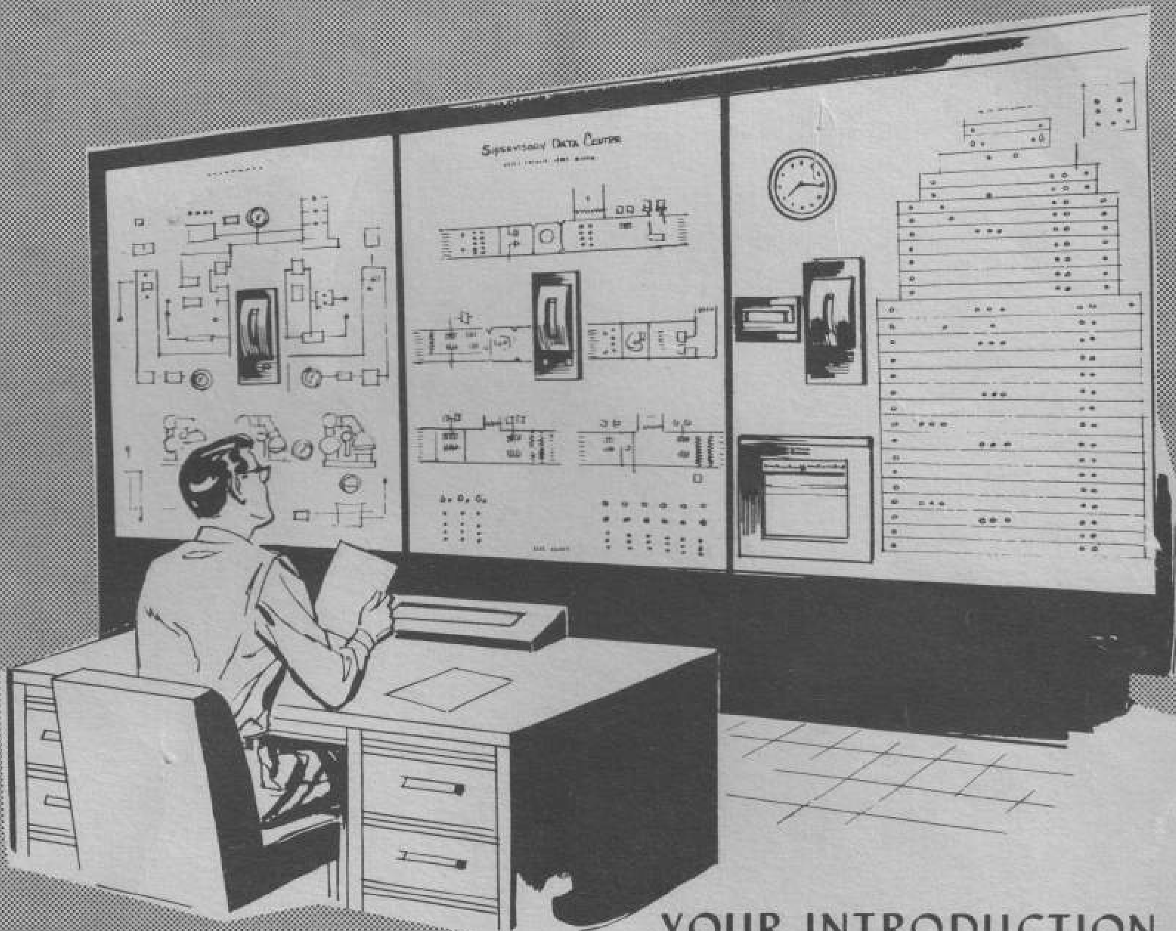


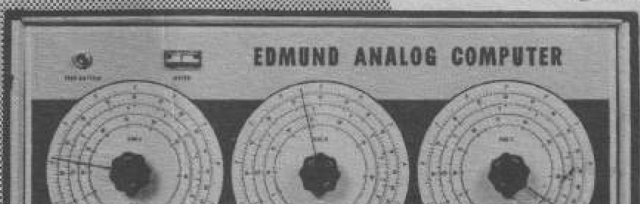
YOUR INTRODUCTION TO
THE WORLD OF THE COMPUTER

THE EDMUND ANALOG COMPUTER KIT

NO. 70,341

Edmund Scientific Co.

Barrington, New Jersey



EDMUND ANALOG COMPUTER

INSTRUCTION MANUAL

BY

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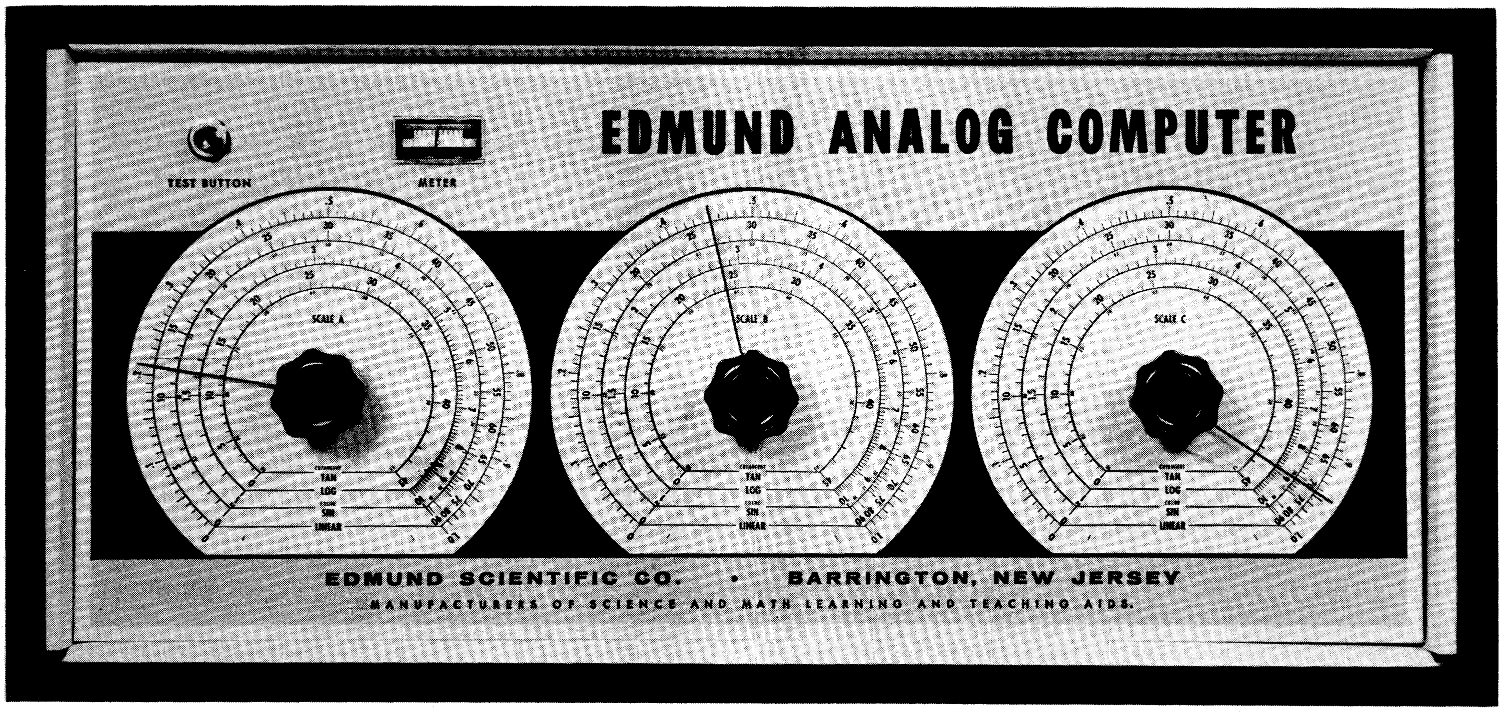
EDMUND SCIENTIFIC COMPANY

BARRINGTON, NEW JERSEY



ABOUT THIS MANUAL

Preparing an instruction manual for the new Edmund Analog Computer brought us up against a difficult problem: we don't know who you are. You who are reading this may be a twelve-year-old boy or girl in the fifth or sixth grade, or a high-school senior, or a professional mathematician with many years of education and experience. Just how are we going to speak to you if we don't know who and what you are? We may use words and ideas that are over your head and leave you completely confused, or we may bore you by rehashing elementary subjects you don't want to be bothered with.

Our only way out has been to try to write for all of you. You will have to help us by being selective in your reading of the manual. If you come across something that is too advanced for you, just don't worry about it. You will still be able to use the computer for simpler calculations. And if, on the other hand, you find us going over ground that is quite familiar to you, then please skip to the next section that does meet your needs.

EDMUND ANALOG COMPUTER

The Edmund Analog Computer was designed to demonstrate electrical analog computing principles and to permit rapid approximate solutions to practical mathematical problems. It is a valuable teaching aid and refresher for young and old alike. Simplicity, quality, and reasonable accuracy were the primary considerations in the designing of the instrument. The computer can be assembled by anyone in an hour or two.

Analog computers solve problems by analogy. That is, they convert numbers into something else which can be more easily manipulated than the numbers themselves. One simple analog computer is the slide rule, in which numbers are converted into easily measured distances. In the Edmund analog computer, numbers are converted into readily measurable voltages.

All analog computers solve problems by making a measurement of one sort or another. Consequently the accuracy of computation is limited by the accuracy of measurement. Error is inherent in all analog computers, and the magnitude of the error depends on the number of computations required to solve the problem as well as on numerous other factors. Limiting the error even to 1% in large problems necessitates the use of extremely accurate computer elements.

Errors even as high as 5%, however, are permissible in many engineering problems; thus the analog computer finds numerous applications in engineering, industry, and science. Errors of about 2% to 3% can be expected from a properly assembled and adjusted Edmund Analog Computer.

For problems that are very complex or that require precise solutions, digital computers are used. Digital computers employ discrete values represented by a number of electrical pulses or, in the case of a desk calculator, by a number of gear teeth. An oversimplified way of putting it is that a digital computer solves problems by counting.

Digital computers are expensive and complicated and usually require a specialist "programmer" for translation of problems into "machine language."

Analog computers, on the other hand, are less expensive and are well understood by most engineers who can readily place a problem on an analog computer in a short period of time and get quick, approximate answers to most of their problems. Much of present day equipment has components with 10% to 20% tolerances; analog computer results are therefore often more than good enough for equipment design and final answers to problems. An analog computer also provides quick checks for detecting large errors that creep into problems solved by more complicated methods.

ASSEMBLY INSTRUCTIONS

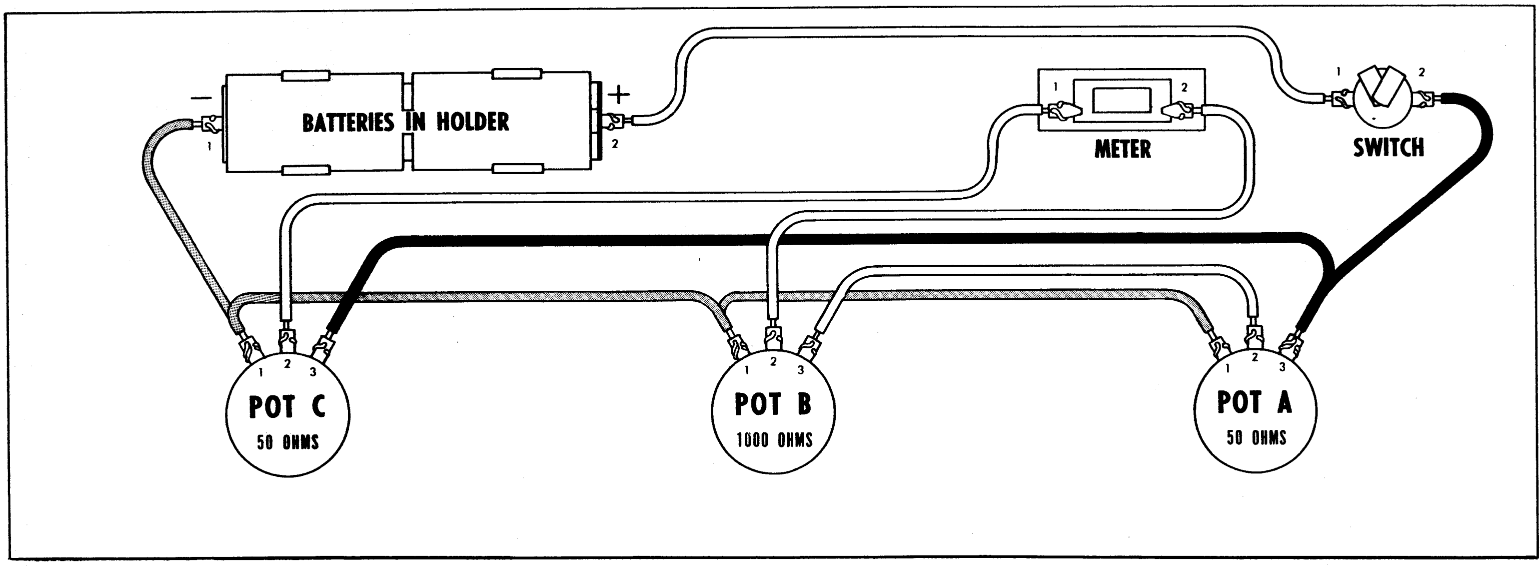
PARTS LIST

- 2 Potentiometers, 50 ohm, with 2 nuts and 2 washers
- 1 Potentiometer, 1,000 ohm, with 2 nuts and 2 washers
- 1 Meter, 1-0-1 ma., with spring metal mounting clip
- 1 Push button switch with 2 nuts and 2 washers
- 1 Battery holder
- 3 Knobs
- 3 Plastic pointers
- 7 Feet, #22 insulated wire
- 1 Piece, double adhesive tape
- 1 Panel board
- 1 Corrugated cardboard tray, 20" x 8-1/2" x 2"
- 1 Strip, corrugated cardboard, 1-1/2" x 60"
- 1 Instruction manual

We suggest that you check off each step as you complete it to make certain that you do not skip anything.

MOUNTING THE COMPONENTS

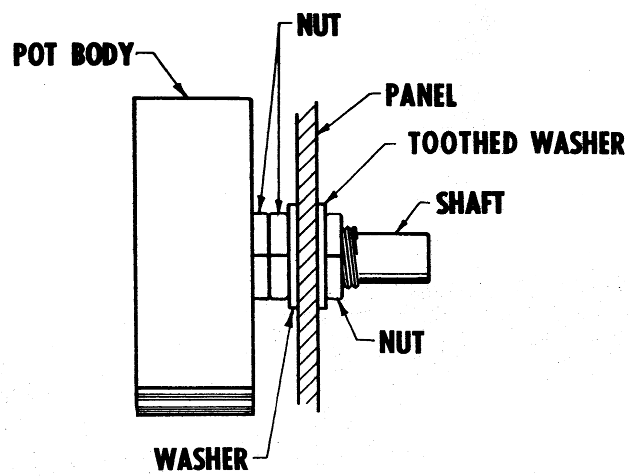
1. Remove all the parts and check them against the parts list.
2. Refer to Figure 1 for the positioning of the various components.
3. Mount the potentiometers as follows: On the threaded bushing of each potentiometer place a hex nut and turn it down until about 3/16" of threads are exposed between the nut and the end of the bushing. Place a washer over the bushing. Push the bushing through the appropriate hole (see Figure 1) in the panel board so that the bushing and shaft protrude beyond the face (printed side) of the panel. Place another washer and nut on the bushing. Position the potentiometer so that the terminals are at the top (see Figure 1). Tighten the nut so that the potentiometer can not slip around in the hole. Mount all three potentiometers in this manner.
4. Mount the push-button switch in its hole as shown in Figure 1. Use two nuts and two washers just as you did with the potentiometers.
5. Insert the meter in its hole and fasten it in place by placing the spring-metal clip over the back of the meter and pushing the clip firmly against the panel. (Do not be concerned if the meter needle is not precisely centered. The rest position of the needle is unimportant.)
6. Take the strip of double adhesive tape and peel off the tan protective layer. Press the adhesive surface firmly to the back of the battery holder. Peel off the blue protective layer. Press the battery holder firmly into place on the panel in the position shown in Figure 1. (Some kits may have the adhesive already attached to the holder. In this case skip the first step. Simply remove the tan covering and press the holder into place.) In removing the protective covering from the adhesive tape, don't try to lift it at the edge. Use a finger nail or any sharp instrument and lift the tape at one of the pre-cut seams.



Pictorial view showing rear of panel with all components and wiring.
FIGURE 1

WIRING THE COMPUTER (See Figure 1)

7. Measure and cut off wire long enough to connect lug 1 at the left (-) end of the battery holder to lug 1 of potentiometer C. Strip off about 1/2" of insulation from each end. Crimp the wire firmly around each lug with a pair of pliers. (To simplify things, we will henceforth refer to the potentiometers as "pots", a standard nickname for them.)
8. In a similar manner, connect lug 2 at the right (+) end of the battery holder to lug 1 of the push button switch.
9. Connect lug 1 of pot C to lug 1 of pot B.
10. Connect lug 2 of pot C to lug 1 of the meter. Note: be very careful when crimping wires around the meter lugs. Excessive movement of these lugs may break the delicate wires inside the meter.
11. Connect lug 3 of pot C to lug 3 of pot A.
12. Connect lug 1 of pot B to lug 1 of pot A.
13. Connect lug 2 of pot B to lug 2 of the meter.
14. Connect lug 3 of pot B to lug 2 of pot A.
15. Connect lug 3 of pot A to lug 2 of the push button switch.
16. Insert two size D dry cells (the standard flashlight size) in the battery holder with their positive terminals (the center posts) to the right.
17. Using a pin, ice pick, or other sharp pointed object and a ruler as a guide, score a shallow groove in each of the three plastic pointers as shown in Figure 3.
18. Using a pen and a ruler, fill the scribed lines with ink. India ink is best, but ordinary writing ink will serve.
19. Cement a plastic pointer to the back of each of the three knobs using Dupont's or similar household cement. Be sure to place the pointers on the knobs so that the inked lines will be on the underneath surface, next to the panel.
20. Rotate the shaft of potentiometer A so that it is turned counterclockwise as far as it will go. Place a pointer knob on the shaft with the indicator line over the left index mark (the short mark just before the zero). Tighten the knob setscrew with a small screwdriver. Rotate the knob fully clockwise. Do not force the knob. The hairline should be over or very close to the right index mark (the short mark just past 1.0). In some cases, the variations in the amount of travel for different potentiometers may make it impossible to set the pointer so that the indicator line coincides with the index marks at both extremes of rotation. If this occurs with one of your potentiometers, split the difference by setting the knob so that the indicator line overshoots (or undershoots) the indices by equal amounts at both extremes.



Method of mounting potentiometers.
FIGURE 2

21. Place knobs on pot B and pot C and adjust them in the same manner.
22. Before placing the panel in the corrugated tray, take the 1-1/2" x 60" strip of corrugated cardboard and place it in the tray so that it bends around the corners and stands away from the walls of the tray. The strip will then support the panel when it is placed in the tray. For more rigidity, you may wish to cement the strip to the back of of the panel.

TESTING THE COMPUTER

23. Test the computer by trying some simple multiplication problems following the method explained in the next section of this manual. If your computer does not operate properly, check first to see if the dry cells are properly inserted in the battery holder (see Figure 1), then recheck your wiring.

SOLDERING THE CONNECTIONS

24. With the wiring completed and tested, you may wish to solder all the wiring connections thus assuring greater accuracy in the calculations you will make with the computer. If you do not have a soldering iron, perhaps a local radio repair man or amateur radio operator will do the soldering for you or allow you to use his equipment. Observe the following simple precautions:

    (a) Use only rosin-core solder. Acid flux solder will eventually cause the joints to corrode. Such corrosion will increase the resistance to the flow of current, thereby introducing errors into the calculations made with the computer.

    (b) When soldering leads to the meter lugs, use extra care. The meter case is made of a plastic that melts at fairly low temperatures. Use the smallest amount of heat that will do the job and "heat sink" the lugs. "Heat sinking" is a technique for protecting a delicate part by conducting heat away from it with some tool. Hold the lug with a pair of long-nosed pliers (between the hole and the meter case) while soldering. If the lugs are loosened excessively by the heat of soldering, a drop of Dupont's or other household cement placed where the lugs enter the case will hold them securely.

MULTIPLICATION: INTRODUCTORY DIRECTIONS

The basic computer equation is AB = C where the letters stand for numbers set for the respective potentiometers as indicated by the pointer hairlines.

To multiply two numbers, set one number on A and the other number on B. Depress and hold down the pushbutton switch and at the same time rotate C until the meter needle approaches zero. Then alternately press and release the switch while adjusting the reading of C until the needle does not move when the switch is pressed and released. (This condition will hereafter be referred to as null.) Null does not necessarily coincide with the zero point on the meter scale. Because of magnetic effects it may be somewhat off zero in either direction.

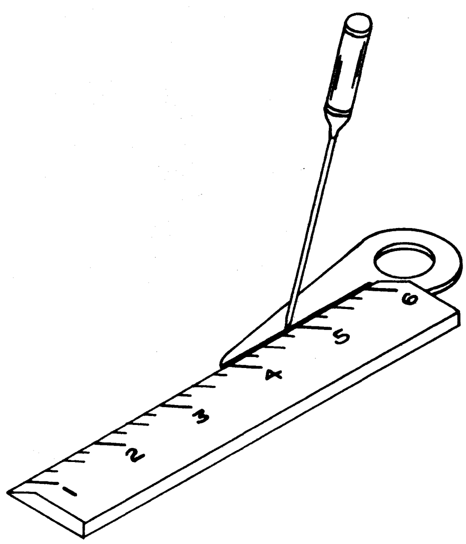
When null is achieved on the meter, the answer to the problem will appear under the hairline of C.

Numbers may be selected from the linear or the trigonometric function scales on the potentiometers. The discussion in this section will be limited to the linear (outer) scale.

Note that the linear scale has two kinds of graduations on it, long and short. The short graduations represent hundredths; the long graduations that are numbered represent tenths. Thus the first short graduation next to zero represents .01, the second .02, and so on. The first unmarked long graduation represents .05 and the second long graduation represents .1, as it is marked. If this type of calibration is not familiar to you, then you should become accustomed to it as quickly as possible by practicing repeatedly until you can set any desired number almost without conscious thought.

If for example you wish to set the pointer for .73, then you will set the hairline over the third short marking after .7. If you wish to set .99, you will set the pointer over the last short marking before 1.0.

Here are some examples to illustrate computer operation:



Method of scribing hairline on pointers.
FIGURE 3

Example 1: .4 x .8 = ?

Set the hairline on A over .4. Set the hairline on B over .8. Depress the switch and rotate C until the meter needle approaches zero. Then alternately press and release the switch while adjusting C until null is achieved. The answer will now appear under the hairline of knob C.

You know, of course, that the answer should be .32. If your answer on the computer lies between .31 and .33 then you can be content that you have done a good job of adjusting the knobs properly on the potentiometer shafts and of setting and reading the computer.

As you use the computer, experience will make your eyes more sensitive to minor fluctuations of the meter needle. This will enable you to become more and more precise in recognizing the null position.

If your answer lies appreciably outside the range of .31 to .33, check first to be sure there is no error in the way you have set pot A and pot B or in your reading of pot C. Be sure that the hairline is precisely over the appropriate graduation on each dial.

If after checking the setting of the pots you still have a reading on C that is outside the .31 to .33 range, then you should check your assembly and wiring of the computer carefully to see whether you have made some mistake. Check also to be sure that none of the knobs has slipped on its shaft.

Always be especially careful in nulling. Be certain that there is no motion in the meter before you read your results. Patience and care in securing nulls will pay off in increased accuracy.

Example 2: .37 x .92 = ?

Set the hairlines over .37 on A and .92 on B. Adjust C for meter null. The answer will appear under the hairline on C. The long-hand result is .3404. Your computer result should lie between .33 and .35.

It is possible to interpolate a third place into your result. For example, if the hairline lies about half way between .51 and .52, you can read this as .515. This practice, however, is not sound mathematically or scientifically. In general, stick to two-place answers on your computer.

In setting the factors, however, as in the next example, it is both permissible and advisable to set a third place figure by interpolation. Remember this as a basic rule for use of the computer: set factors to three places if necessary but read results to two places only.

Example 3. .855 x .567 = ?

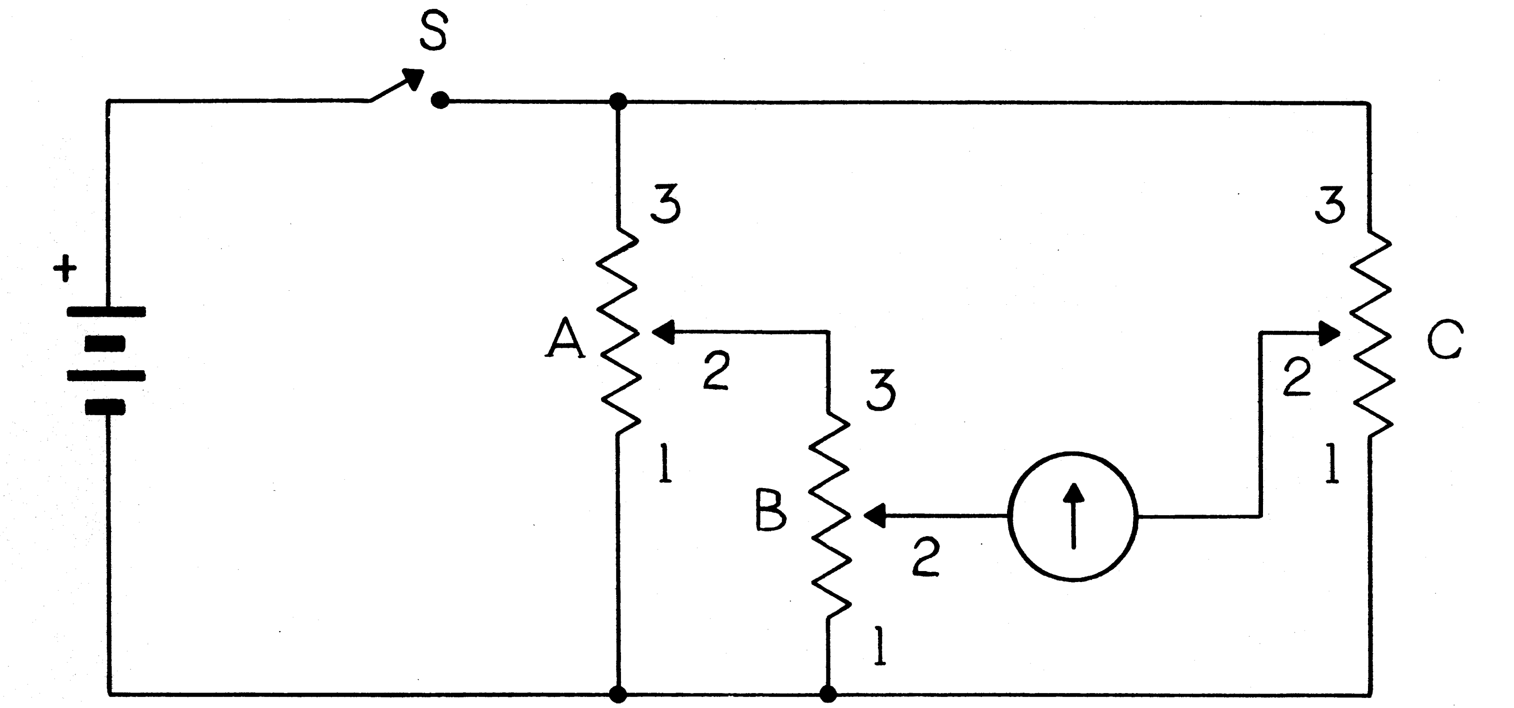
Set A to .855 (1/2 way between .85 and .86) and B to .567 (about 7/10 of the way between .56 and .57). Adjust C for meter null. The result on C will probably lie between .475 and .495, thus comparing quite reasonably with the long-hand result of .484785, which would normally be rounded off to .485.

INTRODUCTORY DIVISION DIRECTIONS

The basic computer equation AB = C may be rewritten A = C/B. Thus, to divide one number by another, set the number to be divided on C, the number by which you're dividing on B, and adjust A for meter null. The answer appears on A.

Example 4: .48 ÷ .6 = ?

Set .48 on C, .6 on B, and adjust A for meter null. An answer between .785 and .815 reflects reasonable accuracy.



Schematic wiring diagram.
FIGURE 4

Example 5: .33 ÷ .98 = ?

Set .33 on C, .98 on B, and adjust A for meter null. An answer between .33 and .35 is reasonable. The rounded off long-hand result is .337.

Example 6: .83 ÷ .61 = ?

Following the procedure outlined above, set .83 on C, .61 on B and adjust A for meter null. Null cannot be achieved, however, since the answer is greater than 1 and A extends only to 1. To handle this problem, write it as (.083 ÷ .61) 10. Now, set .083 on C, .61 on B, and adjust A for meter null. The rounded off long-hand result is (.136) x 10 or 1.36. Anything from .125 to .145 on scale A is reasonable since one of the numbers in the problem was less than .1. Computer accuracy is not as good for small numbers as it is for larger numbers. Methods for getting greater accuracy in small number problems will be described in a later section.

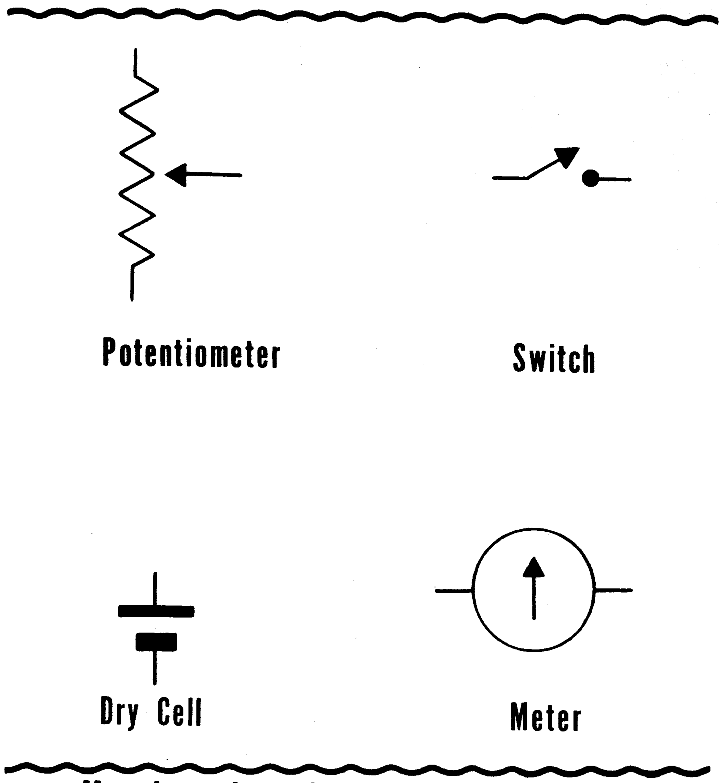
HOW IT WORKS

The symbols in the schematic circuit diagram of Figure 4 are part of the radio-electronic symbol language used by engineers and technicians. What the various symbols represent is shown in Figure 5.

A circuit is "closed" when a path for current exists from one side or terminal of a battery to the other terminal. Thus, current can flow from the positive terminal of the battery through wires and resistance to the other (negative) terminal of the battery. A potentiometer is one form of an electrical resistance. Straight lines designate wires in a schematic diagram. If a wire is cut or disconnected from a terminal in a series circuit such as that of Figure 6 there is no path for current to flow, and the circuit is said to be open. A switch is a connect-disconnect device that closes and opens a circuit when it is operated. Figure 6 is similar to the left hand portion of the circuit of Figure 4 except that a single dry cell is shown and a swtich is not included in the circuit.

If the dry cell in Figure 6 is a 1 volt cell there will be 1 volt between terminals 1 and 3 (the outer terminals) of the potentiometer. If the potentiometer has a linear taper the output voltage (at terminals 1 and 2) will be proportional to the potentiometer setting. Thus, the output voltage will be .5 volts if the potentiometer arm is set at mid position, or .25 volts if the potentiometer were set at 1/4 of full rotation clockwise from terminal 1. Thus, if the potentiometer is provided with a pointer knob and a scale divided into 10 equal parts the knob may be adjusted to get 0, .1, .2, .3, .4, .5, .6, .7, .8, .9, or 1 volt between terminals 1 and 2 simply by setting the knob over the corresponding graduation. The graduations can be identified and marked with these numbers. (See Figure 7).

If the battery voltage is 10 volts instead of 1 the voltage between terminals 1 and 2 will be 10 times the number associated with each graduation. Thus, the input voltage is multiplied by some number between zero and 1 depending on the potentiometer setting. With the pot set at .3 for example, the voltage between terminals 1 and 3 will be .3 x 10 or 3 volts.



Meaning of symbols used in Figure 4.
FIGURE 5

The ten scale divisions can be further subdivided into 10 units each to allow multiplication by two significant figures. This was done to produce the linear scales for the Edmund Analog Computer.

Since the linearity (multiplying accuracy) of the potentiometers can be in error by 1 per cent, there is no justification for further subdivision of the scales.

If terminals 1 and 3 of a second potentiometer are connected to terminals 1 and 2 of the potentiometer in Figure 6 , the ouput voltage of the first potentiometer will be multiplied by the number between 0 and 1 set on the scale of the second potentiometer. This arrangement corresponds to the arrangement of potentiometers A and B in the Edmund Analog Computer. Thus the output voltage at pot B is 3 volts x A x B.

The output voltage can be measured with a voltmeter. Small differences in voltage are, however, hard to detect with a voltmeter. But, if a sensitive current meter and another potentiometer are used as in the Edmund Analog Computer circuit (Figure 4), extremely small voltage can be detected. The reason for this is that a current will flow through the meter unless the voltage between terminals 1 and 2 on pot B equals the voltage between terminals 1 and 2 on pot C.

An extremely sensitive meter (1 milliampere) has been designed into and supplied with your calculator. It is capable of detecting voltage differences of only a couple of millivolts. (A millivolt is 1/1000 of a volt!) This high sensitivity permits accurate nulls and accurate problem answers.

IMPROVING ACCURACY

Some sources of error have been cited in previous sections. The largest source of error inherent to the calculator circuit is the quality of the components. Cheap potentiometers may have 10 to 20 per cent linearity errors. With 3 pots of 10 per cent error in a circuit, the total error can be 30 per cent from this source alone! Better quality potentiometers have been used in your computer to hold the error to approximately 2% to 3%.

The accuracy of the placement of the end clamps on the potentiometers is another factor in potentiometer accuracy. Potentiometer shaft eccentricity or mounting eccentricity relative to the scale center are additional sources of error. The accuracy of the scales and pointer knobs themselves influence precision.

An electrical circuit effect known as "potentiometer loading" can influence accuracy too. If pot B in Figure 4 has a resistance of only 10 times the resistance of pot A, the error from this amount of loading can approach 2 per cent on portions of the scale. If pot B is 20 times the resistance of pot A (as in your computer), loading error is reduced to less than 1 per cent maximum.

And, of course, your skill in detecting null is another factor determing the final accuracy.

The possibility of error from limited meter sensitivity increases for low pot settings. Thus, if A is set to .1 and B is set to .3, the voltage at the output of pot B is 3 x .1 x .3 or .09 volts. This is 90 millivolts. Thus, a meter that can detect a null to within 2 millivolts (.002 volts) might introduce about 2 per cent error for this computation. But if A is set to .5 and B is set to .9 the output voltage at B is 3 x .5 x .9 or 1.35 volts and the error appraches zero.

The greatest sources of error that most builders will encounter will be due to hasty construction and/or hasty calculation.

The principal mechanical source of error is poor adjustment of the pointer knobs.

The principal sources of error introduced during calculation are poor scale interpretation and failure to insist on accurate nulls.

Errors from all sources can be reduced in some cases by making a series of test calculations using increments of .1 (for easy mental checking) and then determining how small changes in knob setting might influence overall accuracy. The process can be repeated till the experiment yeilds the best overall accuracy.

SCALES AND USAGE

Your calculator has, in addition to the linear scales already discussed, the following scales:

Sine	0-90 degrees	(sin)
Cosine	90-0 degrees	(cos)
Logarithm	1-10	(log)
Tangent	0-45 degrees	(tan)
Cotangent	45-0 degrees	(cot)

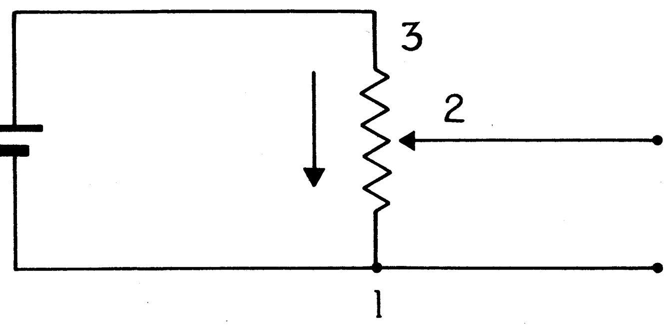
The sine and cosine scales utilize the same graduations since they are complementary over 90 degrees. Sine degrees are marked on the outside and cosine degrees are marked on the inside of the graduated circle.

The tangent and cotangent scales also have a special relationship and utilize the same graduations. Tangent degree numbering is on the outer edge of the inner scale and cotangent numbering is on the inside.

To aid you in making computations rapidly, the scales have been limited in number, and the scales for all the pots have been made alike for easy interpretation.

With the scales provided you can perform multiplication, division, raising to power (squaring, etc.), root taking, logarithmic, and trigonometric operations.

Your computer can handle, in addition to functions mentioned, secants, cosecants, tangents and cotangents out of the ranges on the scales, and numbers much greater than those marked on the linear scale. The next sections tell you how to use your calculator for a wide range of problems.

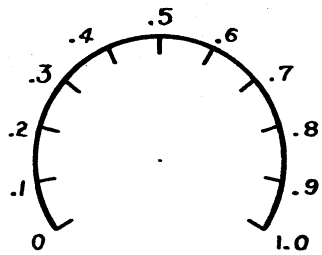


Single potentiometer multiplier.
FIGURE 6

USING POWERS OF TEN

Even if you are still very much of a beginner in mathematics, you have probably already met the concept of "power" in the mathematical sense in such expressions as x^2 or 4^3 . In either of these cases the number written above and to the right is called an exponent, and it signifies that the quantity which it modifies is to be multiplied by itself a certain number of times. For example, 4^2 means 4 x 4 or 16. 2^3 means 2 x 2 x 2 or 8. 10^5 means 10 x 10 x 10 x 10 x 10 or 100,000, and so on.

If the exponent is a 2 or a 3, it is usually read as "squared" or "cubed" respectively. Thus 3^2 is usually read as "three squared" and y^3 is usually read as "y cubed." Larger exponents are usually read as "pow-



Basic graduations for a potentiometer scale.
FIGURE 7

ers." For example 12^7 is ordinarily read as "twelve to the seventh power." Sometimes this is shortened to "twelve to the seventh."

In the following table we show various powers of ten as they are conventionally written and as they are written with exponents. Note that in addition to 10^1, 10^2, 10^3, and so on, we also include 10^0, and 10^{-1}, 10^{-2}, 10^{-3}, etc. If you have not as yet been introduced to zero and negative exponents, then you'll just have to take our word that they truly do represent the quantities shown in the table, as we do not have sufficient space to go into the explanations here.

One million	1,000,000	10^6
One hundred thousand	100,000	10^5
Ten thousand	10,000	10^4
One thousand	1,000	10^3
One hundred	100	10^2
Ten	10	10^1
One	1	10^0
------------------------------	0	-------------
One tenth	.1	10^{-1}
One one-hundredth	.01	10^{-2}
One one-thousandth	.001	10^{-3}
One ten-thousandth	.0001	10^{-4}
One one-hundred-thousandth	.00001	10^{-5}
One one-millionth	.000001	10^{-6}

There is a relatively easy way to remember the relationship between the various powers of ten and the numbers as conventionally written. Note in the table that 10^6 is the same as 1 followed by 6 zeros. 10^4 is the same as 1 followed by 4 zeros. Whenever the exponent is a positive number, then the exponent is equal to the number of zeros that come after the 1 in the number as conventionally written.

> (Caution: don't fall into the trap of thinking for example that 10^{11} means ten followed by eleven zeros. It means one followed by eleven zeros. For a quick easy check, until you are accustomed to using this system, always remind yourself mentally that 10^2 is 100 and that 100 is one followed by two zeros.)

When the exponent is negative (examples: 10^{-3}, 10^{-5}) then the exponent is equal to the number of decimal places in the number as conventionally written. Note that 10^{-2} is the same as .01 (two decimal places) and that 10^{-5} is the same as .00001 (5 decimal places).

Mathematicians and scientists of all sorts commonly handle all very large numbers as multiples of powers of ten. You can readily see why. It would be very clumsy, for example, to do computations concerning the amount of energy radiated by the sun if you had to use the expression 3,800,000,000,000,000,000,000,000 000,000,000 ergs per second. It is much more convenient to express this as 38 x 10^{32} ergs per second. (Actually it is more commonly expressed as 3.8 x 10^{33}, which is of course exactly the same thing.)

The use of such an expression not only saves time and space but, what is far more important, has a distinct advantage in multiplication and division. To multiply powers of ten, all that is necessary is to add the exponents. To divide them, subtract the exponents.

Some examples will show clearly how this happens. You know that 100 x 1,000 is 100,000. Writing this in powers of ten: 10^2 x 10^3 is 10^5. 2 plus 3 equals 5. 1,000,000 divided by 100 is 10,000. Writing this in powers of ten: 10^6 divided by 10^2 is 10^4. 6 minus 2 equals 4.

Now let's see how this is used in an actual problem. Suppose you wish to multiply 378,000 by .000012. Simplify this by thinking of it as 378 x 10^3 multiplied by 12 x 10^{-6}.

Now multiply 378 x 12 to get the product 4536. Next add the exponents of the powers of ten: 3 plus -6 equals -3. The resulting exponent (-3) tells you that there will be three decimal places in your result, which is, therefore, 4.536.

The first few times you use this system you will probably find it very clumsy. If you persevere, however, you will soon find it becoming second nature to you and you will come to look on it as a great time and trouble saver.

By applying this system to your computer, you will find that you can handle numbers that are well outside the range of the calibrations on the scales. If you are dealing, for example, with the number 375, you will express it as .375 x 10^3. The number .00000896 will become for you .896 x 10^{-5}.

Example 7: 37 x .092

Use the same potentiometer setting as .37 x .92 (example 2). The problem reduces to .37 x 10^2 x .92 x 10^{-1}. The answer is the C pot setting at null times 10.

Problems with small numbers are also easier to handle with powers of 10.

Example 8: .000855 x .00000567

This can be written as .855 x 10^{-3} x .567 x 10^{-5}. The pot settings are the same as for example 3. The result on pot C is multiplied by 10^{-3} x 10^{-5} or 10^{-8}.

Example 9: $480 \div 6$

This is $.48 \times 10^3 \div .6 \times 10$ which reduces to $(.48 \div .6)\ 10^{3-1}$ or $(.48 \div .6)\ 10^2$. The pot settings are the same as for example 4, and the result on pot A is multiplied by 10^2. The answer is 80.

Example 10: $330 \div .98$

Write as $.33 \times 10^3 \div .98$. The pot settings are the same as for example 5. The result on pot A is multiplied by 10^3. The answer is 337.

Example 11: $.083 \div 610$

If you write this as $.83 \times 10^{-1} \div .61 \times 10^3$ you know from example 6 that you can't get a null on A. To be sure that you can get a null on A for a given division, write the problem as a fraction. If the numerator (top) exceeds the denominator (bottom), you won't get a null. Therefore, point off another place in the numerator. Thus, .83/.61 is greater than 1 but .083/.61 is less than 1.

Write $.083 \div 610$ as $.083 \div (.61 \times 10^3)$. The result on pot A is multiplied by 10^3 (divided by 10^{-3}). It's $.136 \times 10^{-3} = .000136$.

Practice Problems, Set A (Solutions in back of Manual)	
1.	$.93 \times .78$
2.	$.36 \times 94$
3.	$1.4 \times .07$
4.	$.0026 \times 5.8$
5.	362000×94
6.	$33 \div 78$
7.	$78 \div .92$
8.	$.63 \div 198$
9.	$.078 \div 39$
10.	$63000 \div 39$

SQUARES AND SQUARE ROOTS

To square a number, set the number on pots A and B. Adjust pot C for meter null. The result appears on C. Use powers of 10 as required.

Example 12: $.4^2$

Set .4 on A, .4 on B and adjust C for null. The result .16 appears under the hairline on C.

Example 13: 40^2

This is $(.4 \times 10^2)^2$ which is $.4^2 \times (10^2)^2$ which is $.4^2 \times 10^4$. Pot settings are the same as for example 12. The answer is $.16 \times 10^4$ or 1600.

Example 14: 5200^2

This is $(.52 \times 10^4)^2$ or $.52^2 \times 10^8$. Set .52 on A and B and adjust C to null. Read number under hairline on pot C. The answer is $.2704 \times 10^8$ or 27,040,000.

Example 15: $.0009^2$

This is $.9^2 \times (10^{-3})^2$ or $.9^2 \times 10^{-6}$. The result is $.81 \times 10^{-6}$ or .00000081.

To obtain the square root of a number, break it up into a number between .1 and 1 multiplied by a power of 10. If the power of 10 is an even power (10^2, 10^4, 10^6, 10^{-2} etc.) set the other number on pot C and adjust A and B till they indicate the same value at null.

Example 16: $\sqrt{3200}$

Write this as $.32 \times 10^4$. Set .32 on C. Now adjust A and B till they read the same value at null. An easy way to do this is to set A and B at 1. Then depress the switch with the small finger of your left hand while you use thumb and index finger of the left hand to rotate pot A and the right hand to rotate pot B. Rotate A and B at nearly the same rate. Then A and B will be relatively close to the same value when you approach null. and it will be a relatively easy matter to trim them up to the same value for a null. Pots A and B null at .566 in this case. The square root of 10^4 is 10^2 (divide the exponent by 2 to take the square root of a power of 10), and $.566 \times 10^2$ is 56.6.

If you're taking the square root of a number that isn't a number between .1 and 1 multiplied by an even power of 10, there are two ways to proceed.

Example 17: $\sqrt{320}$

Method 1: When you reduce 320 to a number between .1 and 1 times a power of 10 you have $.32 \times 10^3$. You can proceed as outlined for the even power of 10 case. Then leave the result (.566) set on pot A, set pot B to .316 (the square root of .1) and adjust pot C for meter null. The result (.179) will appear on C. This number multiplied by 100 is the answer. Mathematically you've broken the problem up as follows:

$$\sqrt{320} = \sqrt{.32} \times \sqrt{10^3} = \sqrt{.32} \times \sqrt{10^{-1}} \times \sqrt{10^4} = \sqrt{.32} \times \sqrt{.316} \times \sqrt{10^2}.$$

Method 2: Write 320 as $.032 \times 10^4$. Then set .032 on pot C and adjust A and B for equal value at null. This method is not recommended because accurate nulls are difficult to obtain at small scale values.

Practice Problems, Set B (Solutions in back of Manual)

1. $.39^2$
2. 68^2
3. $.079^2$
4. $\sqrt{.92}$
5. $\sqrt{79}$
6. $\sqrt{590}$
7. $\sqrt{.008}$
8. $\sqrt{6320}$
9. $\sqrt{49}$
10. $\sqrt{4.9}$

SINE-COSINE OPERATIONS

The sine-cosine scales are employed for multiplication and division in the same way that the linear scales are used.

Example 18: .41 cos 56

Set .41 on scale A and cosine 56 on scale B. Adjust C for meter null. The result .239 appears on the linear scale of pot C under the hairline. Note that the cosine scale increases from zero to 90 degrees in the counter-clockwise direction. The linear scale and the sine scale increase in the clockwise direction.

Example 19: 78/sin 62

Set .78 on linear scale of C, sine 62 on B, and adjust A for null. Read result .884 under hairline on the linear scale of A. This result must be multiplied by 100 (since 78 was divided by 100 in the operation) to yield the answer 88.4.

Example 20: 86/sin 23

.86/sine 23 is greater than 1. Therefore, set .086 on linear scale of C, sine 23 on B and adjust A for null. Read .22 on linear scale of A. Since 86 was divided by 1000, the result must be multiplied by 1000. The answer is 220.

TANGENT-COTANGENT OPERATIONS

The tangent-cotangent scales are employed in the same way as the linear scales for tangents of angles equal to or smaller than 45 degrees and cotangents of angles equal to or larger than 45 degrees.

Example 21: 61 tan 38

Set .61 on linear scale of A, tangent 38 on B and adjust C for meter null. The result .476 appears under the hairline on the linear scale of C. The answer is 47.6.

Example 22: 81 cot 69

Set .81 on linear scale of A, cotangent 69 on B (the cotangent scale increases in the counter clockwise direction) and adjust C for meter null. The result .311 appears under the hairline on the linear scale of C. The answer is 31.1.

The tangent of an angle is equal to the reciprocal of the cotangent. Thus, to multiply by the tangent of an angle greater than 45 degrees, simply divide by the cotangent.

Example 23: 31 tan 56

Rewrite the problem as 31/cot 56. Set .31 on C, cotangent 56 on B, and adjust A for meter null. The result .46 appears under the hairline on the linear scale of A. Answer is 46.

In like manner to multiply by the cotangent of a number between 0 and 45 degrees, simply divide by the tangent. A little thought will produce a number of ideas for using the tangent-cotangent scales in multiplication and division. This is left as an exercise for the user.

Practice Problems, Set C (Solutions in back of Manual)

1. 421 sin 47
2. 9.6 cos 31
3. 45.3/cos 51
4. .6/sin 38
5. 32 tan 40
6. 46 cot 40

LOGARITHMIC OPERATIONS

The use of the logarithmic scales requires some knowledge of logarithms. The principal application of these scales will be associated with powers and roots. The accuracy of operations with the logarithmic scales is very limited. The magnitudes of numbers and the rapid rates of change associated with logarithmic cycles require special logarithmic computer instrumentation for accurage results.

The principle employed in handling powers and roots with logarithms is that when $x^A = y$, the relationship may be expressed as A log x = log y. If A is a number greater than 1, the quantity x will be raised to a power. If A is less than 1, a root of x will be obtained.

Example 24: 5^2

Set A to .2 on the linear scale, B to 5 on the log scale and adjust C for meter null. On the C linear scale you'll read about .14. Since 2 was entered on A as .2, the .14 reading on C should be interpreted as 1.4. This number is log y. Now, to find y, rotate pot C to the number after the decimal point (.4) on the linear scale of C. Under the hairline on log scale of C you'll find

2.5. The 1 in front of the decimal point in the 1.4 result obtained previously indicates that 2.5 shall be multiplied by 10. The result therefore is 25.

If the number preceding the decimal point is zero, the number indicated by the part after the decimal point is not multiplied. If a 2 appears ahead of the decimal point, multiply by 100. A 3 indicates multiplication by 1000 etc. The reason for this is that 0 is log 1, 1 is long 10, 2 is long 100, 3 is log 1000, 4 is log 10,000, etc. The logarithm of numbers between 1 and 10 is a number between zero and 1. This should be apparent from examining the scales.

In performing this example the tremendous chance for error in logarithmic operations in a basic calculator should be apparent. In computers employing less accurate potentiometers than the Edmund Analog Computer, errors can become fantastic. Logarithmic operations on the Edmund Computer are, however, useful for checking or estimating powers and roots.

Example 25: 7^3

Set .3 on A linear, 7 on B log, and adjust C for null. Read .254 on C linear. Since .3 on A represented 3, .254 on C represents 2.54. Rotate to .54 linear on C. Read 3.45 on C. log. This should be multiplied by 100 (10^2, the log of 2) which gives the result 345. The long-hand result is 7 x 7 x 7 = 49 x 7 = 343.

Note that if you had interpreted .254 on C linear as .25, the final result would have been about 315. If you had interpreted .254 as .26 on C linear, the final result would have been 400!

Example 26: $9^{4.3}$

This is a problem that requires logarithmic operations, for solution. Set .43 on A linear, 9 on B log, and adjust C for null. On C linear result is about .41. Again this result means 4.1. Set C to .1 linear. Read 1.26 on the log scale of C. 1.26 x 10^4 = 12,600. The actual result is closer to 12,700, but if you obtained a result between 12,500 and 12,900, you did quite well. Any number in that range is roughly within 2% accuracy!

Example 27: $\sqrt[4]{9}$

$\sqrt[4]{9}$ can be written as $9^{1/4}$ which is $9^{.25}$. Set .25 on A linear, 9 on B log, and adjust C for null. Read 1.73 on C log scale. Direct reading on log scale is possible since the scale of A was unmultiplied.

Other operations with the logarithmic scales will be apparent to the more advanced student.

APPLICATIONS

Uses for the Edmund Analog Computer are numerous. It can handle many different problems in arithmetic, geometry, trigonometry, algebra, analytic geometry, mechanics, electricity, electronics, heat, light, sound, etc. The range of application is limited principally to the knowledge and ingenuity of the user.

GEOMETRIC APPLICATIONS

Example 28: Find the area of a rectangle 9.5 by 41 inches.

Set .95 on A linear, .41 on B linear, and null C linear. Result is .39. Find the decimal point by mentally multiplying 10 x 40 = 400, indicating that the answer is 390 square inches. This is an application of the area formula for a rectangle, A = bh.

Example 29: Find the area of a triangle with a base of 4.2 inches and an altitude of 8.7 inches.

This is an application of A = 1/2 bh. Set .42 on A linear, .87 on B linear and null C. Set result on C linear on pot A and set pot B to .5. Null C again. The result on C linear is .183. Supply scale factor of 100 to get answer 18.3 square inches.

Example 30: A circle has a diameter of 9 inches. Find the circumference.

C = $2\pi r$ = πd. Set .314 on A linear (this is $\pi/10$) and .9 (diameter/10) on B linear. Adjust C for null. Result on C linear is .283. Applying scale factor, the answer is 28.3 inches.

Example 31: Find the area of a circle with a 9.7 inch radius.

A = πr^2. Set .97 on A and B linear and null C. You obtain $r^2/100$ on C linear (.94). Set this value on B linear, and set .314 on A. Null C. Result on C linear is .294. Scale factor is 1000. Therefore the answer is 294 square inches.

Geometric applications include the formulae enumerated below. These formulae are stated in words because symbols sometimes vary from book to book or teacher to teacher. Usual symbols are A for area, b for base, h for height or altitude, V for volume, C for circumference, r or R for radius, l for length, w for width.

- Area of a Rectangle = base x height
- Area of a Parallelogram = base x altitude
- Area of a Triangle = 1/2 base x altitude
- Area of a Trapezoid = 1/2 altitude x sum of parallel sides
- Area of a Circle = π x (radius squared)
- Area of an Ellipse = $\pi/4$ x Major Axis x Minor axis
- Area of a Cycloid = ~~3/2 x π x height~~ 3/4 x π x HEIGHT
- Area of a Parabola = 2/3 axial length x mouth width
- Volume of a Parallelopiped = length x width x height
- Volume of a Cone = $\pi/3$ x (radius of base squared) x height
- Volume of a Cylinder = π x (radius of base squared) x height
- Volume of a Pyramid = Area of base x height
- Volume of a Sphere = 4/3 x π x (radius cubed)
- Surface of a Sphere = π x (diameter squared)
- Circumference of a Circle = π x diameter

TRIGONOMETRIC APPLICATIONS

The right triangle shown in Figure 8 is a general right triangle. The angle D does not necessarily have the number of degrees drawn in the illustration and other features of the triangle can vary accordingly. Angle F is always a right angle. These relationships apply:

sin D = y/z
cos D = x/z
tan D = y/x
csc D = 1/sinD = z/y
sec D = 1/cosD = z/x
cot D = 1/tanD = x/y

The relationships for angle E are left as an exercise for the student.

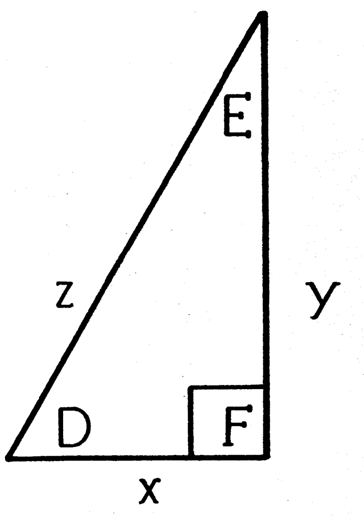
Although secant and cosecant scales are not marked on the calculator scales (too many scales become confusing), they can readily be obtained.

Example 32:	Find csc 50

Set C linear to .1, B to sine 50, and null A. Result on A linear must be multiplied by 10 (since .1 stood for 1 on C). The answer is 1.3.

Follow the same procedure with cosine on B to find the secant on A.

Frequently problems involve the knowledge of an angle and a side of a right triangle, and another side of the triangle must be calculated. Height finding problems, distances across streams, electrical, optics and vector problems are but a few of the many applications. The operation of the trig scale was discussed in the previous section, and examples here will merely illustrate the application of trigonometry.



General notations for right triangles.
FIGURE 8

Example 33: The hypotenuse of a right triangle is 4.1 inches. The angle between the hypotenuse and the base is 56 degrees. Find the length of the base and the height.

In Figure 8, z is the hypotenuse, x is the base, y is the height, and D is the given angle. You're to find x and y. You know z (4.1) and angle D (56 degrees). The definition of sine D and cosine D contain z. Therefore, you use these fuctions.

x = z cos D (see example 18)
y = z sin D

Example 34: A plane is traveling in a direction 62 degrees North of East. It's component of speed in the northerly direction is 78 mph. What is the speed of the plane?

y in Figure 8 is 78 mph, D is 62 degrees, and z is the speed of the plane.

z = y/sin 62 (see example 19)

Example 35: The sine of an angle is .91. What is the cosine?

No computation is necessary. Adjust hairline to .91 on the linear scale of any of the pots. Read 65.4 degrees on the sine scale. Set pointer to 65.4 degrees on the cosine scale, and read opposite value on the linear scale (.415). Similar operations can be employed between all scales.

Logarithms appear in algebra and trig courses. The log scales have applications beyond those outlined in the section on operations.

Example 36: Find the logarithm of 320,000.

Set the hairline of any pointer over 3.2 on the log scale. The mantissa appears under the hairline on the linear scale. It is .505. The characteristic is the power of 10 that 3.2 must be multiplied by to yield 320,000. $3.2 \times 10^5 = 320{,}000$. The characteristic is 5. The logarithm is 5.505.

Example 37: The logarithm of a number is 3.78. What is the number?

Set the hairline over .78 on the linear scale. Read the log scale. This number 6.03 must be multiplied by 10^3 (implied by the characteristic 3). The antilog of 3.78 is 6,030.

It should be apparent that the scales on the Edmund Analog Computer may be used as complete trigonometric and logarithmic tables.

Trigonometric formulae and identities appear in texts on trigonometry and in handbooks. The formulae and identities will extend the use of the calculator. Many of the identities may be checked on the calculator.

PHYSICS AND ENGINEERING APPLICATIONS

Mechanics, Electricity, Heat, Light, Optics, Sound, Electronics, Fluid Mechanics, Modern Physics and other fields that are recognized as fields of specialization or engineering are grouped under this heading. It is apparent that only a small number of the many applications of the calculator can be discussed here.

Example 38: Mechanics - Applicable rectilinear kinematics formulae

Symbols are v - velocity, s - distance, t - time, a - acceleration, g - acceleration of gravity (32 ft./sec^2). Subscripts: 1 - initial, 2 - final, n - normal, t - tangential. Units: t (seconds), s (feet), v (feet/sec), a (ft./sec^2). "g" may be substituted for a in the following formulae when gravity is the cause of acceleration.

Uniform Velocity: $v = s/t$, $s = vt$

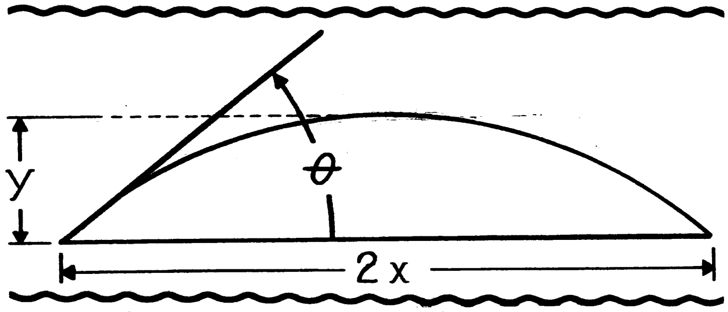
Uniform Acceleration: $a = \frac{v_2 - v_1}{t}$, $v_2 = v_1 + at$,

$s = v_1 t + 1/2 at^2$, $s = \frac{v_2^2 - v_1^2}{2a}$, $v_2 = \sqrt{v_1^2 + 2as}$. Additions or subtractions must be done on paper. It's always a good idea to keep paper handy when working problems to record intermediate results.

Example 39: Mechanics - Applicable circular kinematics formulae.

$A_n = v_t^2/r$ where v_t is uniform. Circular motion angle (θ) in radians, angular velocity (ω) in radians per second, and angular acceleration (α) in radians per second^2 correspond to s, v, and t in example 38. "t" in seconds is the same as in example 38. The formulae of example 38 shall be rewritten with θ substituted for s, ω for v, and α for a by the student in the space below:

When Angular velocity is constant, where n is the number of revolutions, and r is the radius, $\theta = 2\pi n$, $\omega = \theta/t$, $\omega = 2\pi n/t$, $\theta = s_t/r$, $\omega = v_t/r$.



Notations for projectile problems.
FIGURE 9

Example 40: Mechanics - Projectile Motion. Units same as for rectilinear motion.

See Figure 9. The projectile leaves the muzzle with velocity v_1. The velocity component in the x direction is $v_x = v_1$ cosine θ. This component of velocity is retained through the trajectory. The velocity component in the y direction is $v_y = v_1 \sin\theta - gt$ where g is 32 ft/sec^2. The distance traveled in the x direction in t seconds is v_x t. The distance traveled in the y direction in t seconds is $y = v_1 t$ sine $\theta - 1/2\, gt^2$. The range that the projectile will cover in the x direction to impact is $(v_1^2 \text{ sine } 2\theta)/g$. These relationships assume wind resistance zero, flight across a straight surface, and impact at the altitude of firing. Additional relationships exist. The derivation of these are left as an exercise for the student.

Example 41: Mechanics - Kinetics: m is mass (weight in pounds divided by 32 ft/sec^2), a is acceleration in ft/sec^2, w is weight in pounds, F is force in pounds. $F = ma = (w/g)a$.

W is work in foot-pounds, s is distance in feet. $W = Fs$. P is power in foot pounds/second. $P = W/t = Fs/t$. Energy has the same units as work. Potential energy is energy of position $W_p = wh$ where h is position above a reference point. Kinetic energy $W_k = mv^2/2$. These computations can be easily handled on your calculator.

Example 42: Mechanics-Simple Pendulum

The period t of a simple pendulum (Figure 10) is $\pi\sqrt{l/g}$, where t is in seconds, l is in feet, and g is 32 ft/sec^2. The length of a simple pendulum with a period of one second is g/π^2 feet. As an exercise compute the length on your calculator. (Set on A and B linear, null C. Transfer result on C linear to B. Set 32 on C and null A. Read result on A linear.) Hint: π^2 is a constant that occurs frequently. $\pi^2 = 9.9$ is easy to remember. Now try the problem again. Easier, eh? Now that you've computed it, why not make a pendulum and try it? A piece of string, a weight, and a place to fasten the pendulum are all you need.

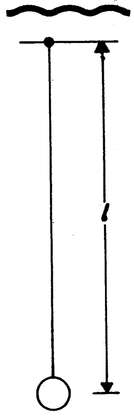


FIGURE 10

Example 43: Other Mechanics Applications

Check in physics textbook on friction, coefficient of friction, moment of inertia, momentum and impulse.

Example 44: Unit Conversions

Frequently units in one system must be converted into units in another system. Convert a foot to centimeters.

$$\frac{1 \text{ ft}}{} \times \frac{12 \text{ in}}{1 \text{ ft}} \times \frac{2.54 \text{ cm}}{1 \text{ in}} = \underline{\qquad\qquad} \text{cm.}$$

This reduces to a multiplication problem and is left as an exercise for the student.

Example 45: Mechanics - Statics

Refer to Figure 11. A weight of 100 pounds is supported at vertex D. x is a horizontal member 3.2 feet long pushing against wall y and z is a guy wire 4.5 feet long fastened at vertex E. What is the force against the wall at vertex F? F_1 is the tension in z, F_2 is the force against the wall.

$F_1 = 100/\cos D$
$\cos D = x/z = 3.2/4.5$
$F_2 = F_1 \sin D = 100 \tan D$

Final solution is left as an exercise for the user. Check section on statics in a physics book for more details and examples.

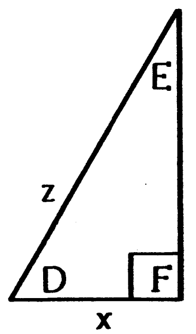


FIGURE 11

Example 46: Electricity - Magnetism

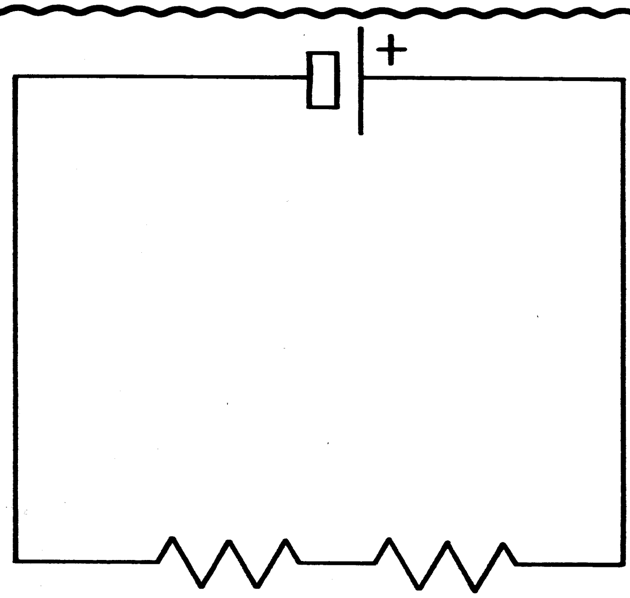
$F = m_1 m_2/d^2$ where m_1 and m_2 are the respective pole strengths of two poles separated by d centimeters. F is measured in dynes. Magnetic Intensity H in oersteds at d centimeters from a pole of strength m is m/d^2. The magnetic flux density B produced by a field intensity H in a medium of permeability μ is μ H. Somewhat analogous relationships exist for electrostatics, except that units differ slightly.

Example 47: Current Electricity

E is electromotive force in volts, I is rate of charge flow in amperes, Q is charge in coulombs, R is resistance in ohms, P is power in watts, and t is time in seconds.
$E = IR$, $I = E/R$, $R = E/I$, $P = EI$, $P = I^2R$, $P = E^2/R$, $I = Q/t$.

If more than one resistor is connected in series (see Figure 12) the same current (I) flows through each, the total resistance is the sum of the resistances, and the applied battery voltage is equal to the sum of the voltage drops across the individual resistors.

If more than one resistance is connected in parallel across a battery (Figure 13) the voltage across each resistance is the same as the voltage of the battery, the current provided by the battery is equal to the sum of the currents through the resistances, and the total resistance seen by the battery is E/I where I is the total current.



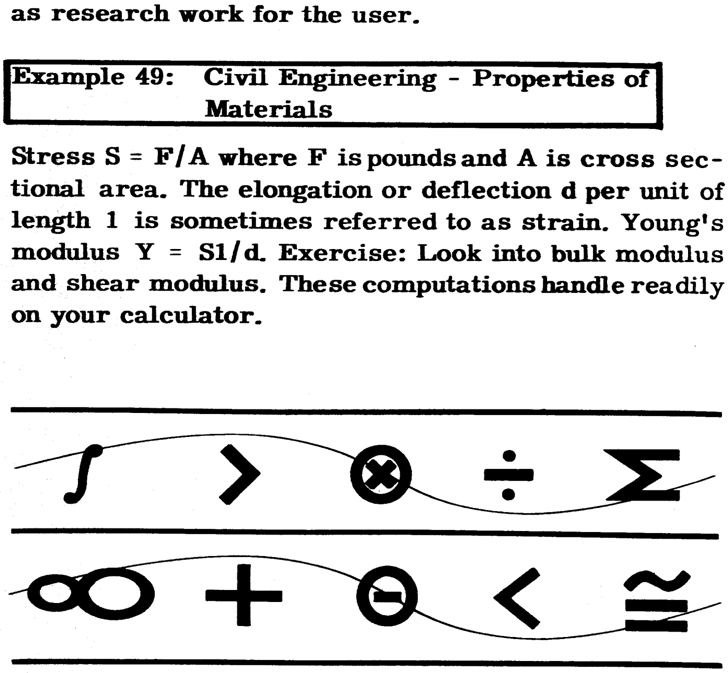
Series electrical circuit.
FIGURE 12

Example 48: Electricity - Alternating Currents

Inductive Reactance $X_L = 2\pi fl$ where f is frequency in cycles and L is inductance in henries. $\tan \theta = X/R$ where θ is phase angle, X is reactance, and R is resistance. $Z = R/\text{cosine } \theta = X/\text{sine } \theta$. Expressions for capacitive reactance and resonant frequency are left as research work for the user.

Example 49: Civil Engineering - Properties of Materials

Stress $S = F/A$ where F is pounds and A is cross sectional area. The elongation or deflection d per unit of length 1 is sometimes referred to as strain. Young's modulus $Y = S1/d$. Exercise: Look into bulk modulus and shear modulus. These computations handle readily on your calculator.

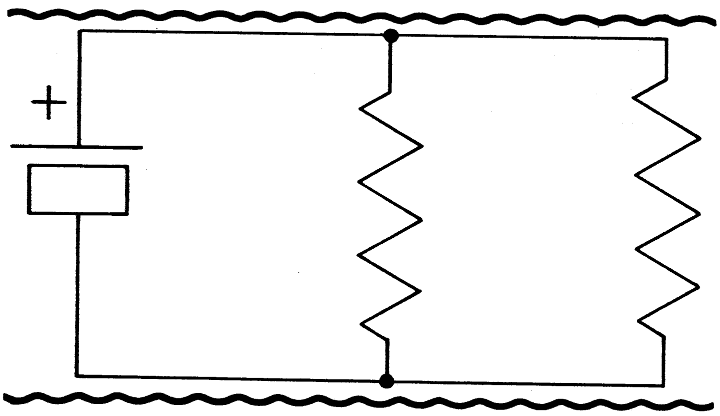


Example 50: Fluid Mechanics - Hydrostatics

Density d = M/v where M is mass and v is volume. Pressure p = F/A where F is force and A is unit area. Check properties of gases and surface tension.

It is easy to see that the list of example applications could be endless. In electricity and electronics there are many more formulae which the calculator will handle. The same is true of other fields. No examples in Optics, Heat, Sound or Modern Physics have been given. These are left as fields for research and exercises for the user.

There are plenty of problems with answers given in math and physics textbooks. These will augment the problems in this manual. You'll find that your calculator has wide applicability in every field.



Parallel electrical circuit.
FIGURE 13

PRACTICE PROBLEM SOLUTIONS (Approximate)

SET A, page 10

1. .726
2. 33.8
3. .098
4. .0151
5. 3.4×10^7
6. .423
7. 84.8
8. .00318
9. .002
10. 1,620

SET B, page 11

1. .152
2. 4620
3. $.622 \times 10^{-2}$ = .00622
4. .96
5. 8.9
6. 24.3
7. .0895
8. 79.6
9. 7
10. 2.22

SET C, page 11

1. 308
2. 7.66
3. 72
4. .975
5. 26.8
6. 54.8