INTRODUCTORY PHYSICS II

PHYSICS 1020 LABORATORY MANUAL SUPPLEMENT

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Section LE-01

Foreword

This Supplement to the Physics 1020 Laboratory Manual includes:

- Alternative versions of the labs requiring computer collection of data, in case computers are not available. These experiments are indicated with a letter "A" in the experiment number; for example, the non-computer version of Experiment 1 in the standard laboratory manual is called Experiment 1A here.
- Extra experiments that can be performed if time permits.

Contents

Experiment 1A

Simple Harmonic Motion

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Experiment 17

Introduction to the Oscilloscope

Experiment 18

Capacitance

Experiment 19

The Crystal Radio

Objective: To build a simple crystal radio receiver and understand its operation.

Method: Build a working crystal radio, using a schematic diagram.

Apparatus:

crystal radio board	solenoid	speaker amplifier	speaker wire
spool of antenna wire	connecting wires (8)	alligator clip	meter stick

Theory: An early simple form of radio receiver (dating from the 1920s) is the *crystal radio receiver*, a version of which we'll be building in this experiment. Some crystal radio designs can be fairly elaborate to provide good reception, but we'll just look at a simple design capable of picking up a few strong stations in the AM radio band (520–1700 kHz). Crystal sets are so named because they originally included a crystal of the metallic mineral *galena* (lead sulfide, PbS) that was touched with a fine wire called a *cat's whisker*. The galena crystal and cat's whisker formed a crude *diode*—a device that permits electric current to flow in only one direction. In this version of the crystal radio, we'll replace the crystal and cat's whisker with a germanium diode. If you look closely at the diode, you can see a tiny bit of germanium metal and a tiny wire inside. The germanium crystal takes the place of the galena crystal of older radio sets.

Figure 19.1: A galena crystal detector with cat's whisker.

In a standard traditional crystal receiver, one listens to radio stations through a high-impedance crystal earpiece or set of headphones. A crystal set like this will work forever for free—it needs no batteries, and runs entirely from the power provided by the radio transmitter. But for sanitary reasons we'll be replacing the crystal earpiece with a battery-powered speaker amplifier. This has the added advantage of allowing everyone in your group to listen to the radio signals at the same time.

The main components of this crystal radio set are an *inductor*, a *capacitor*, and a *diode*, along with connections to an antenna, ground, and headphones. The inductor (the solenoid) and capacitor are connected in parallel, forming an LC circuit. The long antenna wire can pick up radio signals of many different frequencies, but when connected to the LC circuit only the signals at the resonant frequency of the circuit are amplified. The diode permits the resulting signal to travel in only one direction, so that the average signal going to the speaker is nonzero. The ground, roughly speaking, gives the current someplace to go. The capacitance of the capacitor can be varied from 0–365 pF by turning the knob on the crystal radio board, which varies the resonant frequency.

We can compute the resonant frequency of the LC circuit if we know the capacitance C of the variable capacitor and the inductance L of the solenoid, which is given by

$$L = \mu_0 N^2 \frac{A}{\ell}. \tag{19.1}$$

Here $\mu_0 = 4\pi \times 10^{-7}$ H/m is the permeability of free space, N is the total number of turns of wire, A is the cross-sectional area of the solenoid, and ℓ is the length of the solenoid. The resonant frequency of the circuit is given by

$$f = \frac{1}{2\pi\sqrt{LC}}. \tag{19.2}$$

In many areas, the radio you're building in this lab would be able to pick up local commercial AM radio stations. However, there are no commercial stations near the college that emit a signal strong enough to be detected by this simple radio circuit. For this reason, your instructor will assemble a low-power AM radio transmitter and broadcast from inside the classroom. The broadcasts from the transmitter will include a selection of popular songs from the heyday of AM radio, from the 1920s to the 1960s. You will also hear a periodic station identification message in Morse code (as a courtesy to the FCC, in case these transmissions cause interference with local radio broadcasts). The transmitter playlist is shown in Table 19-1.

Procedure

1. **Setup.** Wire the crystal set together using the schematic diagram shown here. Follow these steps:
   (a) Use two connecting wires to connect the inductor (solenoid). One of the inductor terminals will connect to the antenna terminal on the radio board, and the other to the ground.
   (b) Use two connecting wires to connect the inductor and variable capacitor in parallel.
   (c) Use two connecting wires to connect the diode. As you can see from the diagram, the left end connects to the antenna terminal, and the right end to one of the speaker terminals.
   (d) Connect the remaining speaker terminal to the ground terminal on the radio board.
   (e) Connect the antenna wire to the antenna terminal on the radio board. String the antenna wire across the room, near the transmitter antenna wire.
   (f) Connect a connecting wire to the ground terminal on the radio board. Put an alligator clip on the other end of the wire, and clip it to the center screw of an electrical outlet. ***Be very careful not to insert the wire into the electrical outlet.***
   (g) Connect the speaker wires to the speaker terminals on the right-hand side of the board. (These are the two terminals with a resistor between them.) Plug the other end of the speaker wire to the "INPUT" jack of the speaker.
2. Turn on the speaker amplifier and turn up the volume. Turn the capacitor knob to vary the capacitance of the capacitor until you hear a station.

Analysis

1. **Inductance.**
   (a) Count the total number of turns of wire in the solenoid N and record it on your data sheet. Also measure the solenoid diameter d and solenoid length ℓ, and record these on your data sheet.

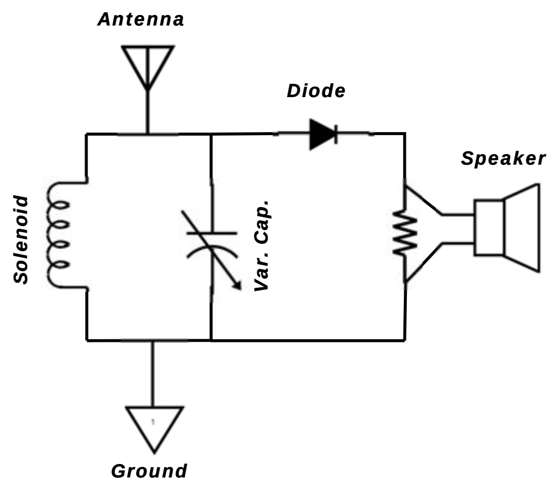


Figure 19.2: Schematic diagram for crystal radio.

(b) Now use equation (19.1) to compute the inductance L of the solenoid. Record the result on your data sheet.

2. Use this value of L along with maximum capacitance of the capacitor ($C = 365$ pF) in equation (19.2) to compute the *minimum* resonant frequency of the radio. This will be the lowest frequency the radio will be able to receive.

3. By examining equation (19.2), what is theoretically the *highest* frequency the radio can receive, given that the capacitor can vary between $C = 0$ and $C = 365$ pF?

Building Your Own Crystal Set

You can build your own crystal set from a few odd parts (e.g. wire, paper towel tube, coat hanger, razor blade, safety pin, and a crystal earpiece) for about $10–$15. Parts, plans, and some excellent complete kits may be obtained from:

- The Crystal Set Society: `http://www.midnightscience.com/`
- Borden Radio Company: `http://www.xtalman.com/`

Table 19-1. Song Playlist for Crystal Radio Lab.

Track	Title	Artist	Year	Time
1	*Maybe Baby*	Buddy Holly and the Crickets	1957	2:03
2	*Kansas City Kitty*	The Rhythmic Eight	1929	2:40
3	*Strangers in the Night*	Frank Sinatra	1966	2:38
4	*Five Foot Two, Eyes of Blue*	The Savoy Orpheans	1925	2:51
5	*Opus One*	Tommy Dorsey	1944	2:59
6	*My Prayer*	The Ink Spots	1939	3:13
7	*Dear Hearts and Gentle People*	Bing Crosby	1949	2:42
8	*At the Jazz Band Ball*	Bix Beiderbecke	1927	2:52
9	*Foggy Mountain Breakdown*	Lester Flatt and Earl Scruggs	1949	2:41
10	Station Identification (Morse Code)*	—	—	1:21
11	*God Bless America*	Kate Smith	1938	2:15
12	*What A Wonderful World*	Louis Armstrong	1968	2:19
13	*Happy Days Are Here Again*	Jack Hylton	1929	3:13
14	*Smoke Gets in Your Eyes*	The Platters	1958	2:38
15	*Earth Angel*	The Penguins	1954	2:59
16	*The Stars and Stripes Forever*	John Philip Sousa	1896	3:34
17	*The Charleston*	The Savoy Orpheans	1925	2:57
18	*Sally Goodwin*	Lester Flatt and Earl Scruggs	196?	2:11
19	*Minnie the Moocher*	Cab Calloway	1931	3:14
20	Station Identification (Morse Code)*	—	—	1:21
21	*Hello Dolly*	Louis Armstrong	1964	2:28
22	*Take the "A" Train*	Duke Ellington	1939	2:58
23	*Sh-Boom*	The Crew Cuts	1954	2:49
24	*The Very Thought of You*	BBC Big Band Orchestra	1934	3:42
25	*Make Someone Happy*	Jimmy Durante	1963	1:54
26	*She's a Great, Great Girl*	Jack Teagarden	1928	3:42
27	*O Susanna*	The Smoky Mountain Band		3:15
28	*St. James' Infirmary*	Cab Calloway	1930	3:05
29	*In the Mood*	Glenn Miller	1939	3:35
30	Station Identification (Morse Code)*	—	—	1:21
31	*Ole Faithful*	Gene Autry	1935	2:45
32	*Don't Be That Way*	Benny Goodman	1938	4:24
33	*At Last*	Glenn Miller	1942	3:08
34	*Blueberry Hill*	Louis Armstrong	1949	2:56
35	*It Might As Well Be Spring*	Dick Haymes	1945	3:11
36	*Whispering Grass*	The Ink Spots	1940	2:45
37	*I'm Getting Sentimental Over You*	Tommy Dorsey	1935	3:40
38	*I'm Sitting on Top of the World*	Al Jolson	1926	1:52
39	*Ain't Misbehavin'*	Fats Waller	1929	4:00
40	Station Identification (Morse Code)*	—	—	1:21
41	*Remarkable Girl*	Ted Weems	1929	3:08
42	*I'm So Lonesome I Could Cry*	Hank Williams	1949	2:49
43	*Boogie Woogie Bugle Boy*	The Andrews Sisters	1941	2:44
44	*Happy Feet*	Paul Whiteman	1930	3:09
45	*If I Didn't Care*	The Ink Spots	1939	3:06
46	*Witchcraft*	Frank Sinatra	1957	2:53
47	*Moonlight in Vermont*	Frank Sinatra	1957	3:33
48	*Happy Trails*	Roy Rogers and Dale Evans	1952	2:55
49	*The Star-Spangled Banner*	US Air Force Academy Band		1:24
50	Station Identification (Morse Code)*	—	—	1:21

*PHYSICS LAB RADIO BROADCAST DE PRINCE GEORGES COMMUNITY COLLEGE PHYSICS DEPT, LARGO MD.

Crystal Radio Lab Worksheet

1. What is the name of the first song you heard on the radio? ______________________

2. (a) Inductor dimensions:

   $N =$ ______________________

   $\ell =$ ______________________

   $d =$ ______________________

   (b) Inductance:

   $L = \mu_0 N^2 \frac{A}{\ell} =$ ______________________

3. Lowest frequency $f_{\text{min}} =$ ______________________

4. Lowest frequency $f_{\text{max}} =$ ______________________

5. Does C increase or decrease as the knob is turned clockwise? ______________________

6. Does f increase or decrease as the knob is turned clockwise? ______________________

International Morse Code

1. A dash is equal to three dots.
2. The space between parts of the same letter is equal to one dot.
3. The space between two letters is equal to three dots.
4. The space between two words is equal to seven dots.

A	• −	U	• • −
B	− • • •	V	• • • −
C	− • − •	W	• − −
D	− • •	X	− • • −
E	•	Y	− • − −
F	• • − •	Z	− − • •
G	− − •		
H	• • • •		
I	• •		
J	• − − −		
K	− • −	1	• − − − −
L	• − • •	2	• • − − −
M	− −	3	• • • − −
N	− •	4	• • • • −
O	− − −	5	• • • • •
P	• − − •	6	− • • • •
Q	− − • −	7	− − • • •
R	• − •	8	− − − • •
S	• • •	9	− − − − •
T	−	0	− − − − −

/

Experiment 20

The Slide Rule

This version of the slide rule lab is for use with the *Scientific American* slide rule.

Introduction

Before electronic calculators became widely available around 1975, students, engineers, and scientists performed mathematical calculations using an instrument called a *slide rule*. With this simple device, you could multiply, divide, calculate reciprocals, squares, square roots, cubes, cube roots, logarithms, sines, cosines, tangents, cotangents, inverse trigonometric functions, and compute powers of numbers. Here we'll build a simple slide rule and show how to use it.

Obtain a Slide Rule

You'll need a slide rule to practice with. We'll use a paper slide rule kit from the May 2006 issue of *Scientific American*, which is duplicated on the last page of this handout. It is very similar to the type used decades ago, and provides good practice in using analog devices.

Also, an excellent software slide rule simulator is available on the Internet at
`http://homepages.slingshot.co.nz/~timb3000/index.html`
You can obtain a real slide rule on the Internet from on-line auction sites or from Sphere Research Corporation: `http://sphere.bc.ca/test/sruniverse.html`
Some popular top-of-the-line models were the Post Versalog 1460, the K+E Deci-Lon, and the Faber-Castell 2/83N.

Instructions

The slide rule has three major limitations compared to electronic calculators:

- It cannot add or subtract. Addition and subtraction must be done using paper and pencil.
- It does not keep track of the decimal point; you locate the decimal point yourself by estimating the answer in your head.
- It can perform calculations to only three or four significant digits.

The slide rule consists of three parts: (1) the *body* (or *stock*); (2) the *slide* (which moves left and right within the body); and (3) the *cursor* (the transparent sliding window with a hairline), which is used to help read the scales. Inscribed on the body and slide are sets of scales. The slide rule from *Scientific American* has nine scales; some more advanced models have 20, 30, or even more. Scales are generally labeled with one or two letters, and these names are standard on most rules.

On the *Scientific American* slide rule, the T, K and A scales are on the upper part of the body; the B, CI, and C scales are on the slide; and the D, L, and S scales are on the lower part of the body.

1. **The C and D Scales.** The C and D scales are the scales that are used most often: they are used to perform multiplication and division.

   Multiplication. Set the left *index* (the left 1) on the C scale over the first number (the multiplicand) on the D scale. Find the second number (the multiplier) on the C scale; move the cursor so that the hairline is over this second number. You then read the product on the D scale under the hairline. If the second number on C is beyond the right-hand end of D, then move the slide to the left and use the right index (the right 1) instead of the left index of C. (Try $2 \times 3 = 6$. Note that this same setting also represents 20×3, 20000×0.03, 0.2×30, etc. You place the decimal place in the result by estimating the answer in your head.)

   Division. Division is actually a bit easier than multiplication. Set the hairline in the cursor over the dividend (the numerator) on the D scale. Then move the slide so that the divisor (the denominator) on the C scale is also under the hairline. The quotient will then be found on the D scale, under either the left or right index of the C scale. (Try $6 \div 2 = 3$.)

2. **The CI Scale.** The CI scale is a reversed C scale; it shows the reciprocals of numbers on the C scale. To find the reciprocal of a number, just set the hairline over the number on the C scale, and read its reciprocal on the CI scale. (Notice that numbers on the CI scale run backwards, increasing from right to left.) (Try $1/4 = 0.25$.)

   One trick of skilled users is to use the CI and D scales for multiplication, instead of the C and D scales, so that you compute $x \times y$ as $x \div (1/y)$. To do this, set the hairline in the cursor over the multiplicand on the D scale. Then move the slide so that the multiplier on the CI scale is also under the hairline. The product will then be found on the D scale, under either the left or right index of the C scale. This trick makes it possible to do multiplication without worrying about running over the right end of the D scale.

3. **The A and B Scales.** These scales are used to find squares and square roots.

   Squares. To square a number, place the hairline over the number on the D scale, and find its square on the A scale. (You could also place the hairline over the number on the C scale, and find its square on the B scale.) (Try $4^2 = 16$.)

   Square roots. To find the square root of a number, place the hairline over the number on the A scale, and read its square root on the D scale. Since the A scale has two scales on it, you have to know which half of the scale to use. You can use this rule: write the number in scientific notation. If the exponent of 10 is even, use the left half of A; if it is odd, use the right half. (Try $\sqrt{9} = 3$, and $\sqrt{60} = 7.75$.)

   You can also multiply and divide using the A and B scales, but with reduced accuracy (due to the smaller scales).

4. **The K Scale.** The K scale is used to find cubes and cube roots.

   Cubes. To find the cube of a number, place the hairline over the number on the D scale, and read its cube on the K scale. (Try $2^3 = 8$.)

   Cube roots. To find the cube root of a number, place the hairline over the number on the K scale, and read its cube root on the D scale. Since the K scale is divided into three parts, you will have to take care to use the correct third of the K scale when doing this. Write the number in scientific notation; if the exponent of 10 is a multiple of 3, then use the left third; if it is 1 more than a multiple of 3, use the middle third; if it is 2 more than a multiple of 3, then use the right third. (Try $\sqrt[3]{27} = 3$.)

5. **The L Scale.** The L scale is used to calculate common (base 10) logarithms. The L scale will only show the part of the logarithm to the right of the decimal point. You must provide the part to the left of the decimal point from knowing the magnitude of the number.

   Place the hairline over a number on the D scale, and read the logarithm (the part to the right of the decimal point) on the L scale. (Try $\log 300 = 2.477$. Since $300 = 3 \times 10^2$, the exponent of 10 (2) gives the part to the left of the decimal. The part to the right of the decimal (0.477) is read on the L scale.)

   To find natural logarithms, use $\ln x = \log x / \log e = 2.30 \log x$. In other words, multiply the base 10 logarithm by 2.30.

6. **The S Scale.** The S scale is used to find sines and cosines of angles.

   Sine of an angle between 0° and 5.°74. the sine of an angle in this range is approximately the angle converted to radians, so just multiply the degrees by $\pi/180 = 0.0175$.

   Sine of an angle between 5.°74 and 90°. Set the hairline over the angle (in degrees) on the S scale (using the black numbers), and read its sine under the hairline on the D scale. (Try $\sin 30° = 0.5$.)

   Cosine of an angle between 0° and 84.°3. Set the hairline over the angle (in degrees) on the S scale (using the grey numbers), and read its cosine under the hairline on the D scale. (Try $\cos 30° = \sin 60° = 0.866$.)

   Cosine of an angle between 84.°3 and 90°. Use $\cos\theta \approx (90° - \theta) \times (\pi/180)$.

7. **The T Scale.** The T scale is used to find tangents and cotangents of angles.

   Tangent of an angle between 0° and 5.°74. The tangent of an angle in this range is approximately the angle converted to radians, so just multiply the degrees by $\pi/180 = 0.0175$.

   Tangent of an angle between 5.°74 and 45°. Set the hairline over the angle (in degrees) on the T scale (black numbers), and find its tangent under the hairline on the D scale. (Try $\tan 30° = 0.577$.)

   Tangent of an angle between 45° and 84.°3. First, align the C and D scales (so that the slide is centered). Set the hairline over the angle (in degrees) on the T scale (grey numbers), and find its tangent under the hairline on the CI scale. (Try $\tan 60° = 1.73$.)

   Cotangent of an angle between 5.°74 and 45°. First, align the C and D scales (so that the slide is centered). Set the hairline over the angle (in degrees) on the T scale (black numbers), and find its cotangent under the hairline on the CI scale. (Try $\cot 30° = 1.73$.)

   Cotangent of an angle between 45° and 84.°3. Set the hairline over the angle (in degrees) on the T scale (grey numbers), and find its cotangent under the hairline on the D scale. (Try $\cot 60° = 0.577$.)

   Cotangent of an angle between 84.°3 and 90°. Use $\cot\theta \approx (90° - \theta) \times (\pi/180)$.

Combining Operations

Skilled slide rule operators can often set the slide rule to perform several operations at once. For example:

- $x \times y \div z$. Do the division first: set the hairline over y on the D scale, then move the slide so that z on the C scale is also under the hairline. Now move the hairline over x on the C scale and read the result on the D scale. (Try $8 \times 3 \div 4 = 6$.)

- $x \times y \times z$. Set the hairline over x on the D scale, then move the slide to place y on the CI scale under the hairline. Move the hairline to z on the C scale, and read the product under the hairline on the D scale. (Try $1.2 \times 2.3 \times 6.4 = 17.66$.)
- $x \times y^2$. Move the slide to put the index (1) on the C scale over the number that is squared (y) on D scale. Move the hairline over the number that is *not* squared (x) on the B scale, and read the result on the A scale. (Try $2 \times 3^2 = 18$.)
- x^3 *and* $x^{3/2}$. If a K scale is not available, the previous method may be used to compute cubes using only the A, B, C, and D scales. Move the slide to put the index (1) on the C scale over x on D scale. Move the hairline over x on the B scale, and read the result on the A scale. (Try $2^3 = 8$.) This method also gives $x^{3/2}$: just read $x^{3/2}$ under the hairline on the D scale. (Try $2^{3/2} = 2.83$.)

(References: "When Slide Rules Ruled" by Cliff Stoll, *Scientific American*, May 2006; and *The Slide Rule* by C.N. Pickworth.)

Exercises

Use the slide rule to calculate the following:

15×17	=	________________
27×45	=	________________
$6 \div 4.5$	=	________________
4.3^2	=	________________
$\sqrt{45}$	=	________________
2.3^3	=	________________
$\log_{10} 3.70$	=	________________
$\sin 22°$	=	________________
$\cos 52°$	=	________________
$\tan 23°$	=	________________

a Cut here

c Cut here

CHRIS HAMANN AND NANCY SHAW

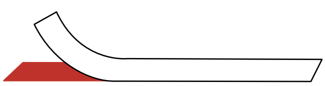
ASSEMBLY INSTRUCTIONS

1 Cut out the entire white panel (*a*). Cut along line between parts A and B (*b*), then remove excess (*c*).

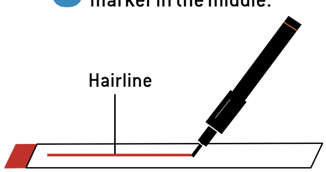
2 Fold part A along the dotted lines.

3 Slip part B into the folded part A.

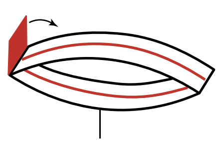
4 To make the cursor (the sliding window that is inscribed with a hairline), use the guides to the left to measure two pieces of transparent tape. Make one section the length of the black line and the other the length of the red line. Place the adhesive sides together.



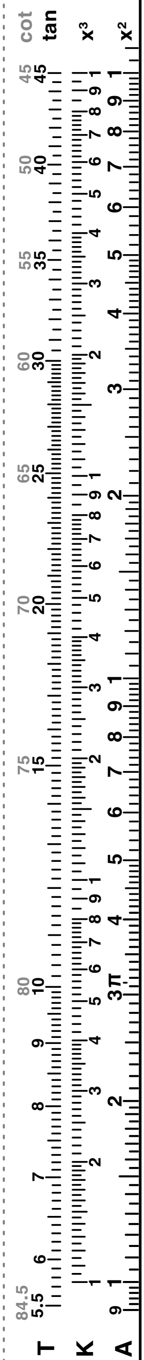
5 Draw a line with a fine marker in the middle.



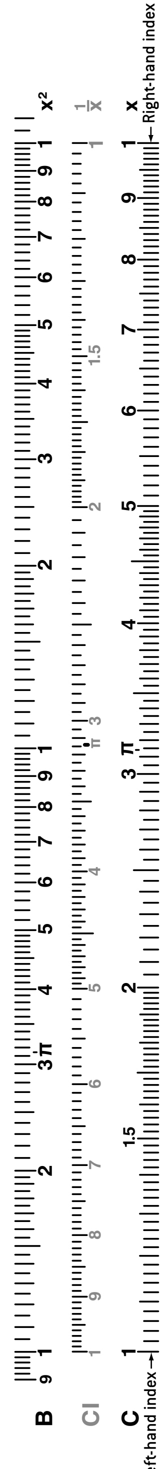
6 Wrap the folded tape around the slide rule for sizing. Use the adhesive end to complete the cursor. Slide cursor onto the rule.



Part **A**



b Cut here



(Slider)

Part **B**

Experiment 21

The Slide Rule

This version of the slide rule lab is for use with the Sterling slide rule.

Introduction

Before electronic calculators became widely available around 1975, students, engineers, and scientists performed mathematical calculations using an instrument called a *slide rule*. With this simple device, you could multiply, divide, calculate reciprocals, squares, square roots, cubes, cube roots, logarithms, sines, cosines, tangents, cotangents, inverse trigonometric functions, and compute powers of numbers. Here we'll learn how to do some basic operations on a simple slide rule.

Obtain a Slide Rule

You'll need a slide rule to practice with. We'll use the Sterling Mannheim slide rule, which was a very inexpensive 9-scale model that sold for about $1. It is very similar to more advanced professional slide rules used decades ago, and provides good practice in using analog devices.[1]

Also, an excellent software slide rule simulator is available on the Internet at `http://homepages.slingshot.co.nz/~timb3000/index.html`. You can obtain a real slide rule on the Internet from on-line auction sites, or refurbished ones from Sphere Research Corporation: `http://sphere.bc.ca/test/sruniverse.html`. Some popular top-of-the-line models were the Post Versalog 1460, the K+E Deci-Lon, and the Faber-Castell 2/83N.

Attached to this lab handout is a copy of a build-it-yourself paper slide rule from the May 2006 issue of *Scientific American*, in case you would like to build your own slide rule and practice at home.

Instructions

The slide rule has three major limitations compared to electronic calculators:

- It cannot add or subtract. Addition and subtraction must be done using paper and pencil.
- It does not keep track of the decimal point; you locate the decimal point yourself by estimating the answer in your head.

[1] The Post 1447 slide rule has the same layout as the Sterling slide rule.

- It can perform calculations to only three or four significant digits.

The slide rule consists of three parts: (1) the *body* (or *stock*); (2) the *slide* (which moves left and right within the body); and (3) the *cursor* (the transparent sliding window with a hairline), which is used to help read the scales. Inscribed on the body and slide are sets of scales. The Sterling slide rule has nine scales; some more advanced models have 20, 30, or even more. Scales are generally labeled with one or two letters, and these names are standard on most rules.

On the Sterling slide rule, the A scale is on the upper part of the body; the B, CI, and C scales are on the slide; and the D and K scales are on the lower part of the body. The slide may be removed and reversed to give access to the S, L, and T scales on the back of the slide.

1. **The C and D Scales.** The C and D scales are the scales that are used most often: they are used to perform multiplication and division.

   Multiplication. Set the left *index* (the left 1) on the C scale over the first number (the multiplicand) on the D scale. Find the second number (the multiplier) on the C scale; move the cursor so that the hairline is over this second number. You then read the product on the D scale under the hairline. If the second number on C is beyond the right-hand end of D, then move the slide to the left and use the right index (the right 1) instead of the left index of C. (Try $2 \times 3 = 6$. Note that this same setting also represents 20×3, 20000×0.03, 0.2×30, etc. You place the decimal place in the result by estimating the answer in your head.)

   Division. Division is actually a bit easier than multiplication. Set the hairline in the cursor over the dividend (the numerator) on the D scale. Then move the slide so that the divisor (the denominator) on the C scale is also under the hairline. The quotient will then be found on the D scale, under either the left or right index of the C scale. (Try $6 \div 2 = 3$.)

2. **The CI Scale.** The CI scale is a reversed C scale; it shows the reciprocals of numbers on the C scale. To find the reciprocal of a number, just set the hairline over the number on the C scale, and read its reciprocal on the CI scale. (Notice that numbers on the CI scale run backwards, increasing from right to left.) (Try $1/4 = 0.25$.)

   One trick of skilled users is to use the CI and D scales for multiplication, instead of the C and D scales, so that you compute $x \times y$ as $x \div (1/y)$. To do this, set the hairline in the cursor over the multiplicand on the D scale. Then move the slide so that the multiplier on the CI scale is also under the hairline. The product will then be found on the D scale, under either the left or right index of the C scale. This trick makes it possible to do multiplication without worrying about running over the right end of the D scale.

3. **The A and B Scales.** These scales are used to find squares and square roots.

   Squares. To square a number, place the hairline over the number on the D scale, and find its square on the A scale. (You could also place the hairline over the number on the C scale, and find its square on the B scale.) (Try $4^2 = 16$.)

   Square roots. To find the square root of a number, place the hairline over the number on the A scale, and read its square root on the D scale. Since the A scale has two scales on it, you have to know which half of the scale to use. You can use this rule: write the number in scientific notation. If the exponent of 10 is even, use the left half of A; if it is odd, use the right half. (Try $\sqrt{9} = 3$, and $\sqrt{60} = 7.75$.)

   You can also multiply and divide using the A and B scales, but with reduced accuracy (due to the smaller scales).

4. **The K Scale.** The K scale is used to find cubes and cube roots.

Cubes. To find the cube of a number, place the hairline over the number on the D scale, and read its cube on the K scale. (Try $2^3 = 8$.)

Cube roots. To find the cube root of a number, place the hairline over the number on the K scale, and read its cube root on the D scale. Since the K scale is divided into three parts, you will have to take care to use the correct third of the K scale when doing this. Write the number in scientific notation; if the exponent of 10 is a multiple of 3, then use the left third; if it is 1 more than a multiple of 3, use the middle third; if it is 2 more than a multiple of 3, then use the right third. (Try $\sqrt[3]{27} = 3$.)

5. **The L Scale.** The L scale is used to calculate common (base 10) logarithms. To use the L scale, remove the slide, flip it over, and re-insert it into the body so that the S, L, and T scales (labels are on the right-hand side) are visible and rightside-up. Align the slide and body so that the slide is perfectly centered—the 45 on the right-hand end of the T scale should line up exactly with the 1 on the right-hand end of the D scale.

   The L scale will only show the part of the logarithm to the right of the decimal point. You must provide the part to the left of the decimal point from knowing the magnitude of the number.

   Place the hairline over a number on the D scale, and read the logarithm (the part to the right of the decimal point) on the L scale. (Try $\log 300 = 2.477$. Since $300 = 3 \times 10^2$, the exponent of 10 (2) gives the part to the left of the decimal. The part to the right of the decimal (0.477) is read on the L scale.)

   To find natural logarithms, use $\ln x = \log x / \log e = 2.30 \log x$. In other words, multiply the base 10 logarithm by 2.30.

6. **The S Scale.** The S scale is used to find sines and cosines of angles. To use the S scale, remove the slide, flip it over, and re-insert it into the body so that the S, L, and T scales (labels are on the right-hand side) are visible and rightside-up. Align the slide and body so that the slide is perfectly centered—the 45 on the right-hand end of the T scale should line up exactly with the 1 on the right-hand end of the D scale. Note that the S scale on the Sterling slide rule is marked off in degrees, minutes, and seconds of arc.

   Sine of an angle between 0° and 0°.573. The sine of an angle in this range is approximately the angle converted to radians, so just multiply the degrees by $\pi/180 = 0.0175$.

   Sine of an angle between 0°.573 and 90°. Set the hairline over the angle (in degrees) on the S scale, and read its sine under the hairline on the A scale. (Try $\sin 30° = 0.5$.)

   Cosine of an angle between 0° and 89°.427. Set the hairline over the *complement* of the angle (that is, 90° minus the angle, in degrees) on the S scale, and read its cosine under the hairline on the A scale. (Try $\cos 30° = \sin 60° = 0.866$.)

   Cosine of an angle between 84°.427 and 90°. Use $\cos\theta \approx (90° - \theta) \times (\pi/180)$.

7. **The T Scale.** The T scale is used to find tangents and cotangents of angles. To use the T scale, remove the slide, flip it over, and re-insert it into the body so that the S, L, and T scales (labels are on the right-hand side) are visible and rightside-up. Align the slide and body so that the slide is perfectly centered—the 45 on the right-hand end of the T scale should line up exactly with the 1 on the right-hand end of the D scale. Note that the T scale on the Sterling slide rule is marked off in degrees, minutes, and seconds of arc.

   Tangent of an angle between 0° and 5°.74. The tangent of an angle in this range is approximately the angle converted to radians, so just multiply the degrees by $\pi/180 = 0.0175$.

   Tangent of an angle between 5°.74 and 45°. Set the hairline over the angle (in degrees) on the T scale, and find its tangent under the hairline on the D scale. (Try $\tan 30° = 0.577$.)

Tangent of an angle between 45° and 84°.3. Set the hairline over the *complement* of the angle (90° minus the angle) on the T scale. Now, without moving the cursor, remove the slide, flip it over, re-insert it into the body, and center the slide in the body. The answer will appear on the CI scale. (Try $\tan 60° = 1.73$.)

Cotangent of an angle between 5°.74 and 45°. Set the hairline over the angle on the T scale. Now, without moving the cursor, remove the slide, flip it over, re-insert it into the body, and center the slide in the body. The answer will appear on the CI scale. (Try $\cot 30° = 1.73$.)

Cotangent of an angle between 45° and 84°.3. Set the hairline over the *complement* of the angle on the T scale. The answer will appear on the D scale. (Try $\cot 60° = 0.577$.)

Cotangent of an angle between 84°.3 and 90°. Use $\cot\theta \approx (90° - \theta) \times (\pi/180)$.

Combining Operations

Skilled slide rule operators can often set the slide rule to perform several operations at once. For example:

- $x \times y \div z$. Do the division first: set the hairline over y on the D scale, then move the slide so that z on the C scale is also under the hairline. Now move the hairline over x on the C scale and read the result on the D scale. (Try $8 \times 3 \div 4 = 6$.)
- $x \times y \times z$. Set the hairline over x on the D scale, then move the slide to place y on the CI scale under the hairline. Move the hairline to z on the C scale, and read the product under the hairline on the D scale. (Try $1.2 \times 2.3 \times 6.4 = 17.66$.)
- $x \times y^2$. Move the slide to put the index (1) on the C scale over the number that is squared (y) on D scale. Move the hairline over the number that is *not* squared (x) on the B scale, and read the result on the A scale. (Try $2 \times 3^2 = 18$.)
- x^3 *and* $x^{3/2}$. If a K scale is not available, the previous method may be used to compute cubes using only the A, B, C, and D scales. Move the slide to put the index (1) on the C scale over x on D scale. Move the hairline over x on the B scale, and read the result on the A scale. (Try $2^3 = 8$.) This method also gives $x^{3/2}$: just read $x^{3/2}$ under the hairline on the D scale. (Try $2^{3/2} = 2.83$.)

Numbers to Powers

Suppose you wish to take a number to an arbitrary power (i.e. y^x). Sophisticated slide rules have a set of "log-log" scales for computing this, but it can also be done on the Sterling rule, using the relation

$$y^x = 10^{x \log y}.$$

Suppose, for example, we wish to find $2.3^{4.6}$. Using the L scale, we find $\log 2.3 = 0.362$; then using the C and D scales, we find $x \log y = 4.6 \times 0.362 = 1.664$. Now we need to compute the antilog, $10^{1.664}$ by looking up 0.664 on the L scale, and reading 46.1 on the D scale. Hence $2.3^{4.6} = 46.1$.

As a common special case,

$$e^x = 10^{0.434x}.$$

The Scientific American Slide Rule

The build-it-yourself slide rule in the May 2006 issue of *Scientific American* has similar scales, but a different layout: the T, K, and A scales are on the upper part of the stock, the B, CI, and C scales are on the slide, and the D, L, and S scales are on the lower part of the stock. The A, B, C, CI, D, and K scales work the same as they do on the Sterling rule. The L scale also works the same, except that the slide does not need to be centered before using it, since the L scale is on the stock. The S and T scales are on the stock instead of the slide, so they work a little differently:

- **The S Scale.** The S scale is used to find sines and cosines of angles. Note that the S scale on the *Scientific American* slide rule is marked off in degrees and decimals of a degree, and covers just one decade of angles instead of two decades like on the Sterling rule; therefore the answer is read on the D scale instead of the A scale.

  Sine of an angle between 0° and 5°.73. The sine of an angle in this range is approximately the angle converted to radians, so just multiply the degrees by $\pi/180 = 0.0175$.

  Sine of an angle between 5°.73 and 90°. Set the hairline over the angle (in degrees) on the S scale, and read its sine under the hairline on the D scale. (Try $\sin 30° = 0.5$.)

  Cosine of an angle between 0° and 84°.3. Set the hairline over the *complement* of the angle (that is, 90° minus the angle, in degrees) on the S scale, and read its cosine under the hairline on the D scale. (Try $\cos 30° = \sin 60° = 0.866$.)

  Cosine of an angle between 84°.427 and 90°. Use $\cos\theta \approx (90° - \theta) \times (\pi/180)$.

- **The T Scale.** The T scale is used to find tangents and cotangents of angles. Note that the T scale on the Sterling slide rule is marked off in degrees and decimals of a degree.

  Tangent of an angle between 0° and 5°.74. The tangent of an angle in this range is approximately the angle converted to radians, so just multiply the degrees by $\pi/180 = 0.0175$.

  Tangent of an angle between 5°.74 and 45°. Set the hairline over the angle (in degrees) on the T scale, and find its tangent under the hairline on the D scale. (Try $\tan 30° = 0.577$.)

  Tangent of an angle between 45° and 84°.3. Set the hairline over the *complement* of the angle (90° minus the angle) on the T scale. Center the slide, and read the answer on the CI scale. (Try $\tan 60° = 1.73$.)

  Cotangent of an angle between 5°.74 and 45°. Set the hairline over the angle on the T scale. Center the slide, and read the answer on the CI scale. (Try $\cot 30° = 1.73$.)

  Cotangent of an angle between 45° and 84°.3. Set the hairline over the *complement* of the angle on the T scale. The answer will appear on the D scale. (Try $\cot 60° = 0.577$.)

  Cotangent of an angle between 84°.3 and 90°. Use $\cot\theta \approx (90° - \theta) \times (\pi/180)$.

(References: "When Slide Rules Ruled" by Cliff Stoll, *Scientific American*, May 2006; and *The Slide Rule* by C.N. Pickworth.)

Exercises

Use the slide rule to calculate the following:

15×17	=	____________________
27×45	=	____________________
$6 \div 4.5$	=	____________________
4.3^2	=	____________________
$\sqrt{45}$	=	____________________
2.3^3	=	____________________
$\log_{10} 37.0$	=	____________________
$\sin 22°$	=	____________________
$\cos 52°$	=	____________________
$\tan 23°$	=	____________________
$1.48^{3.88}$	=	____________________

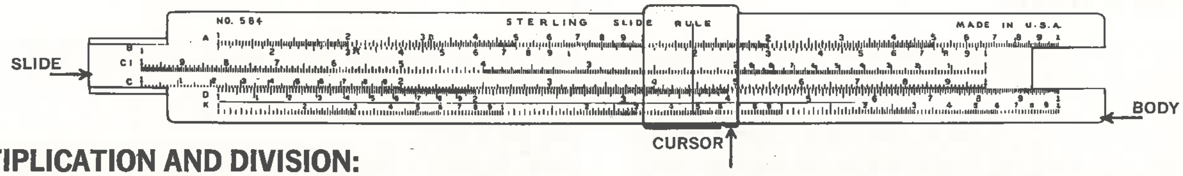
STERLING SLIDE RULE

A QUALITY INSTRUMENT FOR STUDENT OR PROFESSIONAL

OPERATING INSTRUCTIONS

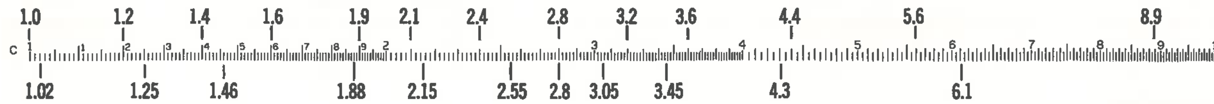
A complete course in use and operation of the slide rule

The Sterling Student Slide Rule is an accurate and convenient instrument for use in computing multiplication, division, proportion, square and cube root problems, as well as sine, tangent and logarithm solutions.
The reading of any slide rule is accurate to the second place, therefore, the third place number can be approximated by mental calculation, by multiplying the last two numbers together and using the last figure as third number in these calculations. Accurate figures beyond this must be done by actual multiplication on paper.
The Sterling Slide Rule has standard A, B, C, CI, D, and K scales. The A, D, and K scales are on the **body**, the B, CI and C scales on the **slide.** The **cursor** travels the full length of the body, and the hairline crosses these scales for direct comparison. On the reverse side of the slide, the S, L, and T scales appear, and the slide may be removed and reversed for use in calculating these values.



MULTIPLICATION AND DIVISION:

For this work, we use only the C and D scales, and in some cases the CI scale. The C and D scale are logarithmic, and start with the unit 1 at the left, thru the unit 10 (or 1) at the right. The space between 1 and 2 has small numbers indicating the "teens" following the left hand 1 or 10. The lines between the figures divide each segment into 10ths. The markings between 2 and 4 again represent individual numbers following 2 or 20, but the markings between unit numbers are in 5ths, or 2/10ths. From 4 to the right hand 1 or 10, each unit space is divided in halves, or 5/10ths. As you read the rule, therefore, these variations of the unit measures must be observed. The diagram below shows these as they appear on the rule, and gives readings as they appear:

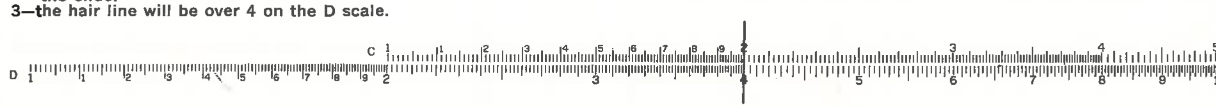


MULTIPLICATION:

On a logarithmic scale, the progression of numbers is constant, therefore the multiple of any unit or number of units can be read only if we place the factor 1 on the line of one of the factors in the problem. **The problem of 2 X 2 is therefore solved as follows:**

1—move the slide until the figure 1 at the **left** is over the 2 on the D scale. (Move the slide to the **right**.)
2—move the cursor until the hairline is over the 2 on the C scale on the slide.
3—the hair line will be over 4 on the D scale.

Similarly you will note 3 X 2 = 6, 4 X 2 = 8, 5 X 2 = 10 **as** you read across the scale.
Bear in mind that this 2 or the 2 on the C scale can represent, 2, 20 or 200. This must be remembered in writing down answers. Also remember that the answer to the problem **always** appears on the same scale from which you **started,** usually the D scale.



DIVISION:

Since division is the reverse of multiplication, we reverse the procedure shown in multiplication, as follows: **Problem:** divide 4 by 2. Start with 4 on the D scale. Move slide to **right** until 2 is over the 4. Against 1 to the left, read 2.

NOW TRY THESE PROBLEMS
5 X 2 (1 of C over 5 of D—read 1 or 10 against 2 of C)
3 X 3 (1 of C over 3 of D—read 9 against 3 of C)
8 ÷ 2 (2 of C over 8 of D—read 4 against 1 of C)
5 ÷ 4 (4 of C over 5 of D—read 1.25 against 1 of C) (SEE BELOW)

For numbers which when multiplied are more than 10, it is necessary to achieve the same effect by using the **right** hand 1 (or ten) as the factor. For instance. 2 X 6 = 12. By placing the **right** hand 1 over 6 and reading against the 2 on the C scale, the cursor will indicate the 12 on the D scale. (**Left** hand 1 or 10 plus the small 2 equals 12).
Similarly, for division, 12 on D divided by 2 on C will read 6 under the **right** hand 1 of the slide.

NOW TRY THESE PROBLEMS
7 X 4 (**right** hand 1 on C over 7 on D. Read **28** on D below the 4 on C)
8 X 9 (**right** hand 1 on C over 9 on D. Read **72** on D below the 8 on C)
64 ÷ 8 (over 64 on D. place 8 on C. Against **right** hand 1 on C. read 8)
72 ÷ 9 (over 72 on D, place 9 on C. Against **right** hand 1 on C, read 8)

Some mulplication problems will "run off the rule." In this case, reverse the slide, using the **right** hand or **left** hand 1, and read the answer as shown.

EXAMPLE: 4 X 4—put **left** hand 1 on C against 4 on D. The 4 on C is "off the rule." Slide the slide to the **left** until the **right** hand 1 is over 4 on D. Against 4 on C, read 16 on D.

USING THE CI SCALE:

The CI scale is the same as the C scale, except that it reads from **right to left.** This scale ("C Inverted") is therefore the RECIPROCAL of the C scale, and can be used to avoid the necessity of moving the slide **left** or **right.**

EXAMPLE: 4 X 4—Reading from the RIGHT on CI place the 4 above the 4 on D—against the **left** hand 1 on CI, read 16 on D. You are now using CI, the reversed or reciprocal scale in place of the C scale, so read these two, CI and D against each other. (SEE BELOW)
24 ÷ 4—place **left** hand 1 on CI above 24 on D—Against 4 on CI read 6 on D.

By reading the C scale against the CI scale, you will note that the product of the two numbers always equals 1 or 10 when multiplied together. Also, the C scale represents the fraction (decimal) of the CI scale.

EXAMPLE: 1/8 = .125—Against 8 on CI read .125 on C. (SEE BELOW)

USING THE A OR B SCALE:

The A and B scales are made up of 2 half size or half length logarithmic scales, therefore they are the SQUARE of the C and D scales. We can therefore square numbers shown on the C or D scale by reading the number times itself on the A or B scale. For practice, remove the slide. You now can clearly read the A against the D scale. Slide the cursor along, until the hairline is over 3 on D—you will read 9 on **left** half of the A scale. Slide it further along to 4 on D—you will read 16 on the **right** half of the A scale.
The square of 5 on D is 25 on the **right** scale of A. (SEE BELOW)
The square of 26 is 676 on the **left** scale of A.
The square of 19 is 361 on **left** scale of A.
The square of 55 is 3025 on the **right** scale of A.
Note that the products have **even** and **odd** numbers of digits. Example 1 and 4 have **even** numbers of digits. Examples 2 and 3 have **odd** numbers of digits. When square root is learned, this factor is most important in determining which half of the A scale to use.

SQUARE ROOT:

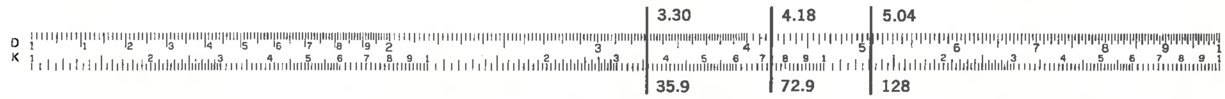
Since the A scale is the square of the numbers on D, the numbers on D are the square roots of the numbers on scale A. Of prime importance here is which half of the A scale to use when putting the number whose square root is desired "into the rule." The rule for this is simple. If ODD number of digits, use the **left** scale. If EVEN number of digits, use the **right** scale:

The square root of 25 (even number of digits—**right** scale) is 5 on D.
The square root of 250 (odd number of digits—**left** scale) is 15.81+ on D scale.
The square root of 2500 (even number of digits—**right** scale) is 50.

USING THE K SCALE:

The K scale, you will note, consists of 3 log scales instead of 2 as in A. The result is that these figures are the CUBE of the D scale figures. 3 X 3 X 3 = 27, or the cube of 3 can be read directly on K by placing the cursor over 3 on D and reading 27 on the MIDDLE part of K scale. Also, the CUBE ROOT of 64 read on K on MIDDLE scale, is 4 (4 X 4 X 4). Cube root: Use K and D scales, in much the way the A and D scales are used for square roots. To find the cube root of a number, move its decimal point over (if necessary) 3 places at a time until a number between 1 and 1000 is obtained. If the resulting number is between 1 and 10, set the cursor to it in the **left** K scale; if between 10 and 100, use the **center** K scale; if between 100 and 1000, use the **right** scale. Then read the value on the D scale. Finally, move the decimal point one third as many places as it was moved in the original number, but in the opposite direction. Example, find the cube root of 35.9; since this is between 10 and 100, set the cursor to 35.9 on the center K scale, and read the cube root, 3.30, on the D scale.

To find the cube root of 0.0729, move the decimal point to the right three places; the resulting value, 72.9, is between 10 and 100, therefore the cursor is set to 72.9 on the **center** K scale, and the reading on the D scale is found, 4.18. Since in the original number the decimal point was moved three places to the right, in the number from the D scale the decimal must be moved one place to the left, giving 0.418, which is the cube root of 0.0729.
To find the cube root of 0.128, move the decimal point to the right three places; the resulting value, 128, is between 100 and 1000, therefore the cursor is set to 128 on the **right** K scale, and the reading on the D scale is found, 5.04. Since in the original number the decimal point was moved three places to the right, in the number from the D scale the decimal must be moved one place to the left, giving 0.504, which is the cube root of 0.128.

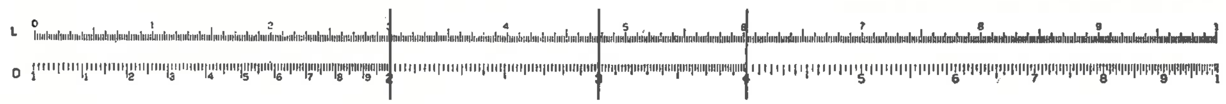


THE L SCALE:

This is a scale exactly 250 millimeters long, graduated into 500 equal parts. By reading a number on this scale, we can find the "mantissa" (decimal portion) of the logarithm of any number on the D scale. Note that the numbers on the L scale are preceded by a decimal point, reading therefore from 0 to 1.0. The D and L scales should be matched for direct reading. The "characteristic" or whole-number portion of the logarithm is equal to one less than the number of digits to the left of the decimal point in the original number. For example, the log of 26.3 is 1.420 (the mantissa .420 from the L scale, the characteristic 1 because in the number 26.3 there are two digits preceding the decimal point); but the log of 263 is 2.420 (characacteristic 2 because there are three digits preceding the decimal point).

EXAMPLES: log 4 (D scale) is 0.6021 (L scale) (SEE BELOW)
log 2 (D scale) is 0.301 (L scale)
log 30 (D scale) is 1.477 (L scale)
log 5000 (D scale) is 3.699 (L scale)

In each of these, only the mantissa (decimal portion) is from the L scale.



THE S SCALE:

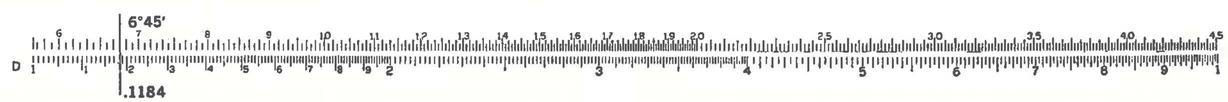
This scale is for direct reading of the sines of angles. The scale is divided in degrees, minutes and seconds. (60' EQUAL 1°). The scale is used in conjunction with the A scale to read the answer directly. It must be noted that sines above 60° must be carefully judged, since the scale decreases rapidly.

To determine the Sine of an angle, follow this example:

Sin 15°48'—Set hairline over 15°48' on S scale—read .272 on A. (SEE BELOW)
Sin 59°—Set hairline over 59 on S scale—read .857 on A.
Sin 1°20'—Set hairline over 1°20' on S scale—read .0233 on A.
(Remember that the **left** scale on A is .1 of **right** scale, therefore an additional decimal is required.)
Sin 4°20' is .0756.

THE T SCALE:

The tangent scale starts at 5.7° and increases up to 45° on the **right**. To find the tangent of 6°45' or 6.75° place the hairline over 6°45' and read .1184 on the D scale. (SEE BELOW)



SPECIAL π MARKINGS: Pi (π) 3.1416 and ($\frac{\pi}{4}$) .7854.

For calculations involving π or $\frac{\pi}{4}$, the A & B scales are clearly marked at 3.1416 and .7854 for accurate readings.

In quick review, here is a problem in each of the scales: check your answers with these, and if any question, refer to the proper instruction:
24.5 X 13.7 (C & D scales) **Answer:** 335.65 (last 2 numbers approximated)
924 ÷ 16 (C & D scales) **Answer:** 57.75
42 X 42 (42^2) (D & A scales) **Answer:** 1764 (end 2 of each number multiplied together gives last 4)
Square root of 2450. **Answer:** 49.5 (A scale—right half—answer on D)
9 X 9 X 9 (9^3) D and K scale. **Answer:** 729 (approx. 730 on scale)
Cube root of 125 (D & K scales—right third of K because of 3 digits) **Answer** is 5 on D scale.
Log 6—(REVERSE SLIDE—Use L and D scale)—.778
Sin 13.4° or 13°24'—S and A scale **Answer:** .232
Tangent 6.75° or 6°45'—T and D scale—.1184

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a Cut here

c Cut here

CHRIS HAMANN AND NANCY SHAW

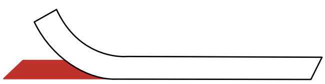
ASSEMBLY INSTRUCTIONS

1 Cut out the entire white panel (*a*). Cut along line between parts A and B (*b*), then remove excess (*c*).

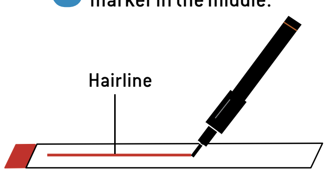
2 Fold part A along the dotted lines.

3 Slip part B into the folded part A.

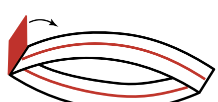
4 To make the cursor (the sliding window that is inscribed with a hairline), use the guides to the left to measure two pieces of transparent tape. Make one section the length of the black line and the other the length of the red line. Place the adhesive sides together.



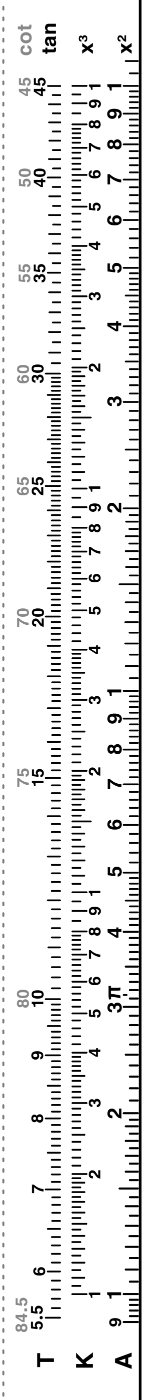
5 Draw a line with a fine marker in the middle.



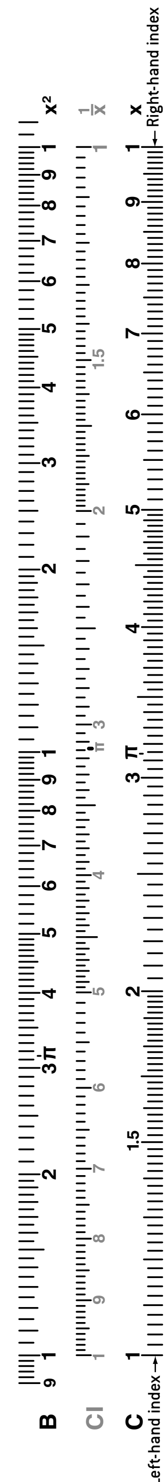
6 Wrap the folded tape around the slide rule for sizing. Use the adhesive end to complete the cursor. Slide cursor onto the rule.



Part **A**



b Cut here



(Slider)

Part **B**

MURPHY'S LAW OF EXPERIMENTAL PHYSICS

In an experiment, if anything can go wrong, it will.

COROLLARIES TO MURPHY'S LAW

1. When something goes wrong, it will do so at the worst possible time.
2. Left to themselves, things always go from bad to worse.
3. If everything seems to be going well, you have obviously overlooked something.