
	RTN	35 22	
	*LBL B	31 25 12	enter counts/min for B channel, subtract BkB, store
020	RCL 2	34 02	
	−	51	
	STO 5	33 05	
	RTN	35 22	
	*LBL C	31 25 13	Calculate Cx, Cy, Tx, Ty
	RCL 4	34 04	
	RCL 1	34 01	
	RCL 5	34 05	
	×	71	
	−	51	
030	1	01	
	RCL 1	34 01	
	RCL 3	34 03	
	×	71	
	−	51	
	÷	81	
	1	01	
	RCL 3	34 03	
	+	61	
	×	71	
040	STO +6	33 61 06	
	STO 7	33 07	
	DSP 0	23 00	
	RCL 5	34 05	
	RCL 3	34 03	
	RCL 4	34 04	
	×	71	
	−	51	
	1	01	
	RCL 1	34 01	
050	RCL 3	34 03	
	×	71	
	−	51	
	÷	81	
	1	01	
	RCL 1	34 01	
	+	61	
	×	71	
	STO +8	33 61 08	
	STO 9	33 09	
060	RCL 7	34 07	output Tx, Ty (if F0 set)
	-x-	31 84	
	RCL 9	34 09	
	F0?	35 71 00	
	-x-	31 84	
	ISZ	31 34	
	RC I	35 34	
	RTN	35 22	
	*LBL a	32 25 11	SF0 for 2 labels
	SF 0	35 51 00	
070	RTN	35 22	
	*LBL b	32 25 12	output total x for all samples, total y (if F0 set). CF0. Clear accumulation registers.
	RCL 6	34 06	
	-x-	31 84	
	RCL 8	34 08	
	F0?	35 71 00	
	-x-	31 84	
	CF 0	35 61 00	
	0	00	
	STO 6	33 06	
080	STO 8	33 08	
	ST I	35 33	
	RTN	35 22	
090			
110			

LABELS

A	B	C	D	E
counts/min A	counts/min B	output Tx,Ty	a↑ Backgd. A	b↑ Backgd B
a: 2 labels	b: Total cpm	c: 1st sample No.	d	e
0	1	2	3	4
5	6	7	8	9

FLAGS	
0	set for 2 isotopes
1	
2	
3	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☑	☐	DEG	☑	FIX	☑
1	☐	☑	GRAD	☐	SCI	☐
2	☐	☑	RAD	☐	ENG	☐
3	☐	☑			n	0

REGISTERS

0	1	2	3	4	5	6	7	8	9
Background A	a	Background B	b	C_A	C_B	ΣC_x	C_x	ΣC_y	C_y
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I
					sample Number

Program Description I

Program Title Critical Reactor Code

Contributor's Name Richard D. Hyman

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City Edmonds **State** Washington **Zip Code** 98020

Program Description, Equations, Variables The program estimates the parameters of a reactor with different fuels, moderator, fuel to moderator ratios, size, and shapes of the reactor. Its most important use is in indicating trends in certain changes of mod. etc.

$$\eta = \frac{\gamma_{235}\Sigma_f(235)}{\Sigma_a(235)+\Sigma_a(238)} = \gamma\frac{\sigma f}{\sigma a}$$

$$f = \frac{\Sigma aF}{\Sigma at} = \frac{\Sigma am}{\Sigma_{aF}}\frac{Vm}{V_F}F + E$$

$$F_{(x)} = 1 + \frac{1}{2}\left(\frac{x}{2}\right)^2 - \frac{1}{12}\left(\frac{x}{2}\right)^4 + \frac{1}{48}\left(\frac{x}{2}\right)^6 \quad : x = {}^{a}/LF$$

$$E(y,z) = 1 + \frac{z^2}{2}\left[\frac{z^2}{z^2-y^2}\ln\left(\frac{z}{y}\right) - \frac{3}{4} + \frac{y^2}{4z^2}\right] : \quad z = {}^{b}/_{LM}, \quad y = {}^{a}/_{LM}$$

$$\rho = \exp - \left[\frac{N_F V_F I}{\Sigma_m \Sigma_{sm} V_m}\right] \qquad I = A + C/\sqrt{a\rho}$$

$$B^2 = \left(\frac{\pi}{R}\right)^2 \text{sphere}$$

$$\varepsilon = 1 + .3\left(\frac{V_F}{V_m}\right) \qquad P_L = \frac{1}{1 + B^2 L_T} \qquad B^2 = 3\left(\frac{\pi}{R}\right)^2 \text{cube}$$

Operating Limits and Warnings This program works best for low enrichment fuel, $(-7^2-5)\%$ this is much like a power reactor. The accuracy is only to be taken as an estimate. But the trends are good. Note: Radius of reactor is stored in S-6 register to change this you must change [P↔S] [STO 6] [P↔S]

New data cards can be made for U^{235} Pu^{299} fuels & H_2O, C, on D_2O moderators. The information needed on these cards can be found in John R. Lamarsh, Introduction to Nuclear Engineering.

P-0 = ρ - Density of Fuel

P-1 = MW - Molecular weight of fuel

P-2 = Atom density of fuel

P-3 = ΣaF - Microscopic cross section of fuel (abs.)(cm-1)

P-4 = Microscopic cross section of mod. (abs.) (cm-1)

P-5 = Const A

P-6 = Const C

P-7 = Σm Σsm

P-8 = Microscopic fission cross section of fuel (in barns)

P-9 = # of nuetrons emitted per fission

S-8 = Diffusion length of moderator (cm)

S-9 = Diffusion length of fuel (cm)

A = Enrichment % of fissile fuel

B = Microscopic abs - cross section of fissile fuel (in barns)

C = Microscopic abs cross section of U^{238} (in barns)

D = Radius of fuel pin (cm)

E = Radius of fuel

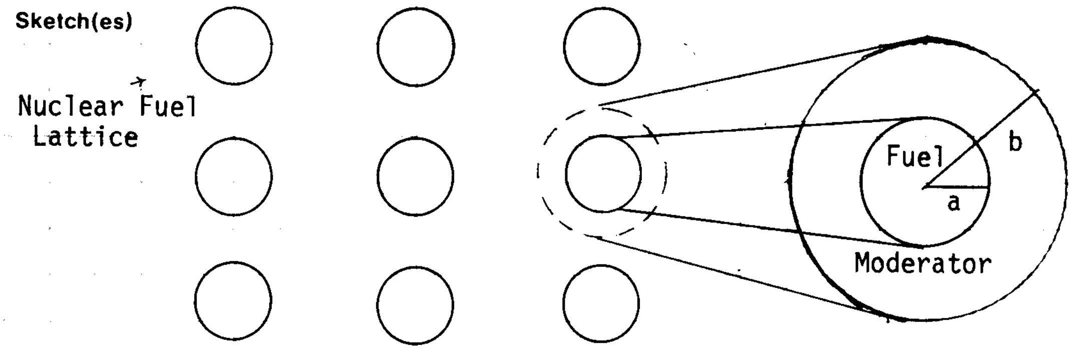
All these must be set for different fuel + moderators this is why it is best to record this on a card.

Values for Diff. Fuel + Moderators

	U^{235}	Pu^{239}	H_2O	D_2O	C
ρ	19.1	21.45			
MW	238	239			
NF	.04833	.04938			
ΣaF					
Σam			.0222	2.9×10^{-5}	.0002728
A	3.0	3.0			
C	38	38			
$\Sigma m \Sigma sm$			1.46	.178	.0608
σf	580	742.5			
γ	2.6	2.98			
Lm			2.85	170	59
L_F	1.55	2.0			
$\sigma afiss$	680	1011.3			
$\sigma a238$	2.7	2.7			

Program Description II

Sketch(es)



Sample Problem(s) What are the parameters of the reactor and is it critical if it is natural Uranium filled graphite moderated with a fuel pin radius of 1.02 cm and a fuel cell radius of 25.4 cm. The reactor is a sphere of radius 5 meters.

η = 1.33 = # of neutrons produced per neutron abs in fuel

f = .811 = # of neutrons abs in fuel per neutron abs

ρ = .98 = probability a neutron is not abs, in 238 uranium

ε = 1.0002 = fast fission factor (from U^{238} fission)

PL= .879 = non leakage probability

k = .936 = neutrons in generation n / neutrons in generation n-1

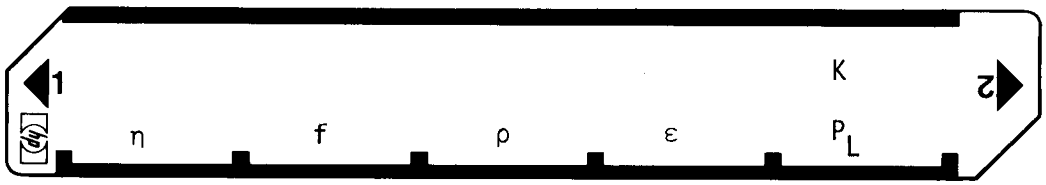
k<1 so reactor is subcritical

Solution(s) Keystrokes assuming data has been stored.

```
         A -----------------> 1.33
         B ----------------->  .811
         C ----------------->  .98
         D -----------------> 1.0002
SF,1 →   E ----------------->  .879
        fE ----------------->  .936
```

Reference(s) See Introduction to Nuclear Engineering, John R. Lamarsh, Volume 1 pag 188, 198, 203, 202, 204, 227, 229-235, Addison-Wesley Publishing Co., 1975.

User Instructions



STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1.	Load side 1 and side 2			
2.	Load data card			
3.	Optional: Sto fuel enrichment	%fiss fuel	[STO] [A]	
4.	Optional: Sto fuel ρ in radius	a/cm	[STO] [D]	
5.	Optional: Sto fuel cell radius	b/cm	[STO] [D]	
6.	Optional: Sto radius of reactor	R/cm	[STO 6]	
			[P↔S]	
7.	Optional: Clear flag 1 for cube reactor		h [CF] [1]	
8.	Optional: Set flag 1 for sphere reactor		h [SF] [1]	
9.	Calculate η		[A]	η
10.	Calculate f		[B]	f
11.	Calculate ρ		[C]	ρ
12.	Calculate ε		[D]	ε
13.	Optional: Calculate K∞		[f] [e]	K∞
14.	Calculate P_L		[E]	P_L
15.	Calcualte K		[f] [e]	K
16.	For new fuel or moderator go to 2			
17.	For same fuel and moderator go to 3			
	NOTE: Step 6 [P↔S] [STO 6] [P↔S]			
18.	Optional: Recall η		[P↔S] [RCL 10]	η
19.	Optional: Recall f		[P↔S] [RCL 11]	f
20.	Optional: Recall ρ		[P↔S] [RCL 2]	ρ
21.	Optional: Recall ε		[P↔S] [RCL 3]	ε
22.	Optional: Recall P_L		[P↔S] [RCL 4]	P_L
23.	Optional: Recall K		[P↔S] [RCL 5]	K

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	
002	1	01	
003	0	00	
004	0	00	
005	RCLA	36 11	
006	-	-45	
007	RCLA	36 11	
008	÷	-24	Calculates η
009	RCLC	36 13	
010	×	-35	
011	RCLB	36 12	
012	+	-55	
013	RCL8	36 08	
014	RCL9	36 09	
015	×	-35	
016	X⇄Y	-41	
017	÷	-24	
018	P⇄S	16-51	
019	STO0	35 00	
020	STO5	35 05	
021	P⇄S	16-51	
022	RTN	24	
023	*LBLB	21 12	
024	RCL0	36 00	
025	RCL1	36 01	
026	÷	-24	
027	.	-62	
028	6	06	Calculates f
029	0	00	
030	2	02	
031	3	03	
032	×	-35	
033	STO2	35 02	
034	RCLA	36 11	
035	%	55	
036	RCLB	36 12	
037	×	-35	
038	1	01	
039	0	00	
040	0	00	
041	RCLA	36 11	
042	-	-45	
043	RCL2	36 02	
044	X⇄Y	-41	
045	%	55	
046	RCLC	36 13	
047	×	-35	
048	+	-55	
049	STO3	35 03	
050	P⇄S	16-51	
051	RCLD	36 14	
052	RCL9	36 09	
053	÷	-24	
054	2	02	
055	÷	-24	
056	STOI	35 46	
057	6	06	
058	Y^x	31	
059	4	04	
060	8	08	
061	1/X	52	
062	×	-35	
063	RCLI	36 46	
064	4	04	
065	Y^x	31	
066	1	01	
067	2	02	
068	1/X	52	
069	×	-35	
070	CHS	-22	
071	+	-55	
072	RCLI	36 46	
073	X^2	53	
074	.	-62	
075	5	05	
076	×	-35	
077	+	-55	
078	1	01	
079	+	-55	
080	RCLE	36 15	
081	X^2	53	
082	STOI	35 46	
083	RCLD	36 14	
084	X^2	53	
085	-	-45	
086	RCLI	36 46	
087	÷	-24	
088	×	-35	
089	P⇄S	16-51	
090	RCL4	36 04	
091	RCL3	36 03	
092	÷	-24	
093	×	-35	
094	P⇄S	16-51	
095	STO1	35 01	
096	RCLE	36 15	
097	RCL8	36 08	
098	÷	-24	
099	STOI	35 46	
100	RCLD	36 14	
101	RCL8	36 08	
102	÷	-24	
103	÷	-24	
104	LN	32	
105	RCLI	36 46	
106	X^2	53	
107	RCLD	36 14	
108	RCL8	36 08	
109	÷	-24	
110	X^2	53	
111	-	-45	
112	RCLI	36 46	

REGIS

0	1	2	3	4	5	6	7	8	9
ρ	MW fuel	N fuel	Σ_{aF}	Σ_{am}	A	C	$\Sigma_{sm}\Sigma_{sm}$	σ_{f25}	γ

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
η	f	ρ	ε	P_L	K	Radius (cm)		L_M	L_F

A	B	C	D	E	I
enrich %	σ_a fiss. fuel	σ_a non fiss fuel	a (cm)	b(cm)	used

97 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
113	X²	53	
114	X⇄Y	-41	
115	÷	-24	
116	×	-35	
117	.	-62	
118	7	07	
119	5	05	
120	-	-45	
121	RCLD	36 14	
122	RCL8	36 08	
123	÷	-24	
124	4	04	
125	÷	-24	
126	RCLI	36 46	
127	÷	-24	
128	RCLI	36 46	
129	÷	-24	
130	+	-55	
131	RCLI	36 46	
132	X²	53	
133	×	-35	
134	2	02	
135	÷	-24	
136	1	01	
137	+	-55	
138	RCL1	36 01	
139	+	-55	
140	1/X	52	
141	STO1	35 01	End of f
142	ST×5	35-35 05	
143	P⇄S	16-51	
144	RTN	24	
145	*LBLC	21 13	
146	RCL0	36 00	
147	RCLD	36 14	
148	×	-35	
149	√X	54	
150	RCL6	36 06	Calculates ρ
151	X⇄Y	-41	
152	÷	-24	
153	RCL5	36 05	
154	+	-55	
155	RCLD	36 14	
156	X²	53	
157	×	-35	
158	RCL2	36 02	
159	×	-35	
160	RCL7	36 07	
161	÷	-24	
162	RCLE	36 15	
163	X²	53	
164	RCLD	36 14	
165	X²	53	
166	-	-45	
167	÷	-24	
168	CHS	-22	

STEP	KEY ENTRY	KEY CODE	COMMENTS
169	e^x	33	
170	P⇄S	16-51	
171	STO2	35 02	
172	ST×5	35-35 05	
173	P⇄S	16-51	End of ρ
174	RTN	24	
175	*LBLD	21 14	
176	RCLD	36 14	
177	X²	53	
178	STOI	35 46	
179	RCLE	36 15	
180	X²	53	Calculates ε
181	RCLI	36 46	
182	-	-45	
183	÷	-24	
184	.	-62	
185	1	01	
186	×	-35	
187	1	01	
188	+	-55	
189	P⇄S	16-51	
190	STO3	35 03	
191	ST×5	35-35 05	
192	P⇄S	16-51	
193	RTN	24	
194	*LBLE	21 15	
195	P⇄S	16-51	
196	Pi	16-24	Calculates P_L
197	RCL6	36 06	
198	÷	-24	
199	X²	53	
200	F1?	16 23 01	
201	GTO1	22 01	
202	3	03	
203	×	-35	
204	*LBL1	21 01	
205	STOI	35 46	
206	RCL8	36 08	
207	GSB9	23 09	
208	STO4	35 04	
209	ST×5	35-35 05	
210	P⇄S	16-51	
211	RTN	24	
212	*LBL9	21 09	
213	X²	53	
214	×	-35	
215	1	01	
216	+	-55	
217	1/X	52	
218	RTN	24	
219	*LBLe	21 16 15	
220	P⇄S	16-51	Recall K
221	RCL5	36 05	
222	P⇄S	16-51	
223	RTN	24	

LABELS

A η	B f	C ρ	D ε	E P_L
a	b	c	d	e
0	1 B	2	3	4
5	6	7	8	9 P_L

FLAGS

0	
1	
2	
3	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☒ ←→	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☒	☐			n	5

Program Description I

Program Title Semi-Empirical Nuclear mass Formula

Contributor's Name Dan Shapira

Address Physics Division, Oak Ridge National Laboratory, Bldg.5500 X-10

City Oak Ridge **State** Tennessee **Zip Code** 37830

Program Description, Equations, Variables A Semi Empirical formula is used to calculate approximate binding energies and mass excess for any nucleus with a given nuclear charge -Z and number of neutrons -N.

Definitions: Binding energy (B.E.)= $Z * M_p + N * M_n - M(Z,N)$

M_p= proton mass(energy) in MeV, M_n= neutron mass in MeV

M(N,Z) = mass of nucleus having Z protons and N neutrons.

Mass Excess = M(Z,N) - A * amu

A = Z + N, 1amu = M(6,6)/12 --- 1/12 mass of ^{12}C

Weizsacker's Semi-Empirical mass formula contains seven terms

$$M(Z,N) = Z*M_p + N*M_n + E_v + E_s + E_c + E_{sym} + E_{pair}$$

$E_v = -a1 * A$, $E_s = a2 * A^{2/3}$, $E_c = a3 * Z^2/A^{1/3}$

$E_{sym} = a4 * (Z-N)^2/A$ E_{pair}= + or - $34/A^{3/4}$ depending on whether Z and N are both odd or both even.

E_{pair}= 0 for odd A nuclei

Operating Limits and Warnings The semiempirical formula has been derived from measured masses and binding energies and is expected to work for nuclei reasonably close to the valley of stability. Usually N ≥ Z especially for heavier nuclei.

Program Description II

Sketch(es)

Sample Problem(s) Which one of the mass-25 isobars (Nuclei with same number of protons+neutrons) is stable.

A=25 isobars are nuclei that can have N(#of neutrons) = 10, 11, 12, 13, 14 etc.
and at the same time Z(#of protons) = 15, 14, 13, 12, 11 respectively

The most stable Isobar will be the one that is most strongly bound nucleus.
The experimental observation is that the only stable Isobar of A=25 is the element Mg (Magnesium) which has Z=12 and N=13

One can make use of the semiempirical mass formula in predicting this result

For each Z and N in this group we shall calculate the binding energies (all the binding energies will be negative numbers) the largest number (in this case the most negative one) will belong to the most stable Isobar.

SOLUTION(S)	KEYSROKES	DISPLAY	COMMENTS
	10, A	10	enter Z of Isobar
	15, B	25	N of Isobar(mass displ.)
	C	-180.69	Display Binding energy
	11, A	26	new Z entered
	14, B	25	new N entered
	C	-193.53	Display binding energy
	12, A, 13, B	25	enter new Z and N
	C	-196.88	Display new binding energy
	13, A, 12, B	25	New Z, N
	C	-190.75	Display new binding energy
	14, A, 11, B	25	New Z, N
	C	-175.14	New binding energy

From the results displayed - the Z=12, N=13 combination has the highest value of binding energy.

Reference(s) De Shalit and Feshbach Theoretical Nuclear Physics

User Instructions

Semi Empirical Nuclear Mass Formula

1 | →E_{vol} | →E_{surf} | →E_{coul} | →E_{symm} | →E_{pair} | 2

Z → | N → | → B.E | → Mass | → M. Ex.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Load Program (sides 1 and 2)				
2a	Enter Number of protons in Nucleus	Z		A	A (=Z+N)
2b	Enter Number of Neutrons in Nucleus	N		B	A (=Z+N)
	--				
	From here on functions may be called on in any order.				
	Get Binding Energy of nucleus (N,Z)			C	B.E.
	" " " per nucleon			r/s	B.E./ A
	Get the Mass of nucleus (Z,N) = Total energy			D	M(Z,N)
	" " " per nucleon			r/s	M(Z,N)/A
	Get the mass excess of nucleus (Z,N)			E	M.E.
	" " " " per nucleon			r/s	M.E./ A
	Get the Volume energy term		f	a	E_v
	" " " " per nucleon			r/s	E_v/ A
	Get Surface energy term		f	b	E_s
	" " " per nucleon			r/s	E_s/ A
	Get Coulomb (charge) energy term		f	c	E_c
	" " " per nucleon			r/s	E_c/ A
	Get Symmetry (N vs Z) energy term		f	d	E_{sym}
	" " " " per nucleon			r/s	E_{sym}/A
	Get Pairing energy term		f	e	E_p
	" " " per nucleon			r/s	E_p/ A
	Note! the program is loaded with flags 0 and 1 on When the first value of Z or N is entered flag 0 is reset and program constants are loaded flag 0 now remains off!!. Hence allways remember to reset flag 0 before recording program on card.				

67 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	LBL A	31 25 11	
	STO 1	33 01	
	RCL 2	34 02	
	LBL 0	31 25 00	
	+	61	
	STO 0	33 00	
	CF 1	35 61 01	
	F? 0	35 71 00	
	GSB 9	31 22 09	
010	RTN	35 22	
	LBL B	31 25 12	
	STO 2	33 02	
	RCL 1	34 01	
	GTO 0	22 00	
	LBL 1	31 25 01	
	F? 1	35 71 01	
	RTN	35 22	
	8	08	
	ST I	35 33	
020	RCL 0	34 00	
	GSB 2	31 22 02	
	RCL 1	34 01	
	GSB 2	31 22 02	
	RCL 2	34 02	
	GSB 2	31 22 02	
	RCL 0	34 00	
	GSB 2	31 22 02	
	RCL 0	34 00	
	3	03	
030	1/x	35 62	
	y^x	35 63	
	x^2	32 54	
	GSB 2	31 22 02	
	RCL 1	34 01	
	x^2	32 54	
	RCL 0	34 00	
	3	03	
	1/x	35 62	
	y^x	35 63	
040	÷	81	
	GSB 2	31 22 02	
	RCL 1	34 01	
	RCL 2	34 02	
	−	51	
	x^2	32 54	
	RCL 0	34 00	
	÷	81	
	GSB 2	31 22 02	
	1	01	
050	CHS	42	
	RCL 1	34 01	
	y^x	35 63	
	1	01	
	CHS	42	
	RCL 2	34 02	
	y^x	35 63	

STEP	KEY ENTRY	KEY CODE	COMMENTS
	+	61	
	RCL 0	34 00	
	•	83	
060	7	07	
	5	05	
	y^x	35 63	
	÷	81	
	GSB 2	31 22 02	
	SF 1	35 51 01	
	RTN	35 22	
	LBL 2	31 25 02	
	RCL (i)	34 24	
	×	71	
070	RC I	35 34	
	9	09	
	+	61	
	ST I	35 33	
	x⇌y	35 52	
	STO (i)	33 24	
	RC I	35 34	
	8	08	
	−	51	
	ST I	35 33	
080	RTN	35 22	
	LBL a	32 25 11	
	GSB 1	31 22 01	
	RCL A	34 11	
	GTO 7	22 07	
	LBL b	32 25 12	
	GSB 1	31 22 01	
	RCL B	34 12	
	GTO 7	22 07	
	LBL c	32 25 13	
090	GSB 1	31 22 01	
	RCL C	34 13	
	GTO 7	22 07	
	LBL d	32 25 14	
	GSB 1	31 22 01	
	RCL D	34 14	
	GTO 7	22 07	
	LBL e	32 25 15	
	GSB 1	31 22 01	
	RCL E	34 15	
100	GTO 7	22 07	
	LBL C	31 25 13	
	GSB 1	31 22 01	
	1	01	
	9	09	
	ST I	35 33	
	GSB 4	31 22 04	
	GTO 7	22 07	
	LBL D	31 25 14	
	GSB 1	31 22 01	
110	1	01	
	7	07	
	ST I	35 33	

REGISTERS

0	1	2	3	4	5	6	7	8	9
A	Z	N						−a.m.u.	$M_{(p)}$

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
$M_{(m)}$	$-a_1$	a_2	a_3	a_4	$-a_5$			$Z*M_p$	$N*M_n$

A	B	C	D	E	I
E_V	E_S	E_C	E_{sym}	E_{pair}	

67 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
	GSB4	31 22 04	
	GTO7	22 07	
	LBL E	31 25 15	
	GSB1	31 22 01	
	1	01	
	6	06	
	STI	35 33	
120	GSB 4	31 22 04	
	LBL 7	31 25 07	
	R/S	84	
	RCL Ø	34 ØØ	
	÷	81	
	RTN	35 22	
	LBL 4	31 25 04	
	Ø	00	
	STO 6	33 06	
	LBL 5	31 25 05	
130	ISZ	31 34	
	RCI	35 34	
	2	Ø2	
	5	Ø5	
	–	51	
	X = 0	31 51	
	GTO 6	22 Ø6	
	RCL(i)	34 24	
	STO+6	33 61 Ø6	
	GTO 5	22 Ø5	
140	LBL 6	31 25 Ø6	
	RCL 6	34 Ø6	
	RTN	35 22	
	LBL 9	31 25 Ø9	
	7	07	
	STI	35 33	
	9	09	
	3	03	
	1	01	
	•	83	
150	5	05	
	0	00	
	4	04	
	CHS	42	
	GSB8	31 22 08	
	9	09	
	3	03	
	8	08	
	•	83	
	7	07	
160	9	09	
	3	03	
	GSB8	31 22 08	
	9	09	
	3	03	
	9	09	
	•	83	
	5	05	
	7	07	
	6	06	
170	GSB8	31 22 08	
	1	01	
	5	05	
	•	83	
	6	06	
	8	08	
	CHS	42	
	GSB8	31 22 08	
	1	01	
	8	08	
180	•	83	
	5	05	
	6	06	
	GSB8	31 22 08	
	•	83	
	7	07	
	1	01	
	7	07	
	GSB8	31 22 08	
	2	02	
190	8	08	
	•	83	
	1	01	
	GSB8	31 22 08	
	1	01	
	7	07	
	CHS	42	
	GSB8	31 22 08	
	CF Ø	35 61 ØØ	
	RCL Ø	34 ØØ	
200	RTN	35 22	
	LBL 8	31 25 Ø8	
	ISZ	31 34	
	STO(i)	33 24	
	RTN	35 22	
210			
220			

LABELS

A	B	C	D	E
ENTER Z	ENTER N	B.E.	M(Z,N)	M. Excess
a →E_v	b →E_s	c →E_c	d →E_{sym}	e →E_{pair}
0 →	1 →	2 →	3 →	4 →
5 →	6 →	7 →	8 →	9 →

FLAGS

0	↘
1	↘
2	
3	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☒	☐	DEG	☐	FIX	☐
1	☒	☐	GRAD	☐	SCI	☒
2	☐	☐	RAD	☐	ENG	☐
3	☐	☐			n	4

Program Description I

Program Title Clebsch-Gordon Coefficients and 3j Symbols Evaluation

Contributor's Name G. Richard Scott
Address 110 Donelsonwood Drive
City Nashville **State** Tennessee **Zip Code** 37214

Program Description, Equations, Variables This program will evaluate all valid Clebsch-Gordon Coefficients and/or "3j" symbols coupling two states of angular momentum which are small enough so that the capacity of the calculator's factorial function is not exceeded. The fundamental formula used by the program is the Racah Formula;

$$\underbrace{\begin{pmatrix} j_1 & j_2 & J \\ m_1 & m_2 & -M \end{pmatrix}}_{3j\ \text{SYMBOL}} = (-1)^{j_1-j_2+M}\sqrt{\Delta(j_1 j_2 J)}\sqrt{(j_1+m_1)!(j_1-m_1)!(j_2+m_2)!(j_2-m_2)!(J+M)!(J-M)!}$$

$$\times\sum_t (-1)^t\Big[t!\,(J-j_2+t+m_1)!\,(J-j_1+t-m_2)!\,(j_1+j_2-J-t)!\times(j_1-t-m_1)!\,(j_2-t+m_2)!\Big]^{-1}$$

$$\text{with } \Delta(j_1 j_2 J) \equiv \Big[(j_1+j_2-J)!\,(j_2+J-j_1)!\,(J+j_1-j_2)!\Big] \div (j_1+j_2+J+1)!$$

SUBJECT TO THE RESTRAINTS ① $|j_1-j_2| \leq J \leq |j_1+j_2|$
② $m_1+m_2=M$

THE CLEBSCH-GORDON COEFFICIENT, $\langle j_1 j_2 m_1 m_2 | JM\rangle = \frac{\sqrt{2J+1}}{(-1)^{j_1-j_2+M}}\begin{pmatrix} j_1 & j_2 & J \\ m_1 & m_2 & -M \end{pmatrix}$

Operating Limits and Warnings If any one term in the Racah formula is greater than 69, an error message will result (or else the calculator will display all 9's in the x-register). If illegitimate values are entered for j_1, j_2, and J or for m_1, m_2, and M, spurious results (ie, non-zero) may be obtained <u>or</u> the the calculator may get caught in a "loop" which will not terminate until the "t" value in the Racah formula exceeds 69.

Program Description II

Sketch(es)

Sample Problem(s) ① SUPPOSE THE C.G. COEFFICIENT $\langle j_1 j_2 m_1 m_2 | JM \rangle$ IS NEEDED WITH $j_1 = \frac{3}{2}$, $j_2 = 2$, $J = \frac{5}{2}$; $m_1 = \frac{1}{2}$, $m_2 = 0$, $M = \frac{1}{2}$.

NOTE FOR SOLUTIONS: j_1 is "entered" by pressing "A"
j_2 " " " " B
J " " " " C
m_1 " " " " f[A]
m_2 " " " " f[B]
M is KEYED IN AS $-M$ and is "entered" by pressing f[C]

② IF THE 3j SYMOL $\begin{pmatrix} j_1 & j_2 & J \\ m_1 & m_2 & -M \end{pmatrix}$ was desired, IT IS STORED IN REGISTER E.

Solution(s) ① 1.5 [A] 2 [B] 2.5 [C] .5 [f][A] 0. [f][B] −.5 [f][C] completes entry of data

[D] starts program → 2.927700221−01 (DIMENSIONLESS)

② [RCL] [E] → 1.195228610−01 (DIMENSIONLESS)

Reference(s) MESSIAH, ALBERT, QUANTUM MECHANICS, VOLUME II, PP 1054–1058, NORTH-HOLLAND PUBLISHING CO. (AMSTERDAM) AND JOHN WILEY & SONS (NEW YORK), 1958. (translated from the French edition)

User Instructions

C. G. Coefficients and 3j Symbols

1					2
$A = j_1$	$B = j_2$	$C = J$		RCL E → 3j	
$a = m_1$	$b = m2$	$c = -M$	START		

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Load side 1 and side 2				
2	Load $j_1, j_2, J, m_1, m_2, -M$: *				
	input j_1	j_1	A		j_1
	input j_2	j_2	B		j_2
	input J	J	C		J
	input m_1	m_1	f	A	m_1
	input m_2	m_2	f	B	m_2
	input-M **	-M	f	C	-M
3	Compute and output C.G. coefficient		D		C.G.
4	Optional: Output 3j symbol's value		RCL	E	3j value
5	For a new case, go to step 2				
	**When data is entered as above, the Clebsch-Gordon coefficient computed is $\langle j_1 j_2 m_1 m_2 \| JM \rangle$, while the 3j symbol which is computed is $\begin{pmatrix} j_1 & j_2 & J \\ m_1 & m_2 & -M \end{pmatrix}$				
	* If an error is made while entering data, it is suggested that step 2 be begun again.				

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	CLEARS REGISTERS AND STORES j_1
002	CLRG	16-53	
003	P⇄S	16-51	
004	CLRG	16-53	
005	STO1	35 01	
006	RTN	24	
007	*LBLB	21 12	STORES j_2
008	STO2	35 02	
009	RTN	24	
010	*LBLC	21 13	STORES J
011	STO3	35 03	
012	P⇄S	16-51	
013	RTN	24	
014	*LBLa	21 16 11	STORES m_1
015	STO1	35 01	
016	RTN	24	
017	*LBLb	21 16 12	STORES m_2
018	STO2	35 02	
019	RTN	24	
020	*LBLc	21 16 13	STORES $-M$
021	STO3	35 03	
022	P⇄S	16-51	
023	RTN	24	
024	*LBLD	21 14	BEGINS COMPUTATIONS $\Delta(j_1 j_2 J)$ IS COMPUTED IN STEPS 25-57
025	RCL1	36 01	
026	RCL2	36 02	
027	RCL3	36 03	
028	-	-45	
029	+	-55	
030	N!	16 52	
031	STO4	35 04	
032	RCL2	36 02	
033	RCL3	36 03	
034	RCL1	36 01	
035	-	-45	
036	+	-55	
037	N!	16 52	
038	ST×4	35-35 04	
039	RCL3	36 03	
040	RCL1	36 01	
041	RCL2	36 02	
042	-	-45	
043	+	-55	
044	N!	16 52	
045	ST×4	35-35 04	
046	1	01	
047	RCL1	36 01	
048	RCL2	36 02	
049	RCL3	36 03	
050	+	-55	
051	+	-55	
052	+	-55	
053	N!	16 52	
054	RCL4	36 04	
055	X⇄Y	-41	
056	÷	-24	
057	√X	54	STORES $\sqrt{\Delta(j_1 j_2 J)}$
058	STO4	35 04	
059	1	01	
060	1	01	
061	STOI	35 46	COMPUTES $\sqrt{(j_1+m_1)!(j_1-m_1)!(j_2+m_2)!(j_2-m_2)!(J+M)!(J-M)!}$
062	RCL1	36 01	
063	RCLi	36 45	
064	+	-55	
065	N!	16 52	
066	RCL1	36 01	
067	RCLi	36 45	
068	-	-45	
069	N!	16 52	
070	x	-35	
071	STO5	35 05	
072	ISZI	16 26 46	
073	RCL2	36 02	
074	RCLi	36 45	
075	+	-55	
076	N!	16 52	
077	RCL2	36 02	
078	RCLi	36 45	
079	-	-45	
080	N!	16 52	
081	x	-35	
082	ST×5	35-35 05	
083	ISZI	16 26 46	
084	RCL3	36 03	
085	RCLi	36 45	
086	+	-55	
087	N!	16 52	
088	RCL3	36 03	
089	RCLi	36 45	
090	-	-45	
091	N!	16 52	
092	x	-35	
093	ST×5	35-35 05	
094	RCL5	36 05	
095	√X	54	
096	STO5	35 05	
097	RCL1	36 01	COMPUTES $(-1)^{j_1-j_2+M}$
098	RCL2	36 02	
099	RCLi	36 45	
100	+	-55	
101	-	-45	
102	1	01	
103	CHS	-22	
104	X⇄Y	-41	
105	Yˣ	31	
106	STO6	35 06	
107	RCL4	36 04	MULTIPLIES COMPUTED SQ. ROOTS TOGETHER; MULTIPLIES BY $(-1)^{j_1-j_2+M}$; STORES IN D
108	RCL5	36 05	
109	RCL6	36 06	
110	x	-35	
111	x	-35	
112	STOD	35 14	

REGISTERS

0	1	2	3	4	5	6	7	8	9
	USED	USED	USED	USED	USED	USED	USED	USED	USED

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
	USED	USED	USED						

A	B	C	D	E	I
USED	USED	USED	USED	3j VALUE	USED

97 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
113	CLX	-51	
114	SF0	16 21 00	COMPUTES
115	STOI	35 46	SUMMATION
116	P⇄S	16-51	IN
117	RCL1	36 01	RACAH
118	STOA	35 11	FORMULA
119	RCL2	36 02	(STEPS
120	STOB	35 12	113-198)
121	RCL3	36 03	
122	STOC	35 13	
123	P⇄S	16-51	
124	*LBL2	21 02	
125	RCL3	36 03	
126	RCLI	36 46	
127	RCLA	36 11	
128	+	-55	
129	+	-55	
130	RCL2	36 02	
131	-	-45	
132	X<0?	16-45	
133	GTO3	22 03	
134	N!	16 52	
135	STO4	35 04	
136	RCL3	36 03	
137	RCLI	36 46	
138	+	-55	
139	RCL1	36 01	
140	RCLB	36 12	
141	+	-55	
142	-	-45	
143	X<0?	16-45	
144	GTO3	22 03	
145	N!	16 52	
146	STO5	35 05	
147	RCL1	36 01	
148	RCL2	36 02	
149	+	-55	
150	RCL3	36 03	
151	RCLI	36 46	
152	+	-55	
153	-	-45	
154	X<0?	16-45	
155	GTO3	22 03	
156	N!	16 52	
157	STO6	35 06	
158	RCL1	36 01	
159	RCLI	36 46	
160	RCLA	36 11	
161	+	-55	
162	-	-45	
163	X<0?	16-45	
164	GTO3	22 03	
165	N!	16 52	
166	STO7	35 07	
167	RCL2	36 02	
168	RCLB	36 12	

STEP	KEY ENTRY	KEY CODE	COMMENTS
169	+	-55	
170	RCLI	36 46	
171	-	-45	
172	X<0?	16-45	
173	GTO3	22 03	
174	N!	16 52	
175	STO8	35 08	
176	CF0	16 22 00	
177	RCL4	36 04	
178	RCL5	36 05	
179	RCL6	36 06	
180	x	-35	
181	x	-35	
182	RCL7	36 07	
183	RCL8	36 08	
184	x	-35	
185	x	-35	
186	RCLI	36 46	
187	N!	16 52	
188	x	-35	
189	1/X	52	
190	1	01	
191	CHS	-22	
192	RCLI	36 46	
193	Yˣ	31	
194	x	-35	
195	ST+9	35-55 09	
196	ISZI	16 26 46	
197	GTO2	22 02	
198	GTO2	22 02	
199	*LBL3	21 03	CHECKS TO
200	ISZI	16 26 46	SEE IF Σ_t finished;
201	F0?	16 23 00	IF SO, COMPUTES
202	GTO2	22 02	3j VALUE,
203	RCL9	36 09	STORES IN
204	RCLD	36 14	REGISTER E
205	x	-35	
206	STOE	35 15	
207	1	01	COMPUTES
208	CHS	-22	CLEBSCH-
209	RCL1	36 01	GORDON
210	RCLC	36 13	COEFFICIENT
211	-	-45	
212	RCL2	36 02	
213	-	-45	
214	Yˣ	31	
215	RCL3	36 03	
216	2	02	
217	x	-35	
218	1	01	
219	+	-55	
220	√X	54	
221	x	-35	
222	RCLE	36 15	
223	x	-35	
224	RTN	24	

LABELS

A j_1	B j_2	C J	D →C.G	E
a m_1	b m_2	c $-M$	d	e
0	1	2 calc	3 calc	4
5	6	7	8	9

FLAGS

0	
1	
2	
3	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☒	☐	DEG	☒	FIX	☐
1	☐	☒	GRAD	☐	SCI	☒
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n 9	

Program Description I

Program Title 32-P REMAINING ON MM.DDYYYY GIVEN MCI ON EARLIER MM.DDYYYY

Contributor's Name GARY G. ALTMAN

Address 3307 NORTHBROOK DRIVE

City MIDDLETON State WISCONSIN Zip Code 53562

Program Description, Equations, Variables

1. JULIAN DAY NUMBER IS CALCULATED AS DESCRIBED IN THE HP-67 STANDARD PAC, PAGE 04-01; THE NUMBER OF DAYS BETWEEN DATE 1 AND DATE 2 IS ALSO CALCULATED AS DESCRIBED IN THE HP-67 STANDARD PAC.
2. RADIOACTIVE DECAY: (INITIAL mCi)$(0.5)^n$ = mCi ON DATE 2, WHERE n = 14.3 / ΔDAYS = THE NUMBER OF HALF-LIVES OF ^{32}P WHICH HAVE OCCURRED.
3. SUBROUTINE D YIELDS: mCi ON DATE 2;
   (mCi ON DATE 2)(2.2×10^9 DPM) = <u>DPM ON DATE 2</u>;
   AND (0.3)(DPM) ≅ <u>CPM ON DATE 2</u>
   [ASSUMES 30% COUNTING EFFICIENCY AND NO QUENCHING]
4. SUBROUTINE f C YIELDS:
   $(0.5)^n$(CPM ON DATE 1) = <u>CPM ON DATE 2</u>; AND
   $[(2.2\times10^9 \text{ DPM}/\text{mCi})/(\text{CPM}/.3)]^{-1}$ = <u>mCi ON DATE 2</u>

Operating Limits and Warnings PROGRAM FAILS IF DATE 1 = DATE 2 OR IF DATE 1 IS MORE RECENT THAN DATE 2.

Program Description II

Sketch(es)

Sample Problem(s) 1. HOW MANY DPM (AND CPM) REMAIN OF A 0.135 mCi ^{32}P SAMPLE? GIVEN: DATE OF SPECIFIC RADIOACTIVITY RATING AS FEB 2, 1977; AND TODAY'S DATE APRIL 22, 1977.

2. HOW MANY CPM (AND mCi) REMAIN OF A 3.2×10^6 CPM SAMPLE OF ^{32}P AS MEASURED BY CHERENKOV RADIATION ON AUGUST 11, 1976?

Solution(s) 1. 2.071977 A (DISPLAY: 2443182) 4.221977 B (DISPLAY: 2443256.) C (DISPLAY: 74., THE NUMBER OF DAYS BETWEEN FEB 7 AND APR 22) 0.135 D (DISPLAY: 8.2220×10^6, 2.466×10^6 - THE DPM AND THE CPM REMAINING)

2. 8.111976 A (2443002.) 4.221977 B (2443256.) C (254. = ΔDAYS) 3.2 EEX 6 f C (ANSWERS: 14., 2.18×10^{-8} - 14 CPM REMAINING, 2.18×10^{-8} mCi REMAINING)

Reference(s) CALENDAR FUNCTIONS, PAGE 04-01 IN HP-67 STANDARD PAC, AND CHASE, G.D. & J.L. RABINOWITZ, PRINCIPLES OF RADIOISOTOPE METHODOLOGY, BURGESS, MINNEAPOLIS, MN (1962).

User Instructions

^{32}P REMAINING

1		INITIAL CPM			2
	DATE 1	DATE 2	Δ DAYS	INITIAL mCi	

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1.	LOAD SIDE 1 AND SIDE 2	—			
2.	INPUT DATE 1 AS MM.DDYYYY	DATE 1		A	JULIAN DAY #
3.	INPUT DATE 2 AS MM.DDYYYY	DATE 2		B	JULIAN DAY #
4.	CALCULATE # OF DAYS BETWEEN	—			
	DATE 1 AND DATE 2	—		C	Δ DAYS
5.	(TO INPUT CPM GO TO STEP 6)				
	INPUT mCi OF ^{32}P AS OF DATE 1	mCi		D	DPM
					CPM
6.	INPUT CPM ON DATE 1	CPM	f	C	CPM
					mCi

67 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	f LBL A	31 25 11	
2	f FIX	31 23	CALC ΔDAYS AND PUT CONTROL 3 IN DISPLAY
3	DSP 2	23 02	
4	RCL 4	34 04	
5	RCL C	34 13	
6	−	51	
7	3	03	
8	GTO 0	22 00	
9	f LBL B	31 25 12	CALCULATE ΔDAYS AND PUT 4 IN DISPLAY
010	RCL 3	34 03	
11	RCL C	34 13	
12	+	61	
13	4	04	
14	f LBL 0	31 25 00	STORE CONTROL CODE
15	h STO i	35 33	
16	h R↓	35 53	STORE CONSTANTS
17	3	03	
18	6	06	
19	5	05	
020	.	83	
21	2	02	
22	5	05	
23	STO 5	33 05	
24	3	03	
25	0	00	
26	.	83	
27	6	06	
28	0	00	
29	0	00	
030	1	01	
31	STO 6	33 06	
32	h R↓	35 53	RETURN ΔDAYS TO DISPLAY
33	h R↓	35 53	
34	h F3?	35 71 03	IF DATA INPUT GO TO 1
35	GTO 1	22 01	
36	h ST i	33 24	STORE ΔDAYS ACCORDING TO CONTROL MODE
37	1	01	
38	2	02	
39	2	02	CALC Y'
040	.	83	
41	1	01	
42	−	51	
43	RCL 5	34 05	
44	÷	81	
45	f INT	31 83	CALC m'.
46	STO 9	33 09	
47	RCL 5	34 05	
48	×	71	
49	f INT	31 83	
050	h RC i	34 24	
51	−	51	
52	CHS	42	
53	STO A	33 11	
54	RCL 6	34 06	
55	÷	81	
56	f INT	31 83	

STEP	KEY ENTRY	KEY CODE	COMMENTS
57	STO 7	33 07	CALC DAY OF MONTH
58	RCL A	34 11	
59	h x⇄y	35 52	
060	RCL 6	34 06	
61	×	71	
62	f INT	31 83	
63	−	51	
64	STO 8	33 08	
65	RCL 7	34 07	BUILD (m'−1).DD PART OF DISPLAY
66	1	01	
67	RCL 8	34 08	
68	f %	31 82	
69	−	51	
070	−	51	
71	RCL 7	34 07	CORRECT m'−1 AND Y' TO M AND Y.
72	1	01	
73	4	04	
74	÷	81	
75	GSB 2	31 22 02	
76	RCL 9	34 09	FINISH BUILDING MM.DDYYYY RESULT AND DISPLAY ANSWER.
77	EEX	43	
78	6	06	
79	÷	81	
080	+	61	
81	DSP 6	23 06	
82	h RTN	35 22	
83	f LBL 1	31 25 01	BREAK DATE INPUT INTO THE INDIVIDUAL COMPONENTS OF MM, DD, YYYY.
84	h R↓	35 53	
85	↑	41	
86	f INT	31 83	
87	STO 7	33 07	
88	−	51	
89	EEX	43	
090	2	02	
91	×	71	
92	↑	41	
93	f INT	31 83	
94	STO 8	33 08	
95	−	51	
96	EEX	43	
97	4	04	
98	×	71	
99	STO 9	33 09	
100	RCL 7	34 07	m+1
101	1	01	
102	+	61	
103	↑	41	m+1 → m'
104	h 1/x	35 62	
105	.	83	
106	7	07	Y → Y'
107	+	61	
108	CHS	42	
109	GSB 2	31 22 02	
110	RCL 6	34 06	COMPUTE JULIAN DAY NUMBER
111	×	71	
112	f INT	31 83	

REGISTERS

0	1	2	3	4	5	6	7	8	9
			DAY 1	DAY 2	365.25	30.6001	MM	DD	YYYY

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I
USED		ΔDAYS			CONTROL

67 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
113	RCL 9	34 09	
114	RCL 5	34 05	
115	x	71	
116	f INT	31 83	
117	+	61	
118	RCL 8	34 08	
119	+	61	
120	h STI	33 24	
121	1	01	
122	7	07	
123	2	02	
124	Ø	00	
125	9	09	
126	8	08	
127	2	02	
128	+	61	
129	DSP Ø	23 00	
130	h RTN	35 22	
131	f LBL 2	31 25 02	IF INPUT TO THIS
132	f INT	31 83	ROUTINE HAS
133	STO + 9	33 61 09	ABS VALUE OF
134	1	01	1 OR >
135	2	02	Y = Y ± 1
136	X	71	M = M ± 12
137	−	51	(+ FOR PLUS INPUT)
138	h RTN	35 22	
139	f LBL C	31 25 13	STORE INPUT
140	DSP Ø	23 00	
141	STO C	33 13	
142	h F3	35 71 03	IF INPUT FLAG
143	h RTN	35 22	TRUE, THEN STOP
144	RCL 4	34 04	COMPUTE Δ DAYS
145	RCL 3	34 03	AND STOP
146	−	51	
147	STO C	33 13	
148	h RTN	35 22	
149	h F3	35 71 03	
150	GTO 4	22 04	
151	f GTO C	31 22 13	COMPUTE Δ DAYS
152	DSP 1	23 01	
153	f LBL D	31 25 14	STORE CONSTANTS
154	STO Ø	33 00	
155	1	01	
156	4	04	
157	•	83	
158	3	03	
159	STO 2	33 02	
160	2	02	
161	•	83	
162	2	02	
163	EEX	43	
164	9	09	
165	STO 1	33 01	
166	f LBL E	31 25 15	$\frac{\Delta DAYS}{14.3} = n$
167	2	02	
168	RCL C	34 13	

STEP	KEY ENTRY	KEY CODE	COMMENTS
169	RCL 2	34 02	
170	÷	81	
171	h y^x	35 63	$(1/2)^n$
172	h 1/x	35 62	
173	RCL Ø	34 00	
174	RCL 1	34 01	
175	X	71	
176	X	71	
177	g SCI	32 23	
178	DSP 4	23 04	
179	f -x-	31 84	DISPLAY DPM
180	↑	41	
181	•	83	
182	3	03	
183	X	71	
184	f -x-	31 84	DISPLAY CPM
185	h RTN	35 22	
186	g LBL c	32 25 13	
187	STO A	33 11	STORE CPM
188	RCL C	34 13	
189	RCL 2	34 02	
190	÷	81	$\frac{\Delta DAYS}{14.3} = n$
191	•	83	
192	5	05	
193	h x⇄y	35 52	
194	h y^x	35 63	$(\frac{1}{2})^n$
195	RCL A	34 11	
196	X	71	
197	f -x-	31 84	DISPLAY CPM
198	•	83	
199	3	03	
200	÷	81	
201	RCL 1	34 01	
202	÷	81	
203	h RTN	35 22	DISPLAY mCi

LABELS

A DATE 1	B DATE 2	C Δ DAYS	D mCi→CPM	E
a	b	c CPM→mCi	d	e
0 CALC	1	2	3	4
5	6	7	8	9

FLAGS

0	
1	
2	
3	INPUT

SET STATUS

FLAGS	ON	OFF
0	☐	☒
1	☐	☒
2	☐	☒
3	☐	☒

TRIG	
DEG	☒
GRAD	☐
RAD	☐

DISP: VARIES	
FIX	☐
SCI	☐
ENG	☐
n	____

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