

A CAPABILITY STUDY ON THE
HP-35
POCKET CALCULATOR

1/3/72

DESCRIPTION:

The HP-35 is a 35-key, pocket-sized scientific and engineering calculator. It performs logarithmic, trigonometric, and mathematical functions with a single keystroke, and eliminates the need to refer to log or trig tables. It displays up to 10 significant decimal digits and automatically positions the decimal point throughout its 200-decade calculating range (10^{-99} to 10^{99}).

In terms of general advantages, this unit provides much of the problem-solving power of a desk-top scientific calculator—combined with the portability and convenience of the slide rule. Unlike the slide rule, it offers unprecedented accuracy, and provides answers in a fraction of the time required for slide rule calculation.

This Capability Report will explain and evaluate special features of Hewlett-Packard's HP-35 Pocket Calculator...typical applications with comparisons of solution times...how the unit operates...advanced technological features...and general specifications.

OPERATIONS:

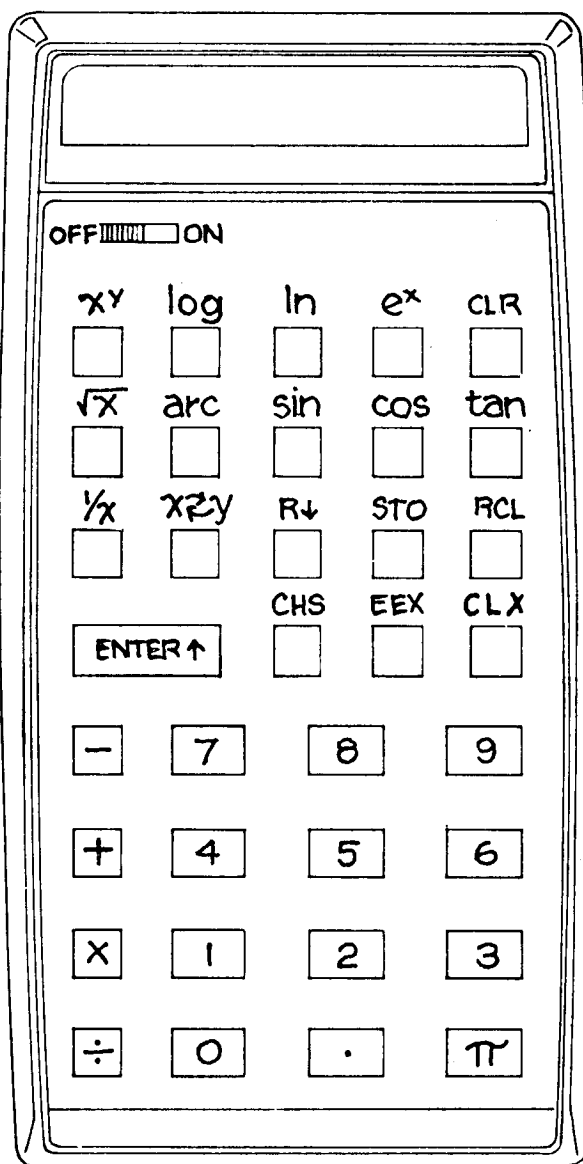


Fig. One -- Actual Size

Figure 1 shows the keyboard of the HP-35. Keyboard operations include the following, most of which are performed by a single keystroke:

Arithmetic: Add, subtract, multiply, divide and square root.

Trigonometric: Sin x, Cos x, Tan x, Arc Sin x, Arc Cos x, Arc Tan x.

Logarithmic: Log₁₀ x, Log_e x, and e^x.

Other functions: x^y, 1/x, π and data storage and positioning keys.

Single Keystroke Functions

A series of specific functions or formulas are pre-programmed into the HP-35 to provide its unique capability for performing trigonometric and exponential functions with a single keystroke. This feature makes it unnecessary to refer to tables for the values of these functions.

Operational Stack and Memory

The HP-35 is provided with an "operational stack" of 4 registers, plus a memory register for constants. The stack is used for solving either simple or complex problems that require intermediate values. It holds the intermediate results and at the appropriate time, automatically brings them back for further processing. This eliminates the need for scratch notes or the re-entry of intermediate answers.

Stack control keys permit the contents of any register to be shifted to the display for review. Examples of how the stack actually functions will be included later in this report.

Automatic Decimal Point Positioning

The HP-35 allows values to be entered in either floating point or scientific notation. Answers larger than 10^{-2} and smaller than 10^{10} are displayed in floating point with the decimal properly positioned. For values outside this range, answers are displayed in scientific notation, with the exponent of 10 shown at the right of the display.

Blanked Digits

Displays pertinent numbers from left to right. Insignificant trailing zeros are automatically blanked for easier reading of the display. Example: $1/2$ is displayed as .5 with no trailing zeros.

Overflow-Underflow and Improper Operations

Overflow and underflow are indicated by the HP-35's closest answers: $9.99... \times 10^{99}$, and 0, respectively. Improper operations, such as the square root of a negative number, are indicated by a flashing display.

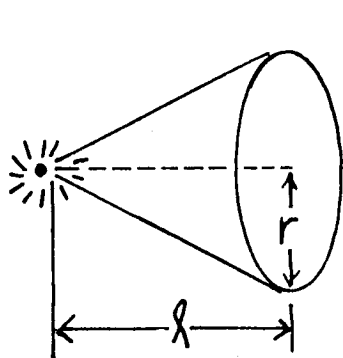
Battery Power or AC Line Operation

A battery pack, consisting of nickel-cadmium rechargeable batteries, provides at least five hours of operation under normal use. When operating on the battery pack, the HP-35 automatically provides positive indication of low battery power. Ten to 15 minutes of operating time remain after this warning signal is flashed. An adapter is provided for AC operation (115 or 230 volts). The unit can be operated on AC while the battery pack is being charged.

The following problems were selected from engineering notebooks and were given to members of Hewlett-Packard's own engineering staff for solutions. Each engineer was asked to time himself in working each problem in two ways: first, with a pilot model of the HP-35 and, second by conventional slide rule methods. Actual results are shown with comparison times, together with key strokes for the HP-35 and scratch notes required for arriving at the slide rule solutions.

In reviewing solutions to the following problems, it should be noted that the HP-35 functions on what is formally known as Lukasiewicz or reverse Polish notation (an adding machine also uses Polish notation). This feature, combined with the operational stack, is solidly based on computer theory, and provides the most efficient method known for evaluating arithmetic expressions. See page 5 for a detailed explanation of the keystrokes used on the calculator.

PROBLEM 1: COLLECTION SOLID ANGLE FROM A POINT SOURCE



$$\Omega = 2\pi \left[1 - \sqrt{\frac{1}{\left(\frac{r}{l}\right)^2 + 1}} \right]$$

LET $r = 2.5 \text{ cm}$
 $l = 10.3 \text{ cm}$

HP-35 SOLUTION

2.5 \uparrow 10.3 \div \uparrow \times 1 $+$ $\left[\frac{1}{x} \right]$ $\left[\sqrt{x} \right]$ CHS \uparrow 1 $+$ 2 \times π \times \rightarrow .1772825509

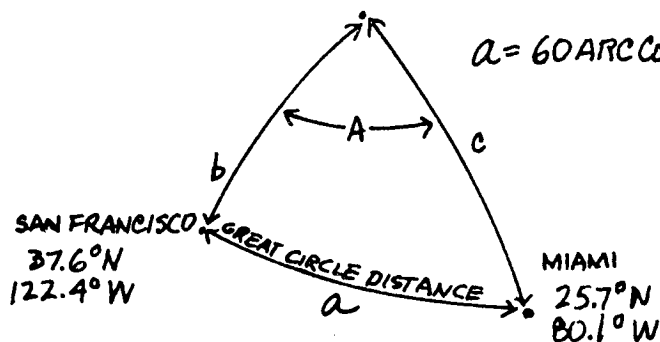
Slide Rule Solution

| | | | | |
|------|-------|------|-------|------|
| | | | 1.000 | |
| .243 | 1.059 | .946 | 972. | |
| | | | .028 | .176 |

TIME ON HP-35: 20 seconds with computation to ten significant digits.

TIME ON SLIDE RULE = 3 minutes, 15 seconds with answer to three decimal places.

PROBLEM 2: GREAT CIRCLE DISTANCE BETWEEN SAN FRANCISCO AND MIAMI



$$a = 60 \text{ ARCCOS} [\cos b \cos c + \sin b \sin c \cos A]$$

$$b = 90 - 37.6 = 52.4^\circ$$

$$c = 90 - 25.7 = 64.3^\circ$$

$$A = 122.4 - 80.1 = 42.3^\circ$$

HP-35 SOLUTION:

$$52.4 [\cos] 64.3 [\cos] [X] 52.4 [\sin] 64.3 [\sin] [X] 42.3 [\cos] [X] [+] \text{arc} [\cos] 60 [X] \rightarrow 2254.093016$$

SLIDE RULE SOLUTION:

| |
|----------------------------------|
| .2645 |
| .528 |
| <hr/> |
| .7925 → 37.55° → <u>2255 mm.</u> |

TIME ON HP-35: 65 seconds with computation to ten significant digits.

TIME ON SLIDE RULE: 5 minutes with answer to three significant digits.

PROBLEM 3: PH OF A BUFFER SOLUTION

$$\alpha_H = 1 + \sum C_B K_A, H^+ = \sqrt{\frac{1}{\alpha_H} \sum \frac{C_A}{K_A}}$$

FOR A MIXTURE OF $\text{Na}_2\text{HPO}_4 @ .03 \text{ M/l}$ AND $\text{NaH}_2\text{PO}_4 @ 8.7 \times 10^{-3} \text{ M/l}$

$$\alpha_H = 1 + [3 \times 10^{-2}] (10^{7.21}) + [8.7 \times 10^{-3}] (10^{2.16})$$

$$-H^+ = \text{LOG} \sqrt{\frac{1}{\alpha_H} \left(\frac{3 \times 10^{-2}}{10^{11.7}} + \frac{8.7 \times 10^{-3}}{10^{7.21}} \right)}$$

HP-35 SOLUTION:

$$7.21 [\uparrow] 10 [x^y] .03 [X] 1 [+] 2.16 [\uparrow] 10 [x^y] .0087 [X] [+] \text{STO} .03 [\uparrow]$$

$$11.7 [\uparrow] 10 [x^y] [\div] .0087 [\uparrow] 7.21 [\uparrow] 10 [x^y] [\div] [+] \text{RCL} [\div] [\sqrt{}] [\log] \rightarrow -7.47877778$$

SLIDE RULE SOLUTION:

$$\begin{aligned}
 L_H &= 1 + 3 \times 10^{5.21} + 8.7 \times 10^{-.84} = 3 \times 10^{5.21} \\
 H &= \sqrt{\frac{1}{3 \times 10^5 \times 10^{-.21}} \left(3 \times 10^{-13.7} + 8.7 \times 10^{-10.21} \right)} \\
 &= \sqrt{\frac{10^{-.21} \times 10^{-11}}{3 \times 10^5} \left(3 \times 10^{-2.7} + 8.7 \times 10^{+.89} \right)} \\
 &= \sqrt{.33 \times 10^{-16} \times 10^{-.21} \left(3 \times .002 + 8.7 \times 7.74 \right)} \\
 &= \sqrt{22.2 \times 10^{-16.21}} = \sqrt{10^{1.348} \times 10^{-16.21}} \quad \begin{array}{r} 16.21 \\ 1.35 \\ \hline 14.86 \end{array} \\
 &= \sqrt{10^{-14.86}} = 10^{-7.43} \\
 PH &= \underline{\underline{7.43}}
 \end{aligned}$$

TIME ON HP-35: 65 seconds with computation to ten significant digits.

TIME ON SLIDE RULE: 5 minutes with answer to three significant digits.

COMPARISON SUMMARY

It should be noted that these comparisons were made by engineers who are not only highly proficient in slide rule calculation, but were also familiar with the operation of the HP-35. Thus, the solution times cited above should not be taken as typical. They do, however, serve to indicate the relative time advantage of the HP-35 and to point up the still more significant advantage of its precise accuracy.

To quote the comments of one Hewlett-Packard engineer who took part in the comparison study: "When you repeat a solution on the HP-35, the answers are precisely the same. On the slide rule, they are close to the same value, but tolerances in manipulation prevent the answers from being exactly the same. I would rate the speed of the HP-35 as a secondary factor to its convenience of use and the security of having accurate answers when running close calculations."

HOW THE HP-35 POCKET CALCULATOR OPERATES

The following is intended as a brief description of the unit's operations. Keyboard functions are broken down into Entry Keys, Memory Keys, Stack Control Keys, Functions with One Argument, and Functions with Two Arguments.

ENTRY KEYS:

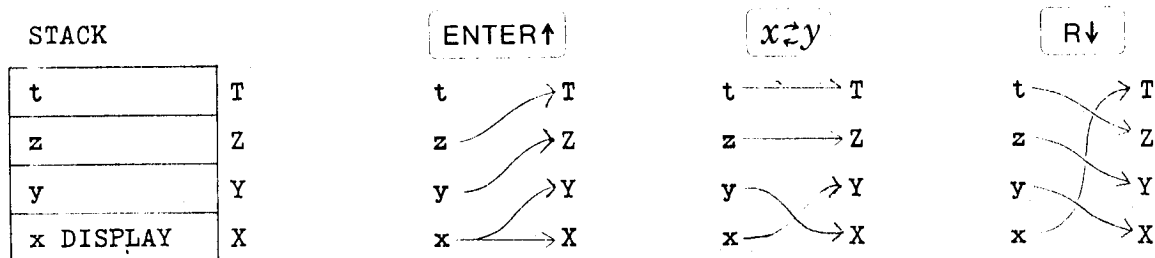
- [0] to [9] and [.] - Numerical entry.
- [π] - Places π, correct to 10 places, into the display.
- [CLR] - Clears all registers including memory.
- [CLx] - Clears entry in X.
- [CHS] - Changes signs of display.
- [EEX] - Next entries are exponent digits. [CHS] must immediately follow EEX for negative exponents.

Memory Keys:

- [STO] - Stores the displayed number (x register) in memory.
- [RCL] - Recalls memory to x register.

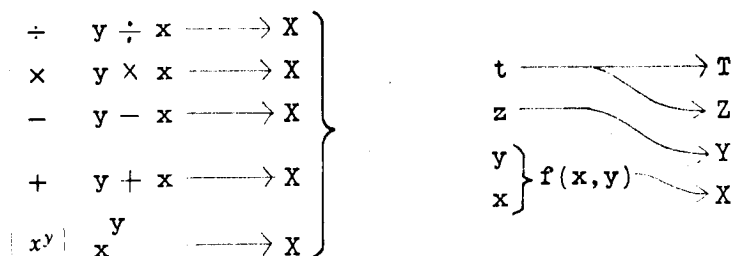
Stack Control Keys:

The stack consists of 4 registers, which are identified by the capital letters X, Y, Z and T. The contents of the stack are identified by the lower case letters x, y, z and t. The three keys shown below are used for entries into the stack...exchanging the contents of the X and Y registers...and "rolling down" the registers for viewing the display.



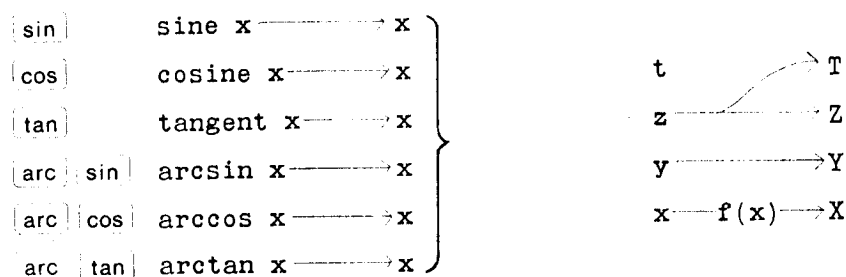
Functions with Two Arguments:

Operations occur from the interaction between the contents of the X and Y registers. Answers appear in the X register, and are automatically displayed.



Functions with One Argument:

All functions with one argument replace x with f(x). For keys $1/x$, \sqrt{x} , log, ln, and e^x , registers Y, Z, and T are unchanged. For trigonometric functions, both forward and inverse, register Z is duplicated into T. ALL ANGLES IN DEGREES.



ADVANTAGES OF OPERATIONAL STACK

The operational stack allows typical problems to be solved with a minimum number of keystrokes. When solving equations with several terms or nested parentheses, the stack stores partial answers as they occur and automatically drops them into place when needed for the next calculation.

The following examples have been chosen to show how the stack functions in actual use. The stack operation charts on the following page show:

BOTTOM ROW: The successive keystrokes used to evaluate the expression.

TOP FOUR ROWS: The contents of the stack following each operation.

NEXT TO BOTTOM ROW: The contents of the display after each operation.

EXAMPLE 1:

$$T = RC \ln \left(1 + \frac{V_{in}}{V_C} \right)$$

KEYS: $V_{in} \uparrow \quad V_C \div 1 \quad + \quad \ln R \quad \times \quad C \quad \times$

STACK OPERATION:

| | | | | | | | | | | | |
|-----------|-----|-----|-----|--------|--------|------------|-------|-------|--------|--------|---------|
| t | | | | | | | | | | | |
| z | | | | | | | | | | | |
| y | | Vin | Vin | | Vin/Vc | | | ln() | | Rln() | |
| DISPLAY x | Vin | Vin | Vc | Vin/Vc | 1 | (1+Vin/Vc) | ln() | R | Rln() | C | RCln() |
| KEY | Vin | ↑ | Vc | ÷ | 1 | + | ln | R | × | C | × |

Example 2: $\frac{(2 + 3) \times 4/5}{\sin 30^\circ} \times 4^{-1.5} = 1.0$

| | | | | | | | | | | | | | | | | | |
|-----------|---|---|---|---|---|----|----|---|----|-----|---|-----|------|------|------|-------|---|
| t | | | | | | | | | | | | | | | | | |
| z | | | | | | | | | | | | | | 8 | 8 | | |
| y | | 2 | 2 | | 5 | | 20 | | 4 | 4 | | 8 | 8 | -1.5 | -1.5 | 8 | |
| DISPLAY x | 2 | 2 | 3 | 5 | 4 | 20 | 5 | 4 | 30 | .5 | 8 | 1.5 | -1.5 | -1.5 | 4 | .125 | 1 |
| KEY | 2 | ↑ | 3 | + | 4 | × | 5 | ÷ | 30 | sin | ÷ | 1.5 | CHS | ↑ | 4 | x^y | × |

Example 3: Compute the annual rate of return (after taxes) on an investment held for 6½ months. Tax Rate = 35%. Buy Price \$2,341, Sell Price = \$2,672.

$$\text{RETURN} = \frac{(2672-2341)(1-0.35)}{2341} \times \frac{12}{6.5} = 16.97\%/\text{YEAR}$$

| | | | | | | | | | | | | | | | | |
|----------|------|------|------|------|-----|-----|-----|-----|-----|--------|--------|-------|-------|-------|-------|-------|
| t | | | | | | | | | | | | | | | | |
| z | | | | | | | 331 | 331 | | | | | | | | |
| y | | 2672 | 2672 | 2672 | | 331 | 1 | 331 | | | 215.15 | | .0919 | | 1.103 | |
| DISPLAY* | 2672 | 2672 | 2341 | 2341 | 331 | 1 | 1 | .35 | .65 | 215.15 | 2341 | .0919 | 12 | 1.103 | 6.5 | .1697 |
| KEY | 2672 | ↑ | 2341 | STO | — | 1 | ↑ | .35 | — | X | RCL | ÷ | 12 | X | 6.5 | ÷ |

ADVANCED TECHNOLOGICAL FEATURES



Large-Scale Integrated Circuits (LSI):

The HP-35 has especially designed MOS/LSI (Metal-Oxide-Semiconductor/ Large-Scale Integration) circuits using a new low-power, high-performance ion-implant process. These circuits are believed to be the largest presently in volume production in the world. Each is equivalent to 6,000 transistors—a total of 30,000.

Light-Emitting-Diode Display (LED):

The bright, easily-read display in the HP-35 was designed specifically for this application by Hewlett-Packard, one of the world's leading producers of optoelectronic devices. Since the displays are made from semi-conductor materials, they—like transistors—do not wear out with time.

Tactile Feedback Keyboard:

The unique keyboard allows grouping of 35 easily-operated keys on a front panel approximately 3x5 inches. Keys are fully spaced for convenient fingertip operation. Each key has a "breakaway" or "overcenter" touch similar to the key action of a high quality electric typewriter.

Compact, Contoured Case:

The HP-35 has been designed to take substantial punishment in field use. The small size of its sculptured, shirt-pocket case is made possible through a combination of modern packaging techniques and high-density integrated circuit electronics. (Figure Two)

Fig. Two

POWER:

AC — 115 or 230 V, $\pm 10\%$, 50 to 60 Hz, 5 watts.

Battery — 500 mw derived from Nickel-Cadmium rechargeable Battery Pack. Meets specifications established by the Radio Technical Commission for Aeronautics, regarding radio frequency interference of devices carried on commercial aircraft.

WEIGHT:

Calculator — 9 ounces
Recharger — 5 ounces
Shipping weight — approx. 2 lbs.

DIMENSIONS:

Length — 5.8 inches
Width — 3.2 inches
Height — 0.7 to 1.3 inches

TEMPERATURE OPERATING RANGE: 0° C TO 40° C (32°F TO 104°F) A.C.

ACCESSORIES INCLUDED:

- * AC Adapter and battery recharger (115/230V).
- * Soft leather case with belt loop.
- * Safety travel case of molded plastic, holds both calculator and recharger and is compact enough to fit most standard attache cases. (Figure Three)
- * Self-adhesive owner name tags for the unit and accessories.
- * Operating manual.

OPTIONAL SECURITY CRADLE:

This optional accessory (Figure 4) helps prevent theft or un-authorized "borrowing." The security cradle can be locked and bolted firmly to a desk or table top, yet still swivel for easy use. For hand-held operation, the unit can be secured with the heavy-duty cable which can be attached to a stationary object. Full details and ordering instructions on this inexpensive option are packed with the calculator.

OTHER OPTIONAL ACCESSORIES:

A protective hard leather Field Carrying Case, a spare battery pack with battery holder for use with the Model HP-35's recharger, and a 12V auto recharger are also available. For details and prices, refer to the information packed with the calculator.

CERTIFICATION AND WARRANTY:

The Hewlett-Packard Company certifies that every HP-35 Pocket Calculator is thoroughly tested and inspected and found to meet its published specifications before it is shipped from the factory. The Hewlett-Packard Company further certifies that its calibration measurements are traceable to the U.S. Bureau of Standards to the extent allowed by the Bureau's calibration facility.

Hewlett-Packard Pocket Calculator Products are warranted against defects in materials and workmanship. This warranty applies for one (1) year from the date of delivery. We will repair or replace components which prove to be defective during the warranty period, provided the defective units are returned to Hewlett-Packard. No other warranty is expressed or implied. We are not liable for consequential damage.

HEWLETT  PACKARD

Advanced Products
10900 Wolfe Road
Cupertino, California 95014

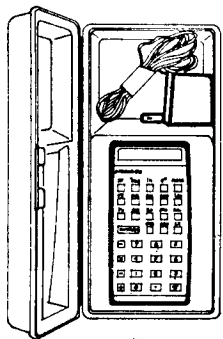


Fig. Three

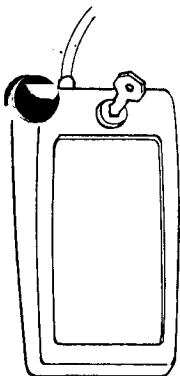


Fig. Four

Here's what 3 distinguished scientists reported after using the HP-35 Pocket Calculator...

"In the time that I have had the new pocket calculator I have shown it to about 20 or 30 engineers including students. After a few moments of stunned silence they invariably say, "It's fantastic" or "Incredible." Then they say, "I want one."

Apart from the social success that I have achieved I have also put the device to work for me. In less than two weeks it has become a way of life. As a super sliderule it is faster, more accurate and more readable. It has one impressive feature that makes it wonderful for design calculations -- you don't have to figure out at the end where the decimal point is. I realized for the first time what a time-saver this can be.

This new calculator will soon become indispensable for engineers and scientists. It will open up possibilities in field work, committee meetings, professional meetings and other activities conducted away from home base, where instant calculating was never available before."

-- R. N. Bracewell
Professor Electrical Engineering
RADIO ASTRONOMY INSTITUTE

"The amount of potential power you have been able to compress into such a small package is impressive, and the evident care with which its characteristics have been planned, make the calculator very convenient. In conferences, on business trips or at an experimental site, the calculator's transcendental functions and exponential ability are especially useful for making and checking calculations. I have enjoyed the relative freedom from the need for tables or paper and pencil which the machine's ability to handle work internally and its functional planning allow. Anyone who has to perform intricate calculations daily and who does not have a program terminal at his desk should find your calculator particularly valuable."

-- Dr. Charles H. Townes
University Professor
UNIVERSITY OF CALIFORNIA

"I have very much enjoyed using the miniature computer for the last few weeks; I find it an unusually versatile and practical tool for people who have need for more than the usual arithmetical operations and who can't restrict their work to a fixed location. It should be particularly handy for technical people who like to continue their work at home. You have certainly done an exacting job in packaging this much computing power into this amount of space."

-- W. K. H. Panofsky
STANFORD UNIVERSITY

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