INTRODUCTION A TIME AND MEASUREMENT

In an attempt to understand natural phenomena, scientists must determine by experiment the magnitude of fundamental quantities. The process of measurement is thus basic to all sciences, and to physics in particular. We begin our study of physics by considering time, one of the most fundamental physical quantities, and some of the ways in which intervals of time can be measured.

We keep track of time as a routine part of daily life without giving much thought to such questions as:

1. How old are really old objects such as the sun, or conversely, how brief are events such as the blinking of the eye.

2. How might we determine the age of the sun or the length of an eye-blink

This chapter will not answer all your questions about the concept of time and its measurement, but it will raise some issues which should broaden your outlook considerably. It will also serve as a first indicator of the manner in which physicists go about analyzing the workings of the world about them.

We will also see in a bit more detail how scientists express the accuracy to which their measurements have been made and also the kinds of units (meters, feet, seconds, etc) in which the results of measurements are expressed. This is important background material for your later study of fundamental physical concepts.

PERFORMANCE OBJECTIVES

Upon the completion of this chapter your should:

1. be able to measure and interpret long and short time intervals using photographic and stroboscopic techniques.

2. be able to express any number in scientific notation.

3. be able to understand and use proper methods of:

    a. adding and subtracting exponents, and
    b. multiply and divide large and small numbers using scientific notation.

4. be able to make order of magnitude approximations.

5. be able to express measurements with the appropriate number of scientific digits.

6. be able to express calculations from experimental data to the appropriate number of significant digits.

7. be able to express measurement in appropriate metric units.

Check ① all Page #'s

INTRODUCTION A STUDY GUIDE -1-

1. Read the enclosed article titled: "Four Pieces of Advice to Young People" taken from Project Physics Reader Number One.

As the year progresses, you will think that your instructor is interested only in physics as he keeps after you to do more and more. However, the opinions and advice given by the author, Warren Weaver, are ones that your instructor fully agrees with.

2. Read Section 2-1: The Starting Point: The Senses page 7
   2-2: The Need to Extend the Senses page 8
   2-3: Time and Its Sweep page 9

3. Read Section 2-4: Short Time Intervals; Multiple Flash page 10
   2-5: Repetitive Motion: the Stroboscope page 12

4. Why use high speed photography, time lapse photography, and stroboscopes in the study of physics?

5. Problem: page 19: #19

6. Included in this packet are Study Notes "Using Hand-Operated Stroboscope". Familiarize yourself with its operation.

   a. Why is the strobe used for repetitive motions only?

7. Determine the frequency of the motor stroboscope using various number of openings of the hand strobe. (Since taking data involves judgments, it is well to take several trials and average the results.) Your instructor wishes to see all data taken as well as calculations made. (All data is to be reported in table form.) MOTOR STROBE HAND STROBE

8. Determine the frequency of the fan with the hand strobe. After reporting your findings to your instructor, ask for information as to the use of he electronic strobe. FAN

   a. Next, determine the frequency of the fan using the electronic strobe. Compare this frequency with that gathered with the hand strobe.

   b. How do the results compare? Or how well did you do? (To answer these questions correctly, one must find the per cent error between the two.

   c. You need only to present to the instructor all data gathered.

9. Still having trouble with the strobe? A work sheet titled "How Can We Measure Short Intervals of Time" is enclosed to help you. Complete only as much as you feel you need to.

10. Experiment: "Measuring Short Time Intervals" PAPER TIMER

   a. Determine the frequency of a paper timer using either the hand or electronic strobe: PAPER

   b. Determine the frequency of the paper timer using paper tape. CARBON DISC

   c. Optional...Determine the frequency of a neon or argon lamp.

b. Determine the frequency of the paper timer using paper tape.

c. Optional...Determine the frequency of a neon or argon lamp.

d. Report all information in proper written form to your instructor.

11. View Film Loop "Tacoma Narrows Bridge". (Film Loop Notes enclosed.)

12. Problems: Page 19: #15 #16 #17 #20 #21 #22

13. (9.4 x E9) - (86.3 x E-4) = ____________________

Any doubts as to when and how to use exponents and scientific notation? If so, T.T. & S. pages 13-16 has much help. Do not skip over this lightly. A few minutes spent wisely now will save hours later on.

14. Read Section 2-6: Comparing Times; Counting Units page 14
2-7: Times Large and Small-Orders of Magnitude page 15
2-8: The Direction of Time page 18

15. What do we mean when we use the term "order of magnitude"?

16. What is the dividing line between one order of magnitude and the next, say for:

a. 10^1 and 10^2? b. 10^3 and 10^4? c. 10^-5 and 10^-4

d. Develop a mathematical proof to show the value of 10^1.5. For 10^2.5.

e. Discuss your proof with your instructor.

17. Estimate to the nearest order of magnitude the number of ping-pong balls needed to fill room 146. Present your answer with all work to your instructor.

18. A recent advertisement showed a station wagon full of ping-pong balls. At 10 cents each, approximate the cost of the ping-pong balls to fill the wagon. Do you think the back of the wagon was filled with ping-pong balls?

19. Problems: page 19: #10 #12 #23

20. Read Section 3-3: Small Distances page 30
3-6: On the Limitations of Measuring page 34
3-7: Significant Figures page 35

21. Measure the three objects indicated below using the meter stick, vernier caliper and micrometer. Place your measurements in the space provided.

Note...All instruments do not measure each item.

Make sure each measurement is recorded using appropriate number of significant figures.

All measurements should be in the same units.

Study Notes on the use of the vernier caliper and the micrometer are enclosed in this packet.

Object	Meter Stick	Vernier Caliper	Micrometer
Lab Table (length)			
Aluminum Cube (side)			
Wire (diameter)			

Have all answers evaluated by your instructor.

22. Which has thicker hair. A blonde? A brunette? or a red head?

23. Problems: page 39: #25 #27 #30 1 DISCUSS

24. We are in the process of setting the stage of the physical world. The stage, the framework within which all the events that we study take place is spanned by time and by space. It is made lifelike by their combination - motion. Since time is one-dimensional and space is three-dimensional, we must be living in a four-dimensional world. Formulate your understanding of the 4-dimensional world and explain it to your instructor.

25. A written exercise is enclosed. Complete the problems, have them evaluated by your instructor and then correct any mistakes.

27. On the day designated you will take the chapter test. At the beginning of this class period, you will turn in your packet with all work done. All material is to be in an organized manner. Do not include any sheets that have no work on them. Exceptions are intro sheet, and the study guide sheets. You will be given packet Introduction - B material at this time.

Thought for the chapter:

I wouldn't touch that with a 3.049 meter pole.

THE WIZARD OF ID By Parker and Hart

Answers Introduction A

5. (19) 1, 1/2, 1/3, 1/4, ...

9. (1) repetitive, period, frequency, 1/T
   (2) 30, 1/30
   (3) position, each, frequency, yes, no, fastest
   (4) 2.8, 2.8, 5.6, 11.2
   (5) 3.2, 1/3.2
   (6) more, forward, fast
   (8) 43.2/sec or 43.2 Hertz
   (Summary) repetitive, equal, multiple, slow, fast

12. (17) 80
    (20) 8, 16, 24, 32, 40, ... 32, 64, 96, 128, ...
    (21) (a) 26/sec (b) 26/sec (c) about 2%

16. (a) $10^{1.5} = 31.6$ (b) $10^{3.5} = 3160$ (c) $10^{-4.5} = 3.16 \times 10^{-5}$

19. (10) 10,000 flashes/sec
    (12) 5 min
    (13) (a) 34 m (b) 1.2×10^{-6} sec

22. Contact WILLING donors and see.

23. (25) (a) 14.1 m^2 (b) 24.5 cm (c) 0.3 cm
    (27) (a) 64 cm^3 (b) 63 cm^3 (in (a) 64 +or− 0.5 cm^3, in (b) + or − 1 cm^3)
    (c) 1/64 = 1.6% of total volume

    (30) (a) 9.1 hr (b) 5.5 hr (c) 3.5 hr more

DESCRIPTION. The stroboscope (or strobe) is a device for measuring short time intervals. Objects having uniform oscillating, reciprocating or rotary motion can be studied and the motion made to appear "stopped". A strobe is usually a large disk with one or more slits spaced at equal intervals around the circumference axially mounted for rotation.

The strobe consists of 2 concentric disks mounted on an axial sleeve bearing which fits a shaft mounted in a wooden handle. One disk may be adjusted with respect to the other to provide 1,2,3,4,6 or 12 uniformly spaced radial slits near the periphery.

THEORY. Study of motion can be made without timing the motion, but frequently it is desired to measure the period of time required for a repeating event to occur. The strobe is used to measure events that occur repetitively over short intervals of time. The strobe is rotated at a speed such that a slit on the strobe comes into viewing position each time that one complete repeating event takes place. Sighting at a given position on the strobe, a view is obtained through the strobe every time a slit moves into that position. If a repeating event takes place during the same interval of time, that event will appear to be stopped. Consequently, by adjusting the speed of rotation of the strobe to make the motion appear stopped, the periods are automatically set equal: and the speed of the strobe --a controllable factor--is thus used to measure an unknown short time interval.

OPERATION. The strobe may be used to "stop" the waves in a ripple tank, the blades of an electric fan, the vibrator of a tape timer, the vibration of a wave generator and other types of vibratory or rotary motion, provided the frequency is not too high.

Adjust the position of one disk with respect to the other until the finger holes are aligned. By slight further adjustment, open the desired number of slits--1,2,3,4,6 or 12. The strobe may be operated by holding it in either hand. Use the forefinger of the other hand to rotate the disks. See Figures 1 and 2. Sight through the slit while rotating the disks and adjust the speed until the motion of the object appears stopped.

Satisfactory use of the strobe requires practice and for this purpose, one slit is usually the best. Practice "strobing" several rotating objects to get the "feel of it" and to develop a skill in its smooth operation. Where the rotating object is uniform or composed of symmetrical blades or teeth, it is necessary to place a prominent identifying mark on the object. At higher frequencies, it is desirable to use either 6 or 12 slits.

- over -

INTERPRETING RESULTS. The motion of an object may appear stopped or a stationary image obtained when the speed of rotation of the strobe is a SUBMULTIPLE of the speed of the object. The rotating object may have a frequency two or more times that of the strobe. Therefore, when motion is stopped and a single stationary image is obtained, the speed of the strobe must be increased to see if the motion can be stopped again. The HIGHEST speed at which a single stationary image is formed is the correct speed.

To determine the frequency of the object, multiply the revolutions of the strobe per second by the number of open slits. The following will clarify.

Maintain the "stopped" motion at the highest speed for say 10 seconds. Count the number of strobe revolutions during that period.

When one divides the number of revolutions by the time interval one gets the frequency that the hand strobe was turning.

Next one multiples the frequency of the hand strobe by the number of open slits which represents the number of views per revolution. This gives the frequency of the object.

In summary:

$$\frac{\text{Number of Revolutions}}{\text{Amount of Time}} \times \frac{\text{Slits or Views}}{\text{revolution}} = \text{frequency of object}$$

FOUR PIECES OF ADVICE TO YOUNG PEOPLE

Warren Weaver 1966

One of the great prerogatives of age is the right to give advice to the young. Of course, the other side of the coin is that one of the prerogatives of youth is to disregard this advice. But . . . I am going to give you four pieces of advice, and you may do with all four of them precisely what you see fit.

The first one is this: I urge each one of you not to decide prematurely what field of science, what specialty of science you are going to make your own. Science moves very rapidly. Five years from now or ten years from now there will be opportunities in science which are almost not discernible at the present time. And, I think there are also, of course, fads in science. Science goes all out at any one moment for work in one certain direction and the other fields are thought of as being rather old-fashioned. But, don't let that fool you. Sometimes some of these very old problems turn out to be extremely significant.

May I just remind you that there is no physical entity that the mind of man has thought about longer than the phenomenon of light. One would ordinarily say that it would be simply impossible at the present day for someone to sit down and get a brand new idea about light, because think of the thousands of scientists that have worked on that subject. And yet, you see this is what two scientists did only just a few years ago when the laser was invented. They got a brand new idea about light and it has turned out to be a phenomenally important one.

So, I urge you not to make üp your minds too narrowly, to soon. Of course that means that what you ought to do is to be certain that you get a very solid basic foundation in science so that you can then adjust yourselves to the opportunities of the future when they arise. What is that basic foundation? Well, of course, you don't expect me to say much more than mathematics, do you? Because I was originally trained as a mathematician and mathematics is certainly at the bottom of all this. But I also mean the fundamentals of physics and the fundamentals of chemistry. These two, incidentally, are almost indistinguishable nowadays from the fundamentals of biology.

The second piece of advice that I will just mention to you because maybe some of you are thinking too exclusively in terms of a career in research. In my judgement there is no life that is possible to be lived on this planet that is more pleasant and more rewarding than the combined activity of teaching and research.

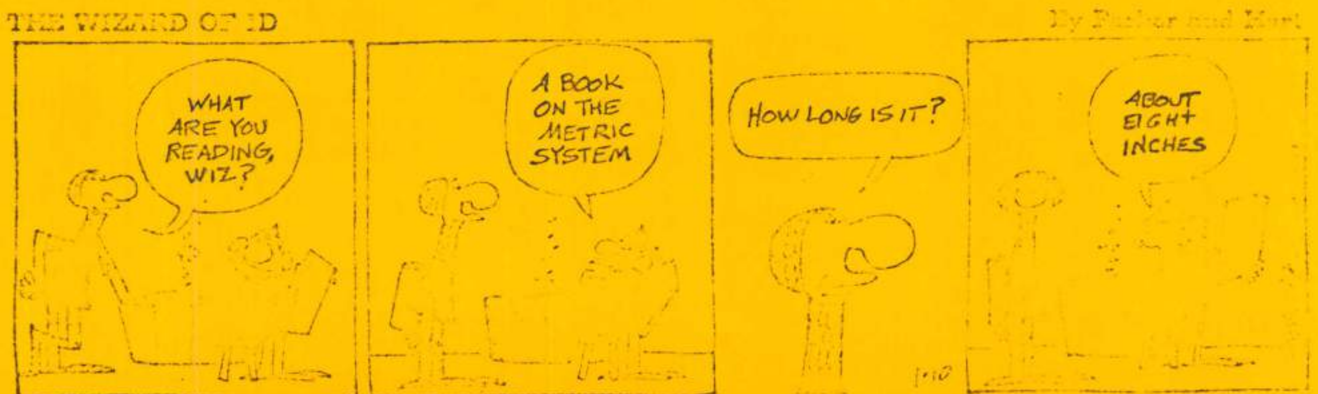
I hope very much that many of you look forward to becoming teachers. It is a wonderful life. I don't know of any better one myself, any more pleasant one, or any more rewarding one. And the almost incredible fact is that they even pay you for it. And, now a days, they don't pay you too badly. Of course, when I started, they did. But, nowadays, the pay is pretty good.

My third piece of advice - may I urge every single one of you to prepare yourself not only to be a scientist, but to be a scientist-citizen. You have to accept the responsibilities of citizenship in a free democracy. And those are great responsibilities and because of the roll which science plays in our modern world, we need more and more people who understand science but who are also sensitive to and aware of the responsibilities of citizenship.

And the final piece of advice is - and maybe this will surprise you: Do not overestimate science, do not think that science is all that there is, do not concentrate so completely on science that you end up by living a warped sort of life. Science is not all that there is, and science is not capable of solving all of life's problems. There are also many more important problems that science cannot solve.

And so I hope very much there's nobody in this room who is going to spend the next seven days without reading some poetry. I hope that there's nobody in this room that's going to spend the next seven days without listening to some music, some good music, some modern music, some music. I hope very much that there's nobody here who is not interested in the creative arts, interested in drama, interested in the dance. I hope that you interest yourselves seriously in religion, because if you do not open your minds and open your activities to this range of things, you are going to lead too narrow a life.

Taken from PROJECT PHYSICS READER, volume 1, Preliminary Version 1967-1968. The reader is one of six developed to supplement the HARVARD PROJECT PHYSICS program.



W-4. TACOMA NARROWS BRIDGE COLLAPSE

The failure of the Tacoma Narrows bridge in 1940 is described in several publications. The following account is drawn from the official investigation of the failure: Texas A and M College Eng. Exp. Sta. Bull. No. 78, 1944; University of Washington Eng. Exp. Sta. Bull. No. 116, parts I - IV, 1950-54; and from Prof. F. B. Farquharson, Director of the Engineering Experiment Station of the University of Washington (private communication).

The length of the main span (between towers) was 2800 ft. and the width, between cables, center-to-center, was 39 ft. Even during construction, the bridge sometimes developed vertical wave motions of extraordinary amplitude. Corrective measures were applied: hydraulic buffers at each end of the main span (which, however, became inoperative soon after installation) and diagonal stays ("ties") between the stiffening girders and cables at mid-span. After opening to traffic, hold-downs were installed tying the girders in the side spans to massive concrete blocks on land. These reduced the waves in the side spans but not in the main span.

Length (main span)	2800 ft
Width (c.to c. of cables)	39 ft
Start of construction	Nov.23,1938
Opened for traffic	July 1,1940
Failure of bridge	Nov. 7,1940

In the four months of active life of the bridge before failure, only transverse vibrations were observed prior to Nov. 7, 1940. Many vertical modes of vibration were observed. The main towers were nodes, of course, and there were from 0 to 8 nodes between the two main towers. Maximum double amplitude (crest to trough) was about 5 ft in a mode with 2 nodes between the towers; the frequency of vibration at that time was 12 vib/min. When the bridge was vibrating in this mode, some motorists were uneasy at seeing a car ahead disappear from view, only to reappear several times while making one crossing. Nevertheless, revenue from the bridge traffic exceeded the anticipated amount.

The most frequently observed motion was one with no nodes between the towers (frequency 8 vib/min); this might well be called the fundamental mode. The maximum recorded double amplitude for this mode was 2 ft.

Measurements made before failure indicated a correlation between wind velocity and mode of vibration; higher velocities favored modes with higher frequency. Similar results were obtained in the years 1940-45 by mathematical analysis, as well as from scale-model tests. This correlation may be explained by the fact that turbulent velocity fluctuations of winds can be considered as composed of a superposition of many periodic fluctuations, and the fluctuations of higher frequency are preponderant at higher wind velocities. More generally, wind-excited vibrations result from vortex shedding, and the frequency of vortex shedding is proportional to wind velocity.

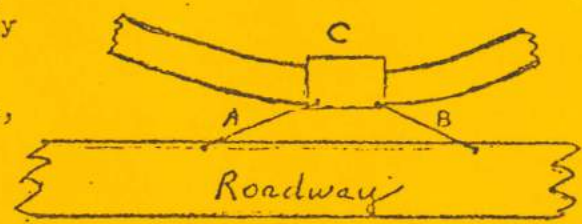
On the other hand, both observation and theory agree that there was no significant correlation between wind velocity and <u>amplitude</u> of vibration. Motions of several feet were sometimes observed with wind velocities as low as 3 or 4 mi/hr; at other times the bridge remained motionless in winds as high as 35 mi/hr.

The K-bracing under the deck appears to have weakened during a midnight storm several days prior to Nov. 7, 1940. During the storm the bridge was observed by only one person, who reported its behavior to be different from any previous behavior. This is interpreted to mean that the bridge had a larger amplitude of transverse vibration than had previously been observed.

Early on the morning of Nov. 7, the bridge developed motions of a type previously observed, but with larger-than-usual amplitude. The wind velocity was 40 to 45 mi/hr, larger than any previously encountered by the bridge. Traffic was shut down. By 9:30 a.m. the span was vibrating in 8 or 9 segments with frequency 36 vib/min and double amplitude about 3 ft. While measurements were under way, at about 10:00 a.m., the main span abruptly began to vibrate torsionally in 2 segments with frequency 14 vib/min. Later the torsional frequency changed to 12 vib/min. The amplitude of torsional vibration quickly built up to about 35° each direction from horizontal. The change to torsional mode "appeared to take place without any intermediate stages and with such extreme violence that the span appeared about to roll completely over. The most startling condition arose out of the fact that from a line of sight very nearly parallel to the bridge the upper side of the roadway was visible while what appeared to be a nearly perpendicular view of the bottom of the roadway was offered on the Tacoma side." The main span broke up shortly after 11:00 a.m.

During most of the catastrophic torsional vibration there was a transverse nodal line at mid-span, and a longitudinal nodal line down the center of the roadway (the yellow center stripe!) Note that Prof. Farquharson sensibly strides(?) down the nodal line as he leaves the bridge after making observations on the condition of the stays and, incidentally, trying to save a small dog in a stalled car. Other torsional modes appeared briefly from time to time during the hour before the bridge gave way under the stresses which so greatly exceeded the design values.

The crucial event at 10 a.m. which directly led to the castastrophic torsional vibration was apparently the loosening of the north cable in its collar by which the roadway was suspended. At 9:30 a.m., photos made at the center showed that the diagonal stays A and B were alternately slack and, therefore, partially ineffective. It is probable that the (unsuspected) failure of the K-bracing several days earlier had thrown an added stress on these stays. The center of the cable was moving back and forth relative to the center of the suspended span. However, at that time there was no slipping of the collar C itself relative to the cable. Evidently at 10 a.m. this collar started to slip, with a double amplitude about 42 inches. This allowed the structure to twist as one of the main cables became alternately longer and shorter on each side of center. The wind velocity was close enough to the critical velocity for the torsional mode observed, and the vibration built up by resonance and was maintained until collapse inevitably took place.



Following failure of the center span, the cables, originally parabolic, assumed a free-hanging catenary shape. Release of tension allowed the two towers to sag shoreward some 25 ft (measured at the top). The cables remained intact except for a 42-inch section in the center of north cable over which the collar had scraped; 500 of the 6308 strands of No. 6 galvanized cold-drawn steel wire were ruptured by the sliding collar.

The Tacoma Narrows bridge was unusually long and narrow compared with other suspension bridges previously built. The original design called for stiffening the suspended structure with trusses. However, funds were not available and a cheaper stiffening was adopted using 8-foot tall girders running the length of the bridge on each side. These girders are shown in the film sequence during construction of the bridge. Unfortunately, the stiffening was inadequate. The theory of aerodynamic stability of suspension bridges had not yet been fully worked out, and wind-tunnel facilities were not readily available due to the pre-war military effort. (Incidentally, a tunnel moving great quantities of air at rather slow velocities, carefully controlled, would have been needed). As a result, a scale model was constructed (standard practice) and applied to the evaluation of the bridge under <u>static</u> conditions (including wind force.) However, need for a three-dimensional dynamic model was recognized and the model (first of its kind) was under development and partial use at the time of collapse. The problem of stability involves aerodynamic lift and is sensitive to the profile of the deck. Plans were under way to burn a series of large holes through the plate girders, but the gale got there first. Later wind-tunnel tests with a 50:1 model of the original bridge showed that this emergency measure would have worked.

The bridge was rebuilt using the original anchorages and tower foundations. The main cable spacing was increased to 60 ft (four lanes of traffic) and the towers increased in height by 59 ft to 507 ft. Studies at the University of Washington Engineering Experiment Station using a dynamic 50:1 model, coupled with extensive mathematical analysis, resulted in a design for the new bridge which used deep stiffening trusses instead of the 8-ft girders of the original bridge. The new bridge was opened to traffic in the winter of 1950-51, and during this winter it was exposed to some of the highest winds of recent years. The bridge is entirely successful.

This film was made at the Ohio State University, and was produced by Franklin Miller, Jr., Dept. of Physics, Kenyon College, Gambier, Ohio, under a grant from the National Science Foundation.

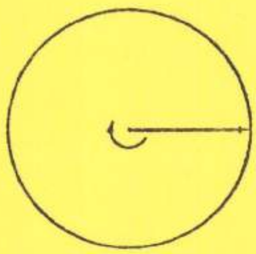
HOW CAN WE MEASURE SHORT INTERVALS OF TIME?

Time is measured by a regularly repeating motion such as the swinging of a pendulum or the turning of a wheel.

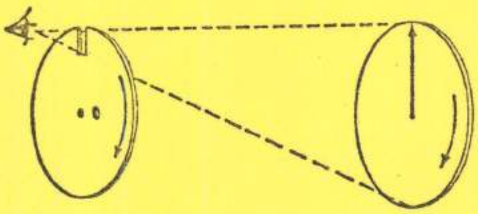
1. Motion which repeats itself at regular intervals is called......................motion. The time required for one complete motion is called the ....of the motion. We can symbolize it by the letter T. The number of complete motions in unit time is called the..........................of the motion. We can symbolize it by the letter f. Write below an equation showing the relationship between T and f.

$$f =$$

2. The arrow shown at the right is rotating clockwise at 1800 rev/min. It has a frequency of ....rev/sec and a period of............sec.



3. A *stroboscope* (sometimes shortened to *strobe*) is a device that enables you to see an object briefly at regular intervals. Your hand stroboscope is a disk that has one or more windows in it and is fastened to a handle in such a



way that the disk can be rotated at various speeds. When you rotate the stroboscope and look through the windows at the rotating arrow described in Question 2, you will see the glimpses of the arrow at regular intervals. The arrow will appear to be standing still if it is always in the same ....when you look at it. This will be true if a window passes in front of your eye ....time that the arrow makes one complete revolution. Call the number of views per second the *viewing rate*. Then we can say that the arrow will appear to stand still when the viewing rate is equal to the.........................of the arrow. One condition for a stationary appearance of the arrow is:

viewing rate $= f$

Will the arrow appear to be standing still if the viewing rate equals $\frac{1}{2}f$?............Explain............

....

....

Will the arrow appear to be standing still if the viewing rate equals $2f$?............Explain............

....

....

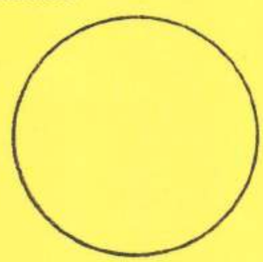
To be sure that the viewing rate is equal to f and not some fraction of f, the strobe should be turned at the (*fastest, slowest*)......................rate that makes the object appear stationary.

4. A stroboscope with one window makes 28 turns in 10 sec. It makes............turn(s) in 1 sec. The viewing rate is............view(s) per second. If the stroboscope had two windows and made 28 turns in 10 sec, the viewing rate would be............ view(s) per second. If the stroboscope had four windows, the viewing rate would be..........view(s) per second.

5. If the viewing rate is 3.2 views/sec, an object which makes............revolution(s) per second will appear stationary. The period of time between views is............second(s).

6. An arrow rotates at 12 rev/sec. It is viewed 11 times/sec. The arrow will make a little (*more, less*)................than one complete turn each time you look at it. It will appear to be turning (*forward, backward*)...................... If the arrow appears to be turning slowly backward, the viewing rate is too (*fast, slow*)..................

7. If you looked at the arrow twice on each turn, you would see it .... Draw a diagram showing how it would look.



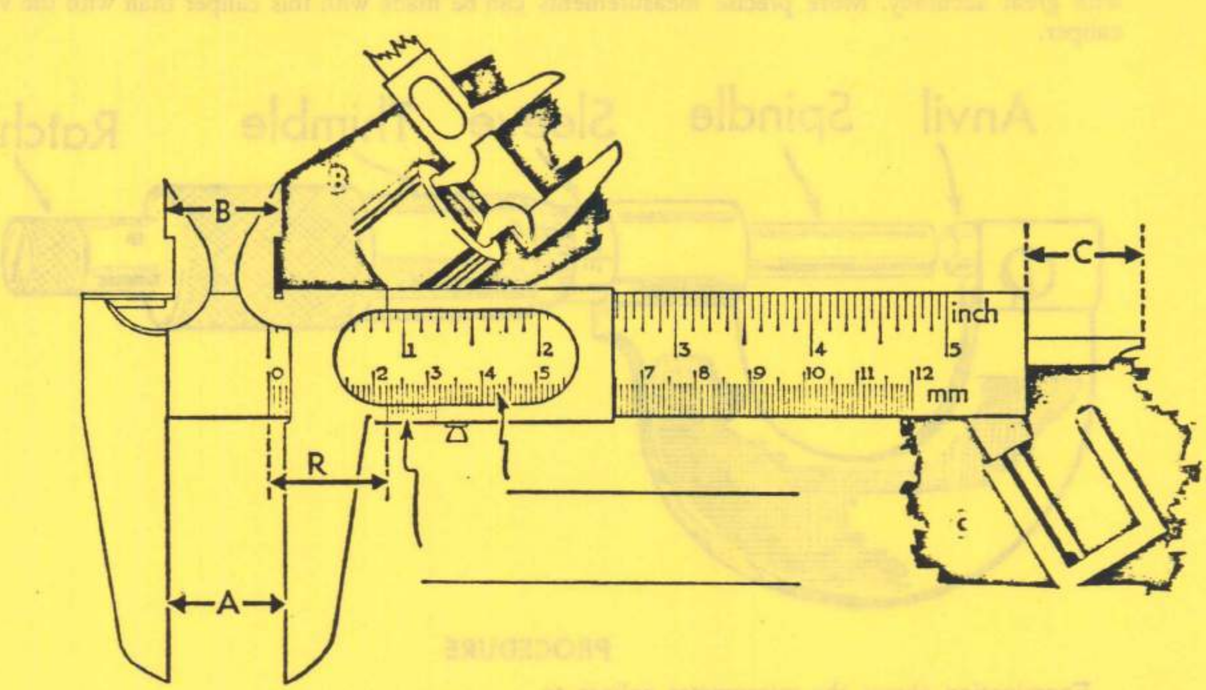
8. A strobe has 12 windows and makes 36 turns in 10 sec. What frequency of rotation will it "stop"?

Ans..................................

THE VERNIER CALIPER

How can tenths of a millimeter be measured accurately?

In the preceding experiment, the decimal part of the smallest division of the scale was estimated. Through the use of a vernier scale, this decimal part may be read exactly. The vernier is a sliding scale which may be attached to any fixed scale.



PROCEDURE

Examine the vernier caliper and locate the two scales: the fixed scale and the vernier sliding scale. Indicate them on the diagram above. If the instrument reads in metric units, the fixed scale is divided into centimeters and millimeters. Close the jaws of the caliper.

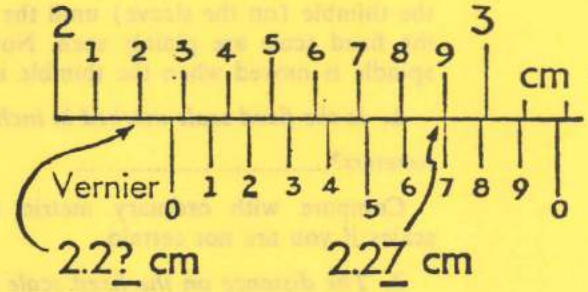
1. *Does the zero mark of the vernier (sliding) scale coincide with zero on the fixed scale?*........

2. *How many divisions are there on the vernier scale?*...............

3. *Over how many millimeters on the fixed scale does the vernier scale extend?* (Examine carefully.)...............

If the jaws are opened 0.1 mm, the first division mark of the vernier will be exactly opposite the 1-mm mark of the fixed scale; if opened 0.3 mm, the third vernier line will coincide with the 3-mm mark of the fixed scale, etc. There will always be one division mark of the vernier which will lie in exact line with a division of the fixed scale.

The following diagram shows a setting for the two scales. The zero mark of the vernier gives



the reading to centimeters and millimeters (tenths of a centimeter). The reading is 2.2 cm. To determine the tenths of a millimeter (hundredths of a centimeter), locate the only division of the vernier scale which is exactly in line with a division of the fixed scale. In the diagram, this is the seventh mark. The entire reading of the scales is therefore 2.27 cm.

4. *Refer again to the diagram*

What is the relationship between the distances marked A, B, and C and the distance R?........

....

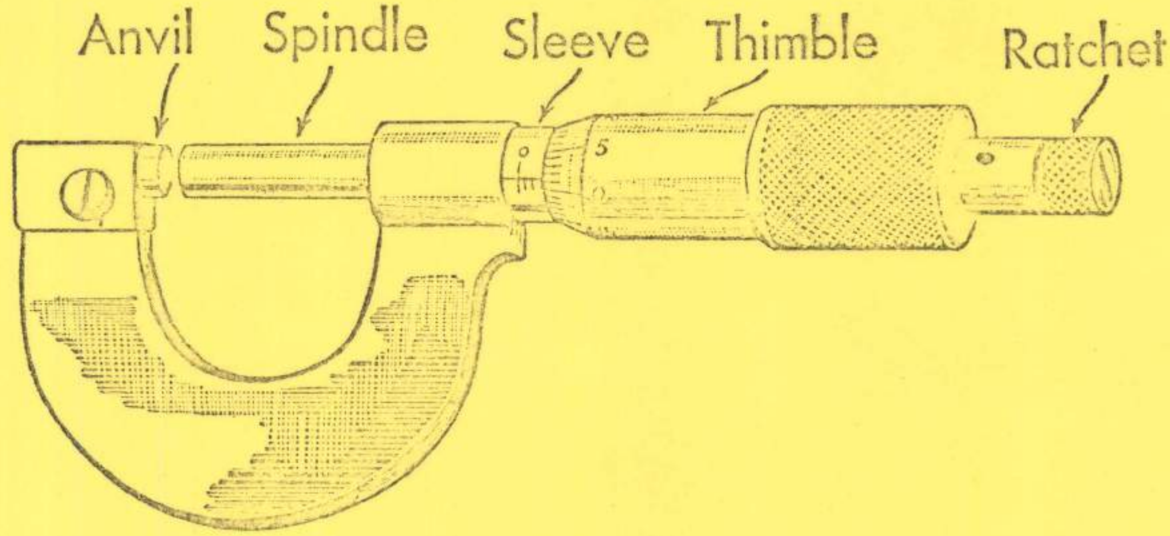
....

Practice reading the caliper by opening it to different positions.

THE MICROMETER CALIPER

How is the micrometer caliper used?

The micrometer caliper is commonly used in shops and factories for measuring machine parts with great accuracy. More precise measurements can be made with this caliper than with the vernier caliper.



PROCEDURE

Examination shows the micrometer caliper to consist of two scales, one fixed and one revolving (on the beveled edge of the thimble). Turn the thimble (on the sleeve) until the divisions on the fixed scale are plainly seen. Notice that the spindle is moved when the thimble is turned.

1. *Is the fixed scale marked in inches or in centimeters?.................................*

Compare with ordinary metric and English scales if you are not certain.

2. *The distance on the fixed scale from 0 to 1, 1 to 2, etc., is what measurement?......................*

Set the revolving scale so that 0 on it is exactly on the line at 1 on the fixed scale. Turn the thimble until it has made exactly one revolution.

3. *Does the revolving scale read 25, 50, or 100?*

4. *Has one revolution of the thimble opened the spindle to the next vertical division mark on the fixed scale?................*

If not, turn the thimble until the spindle has been moved one space on the fixed scale.

5. *How many revolutions did the thimble make?................*

6. *Each division on the revolving scale, therefore, is what fraction of the smallest division on the fixed scale?................*

Turn the thimble until the spindle touches the other side of the caliper (the anvil). If the caliper has a ratchet, *always* close the spindle by turning the ratchet.

Does the revolving scale read zero when the spindle is closed? If not, record the number of divisions away from zero as the zero correction.

7. *If the revolving scale goes past the zero of the fixed scale, will the correction have to be added or subtracted to get the true reading?*

If the caliper requires more than one revolution of the thimble for one fixed scale division, you must carefully observe how many revolutions it has made at each setting.

1. $v = 90 \frac{KM}{hr}$ $d = vt = 90 \frac{KM}{hr} \times 2.3\,min \times \frac{1\,hr}{60\,min} = $ (3.45 [illegible])

$d =$

$t = 2.3$ MIN

2. $1000\,yrs \times \frac{365\,da}{1\,yr} \times \frac{24\,hr}{1\,da} = $ (8.76×10^6 hr)

3. (4.5×10^9 YRS)

4. $v = 3 \times 10^8 \frac{M}{sec}$ $t = \frac{d}{v} = \frac{0.2\,cM\ sec}{3 \times 10^8\,M} \frac{1\,M}{10^2\,cm}$ (6.67×10^{-12} sec)

$t = ?$

$d = 0.2$ CM

5. $\frac{TIME}{\#\ PICTURES} = \frac{100\,da\ sec}{10\,MIN \times 24\ frames} \times \frac{1\,MIN}{60\,sec} \times \frac{24\,hr}{1\,da} \times \frac{60\,MIN}{1\,hr} = $ (10 MIN)

6. $v = 3 \times 10^8 \frac{M}{sec}$ $d = vt = 3 \times 10^8 \frac{M}{sec} \times 2.3\,yr \times \frac{365\,da}{1\,yr} \times \frac{24\,hr}{1\,da} \times \frac{3600\,sec}{1\,[illegible]}$

$d = ?$

$t = 2.3$ yrs

(2.18×10^{16} M)

7. $10^{11} \frac{SUNS}{galaxy} \times 10^{11}\,galaxy = $ (10^{22})

8. $1\,bb/ft^3$ $10^3\,ft \times 10^3\,ft \times 10^3\,ft \times \frac{1\,bb}{ft^3} = $ (10^9 b.b.)

9. $d = 9.3 \times 10^7$ Mi $9.3 \times 10^7\,mi \times \frac{1600\,M}{mi} = $ (1.49×10^{11} M)

$1600\,M = 1\,mi$

Introduction A WRITTEN EXERCISE

1. An automobile travels 90 kilometers per hour. How far does this automobile travel in 2.3 minutes?

2. How many hours are there in 1000 years?

3. The age of the earth has been estimated to be 4,500,000,000 years. Express the age of the earth using proper scientific notation.

4. Light travels 3×10^8 m/sec. How long does it take light to travel through a window 0.2 cm thick? Express your answer in scientific notation.

5. If the total growth of a plant which requires 100 days is to be shown on a ten minute film (at 24 frames per second), what time interval should elapse between successive pictures?

6. Light travels 3×10^8 m/sec. How far does light travel in 2.3 years? Express your answer in scientific notation.

7. Our sun is one of a hundred billion distant suns that make up our galaxy, the Milky Way. There are nearly a hundred billion galaxies visible through the Mt. Palomar telescope. How many stars are there in the part of the universe we can observe if we assume that our galaxy has an average number of stars?

8. Estimate to the nearest order of magnitude the number of basketballs the coliseum (where the Cav's play) will hold?

9. The radius of the earth's orbit is 93,000,000 miles. There are approximately 1600 meters per mile. What is the radius of the earth's orbit in meters?

10. Remember, all work must be available for your instructor's inspection. Is it neat and organized? Have you used units throughout? If not, you might as well do so as you will not be allowed to go on.

Introduction A WRITTEN EXERCISE

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PHYSICS WORK SHEET: SCIENTIFIC NOTATION WS-1

I. EXPRESS IN SCIENTIFIC NOTATION NAME ____________________

1. 26000 ____________

2. .0037 ____________

3. .0005 ____________

4. 93000 ____________

5. .000007 ____________

6. 186,000,000 ____________

II. COMPUTE; EXPRESS ANSWER IN SCIENTIFIC NOTATION

7. $(3.2 \times 10^3) \times (1.6 \times 10^2) =$ ____________

8. $(1.2 \times 10^5) \times (3 \times 10^3) =$ ____________

9. $(4.3 \times 10^6) \times (1.4 \times 10^{-5}) =$ ____________

10. $(3.1 \times 10^{-5}) \times (2.2 \times 10^4) =$ ____________

11. $(.00005) \times (.000006) =$ ____________

12. $(3000000) \times (.000003) =$ ____________

13. $\dfrac{4.2 \times 10^4}{2.1 \times 10^2} =$ ____________

14. $\dfrac{9.3 \times 10^{-5}}{3 \times 10^{-6}} =$ ____________

15. $\dfrac{4 \times 10^3}{2 \times 10^4} =$ ____________

16. $\dfrac{2 \times 10^5}{5 \times 10^8} =$ ____________

17. $\dfrac{(3 \times 10^4) \times (4 \times 10^2)}{(2 \times 10^3) \times (6 \times 10^4)} =$ ____________

PHYSICS WORK SHEET: METRIC/SCIENTIFIC NOTATION

I. CHANGE THESE AS INDICATED: NAME ____________________

(1) 3 km = __________ m
(2) 36 m = __________ mm
(3) 5320 mm = __________ m
(4) 14.7 cm = __________ Hm
(5) 324 cm = __________ DM
(6) 324 cm = __________ m
(7) 324 mm = __________ m
(8) 32.4 cm = __________ DAm

II. CONVERT THESE TO THE UNIT INDICATED IN THE ANSWER; THEN ADD THEM.

(9) 7000 mm + 300 cm + 80 Dm = __________ m

(10) 32 Hm + 932 DAm + 7.2 Km = __________ Km

(11) 4.3 Dm + .0001 Km + 0.3 m = __________ Cm

III. CHANGE THESE AS INDICATED:

(12) 6 mm = __________ cm = __________ m

(13) 9 cm = __________ m = __________ mm

(14) 27 mm = __________ cm = __________ m

IV. SIMPLIFY THESE:

(15) $(4\times10^{2})\times(2\times10^{6}) =$ __________
(16) $(3\times10^{-2})\times(3\times10^{-3}) =$ __________
(17) $(6\times10^{4})\times(3\times10^{-2}) =$ __________
(18) $(8\times10^{-8})(1.8\times10^{10}) =$ __________
(19) $(3.6\times10^{18})(1.8\times10^{10}) =$ __________
(20) $(8\times10^{-8})(7\times10^{4}) =$ __________

(21) $\frac{8\times10^{4}}{2\times10^{3}} =$ __________
(22) $\frac{16\times10^{4}}{4\times10^{7}} =$ __________
(23) $\frac{.0064}{.008} =$ __________

(24) $\frac{20\times10^{6}}{5\times10^{-2}} =$ __________
(25) $\frac{12\times10^{5}}{3\times10^{-4}} =$ __________
(26) $\frac{5\times10^{-1}\times4\times10^{2}}{2\times10^{-2}} =$ __________

CHAPTER 2

TABLE 1

Orders of Magnitude of Times

Each interval is one-tenth of the preceding interval.

TIME INTERVAL IN SECONDS	ASSOCIATED EVENT
10^{18}	Expected total life of the sun as a normal star
10^{17}	Age of the oldest rocks
	Time elapsed since first fossil life
	Time elapsed since first land life
10^{16}	Time for the sun to revolve around the galaxy
	Age of the Appalachian Mountains
10^{15}	Time elapsed since dinosaurs
10^{14}	Remaining life of Niagara Falls
10^{13}	Time elapsed since earliest men
10^{12}	
10^{11}	Time elapsed since earliest agriculture
	Time elapsed since earliest writing
	Time elapsed since the beginning of the Christian Era
10^{10}	Time elapsed since the discovery of America
10^{9}	Human life span
10^{8}	Time elapsed since you began school
10^{7}	Time for the earth to revolve around the sun (year)
10^{6}	One month
10^{5}	Time for the earth to rotate once on its axis (day)
10^{4}	Duration of average baseball game
10^{3}	Time for light from the sun to reach the earth
10^{2}	One minute
10^{1}	
10^{0}	Time between heartbeats (1 second)
10^{-1}	Time for bullet (.30 caliber) to cover the length of a football field (300 ft)
10^{-2}	Time for electric fan to complete one turn
10^{-3}	Time for fly to beat its wings once
	Time that a fired bullet is in the barrel of a rifle
10^{-4}	Time for one vibration of the highest-pitched audible sound
10^{-5}	Time during which firecracker is exploding
10^{-6}	Time for high-speed bullet to cross a letter of type
10^{-7}	Time for electron beam to go from source to screen in TV tube
10^{-8}	Time for light to cross a room
10^{-9}	Time during which an atom emits visible light
10^{-10}	
10^{-11}	Time for light to penetrate windowpane
10^{-12}	Time for air molecule to spin once
10^{-13}	
10^{-14}	
10^{-15}	Time for electron to revolve around proton in hydrogen atom
10^{-16}	
10^{-17}	
10^{-18}	
10^{-19}	
10^{-20}	Time for innermost electron to revolve around nucleus in heaviest atom
10^{-21}	
10^{-22}	
10^{-23}	Time for light to cross the nucleus

still further we must build intricate instruments and learn to interpret their readings. In this manner, for example, we can measure the age of the earth by methods that depend upon the laws of radioactivity. See, for example, the book by Patrick Hurley mentioned in the reading references at the end of the chapter.

For very short times, below direct perception, about three or four orders of magnitude to 10^{-5} second cover the ordinary motions and changes of the fastest-moving things men can make, even explosions. For still smaller orders of magnitude, we can use the much more responsive electrons as the "parts" of a clock and go to

Name Key

Mods

Introduction A QUIZ (A)

1. What is the period of a motor turning at 1200 rpm?

$T = \frac{1}{f} = \frac{1}{1200} \frac{MIN}{rev} = \frac{1}{1200} MIN = 8.3\bar{3} \times 10^{-4} MIN = .05 sec$

$f = 1200 \frac{rev}{MIN} =$

2. a. How is frequency and period related? $f = \frac{1}{T}$ $T = \frac{1}{f}$

   b. What symbol do we use for each? f T

   c. What is the unit(s) of each? $\frac{1}{sec}$ sec

3. A 12-slit stroboscope is rotated at a constant rate for 20 seconds to determine that a motor shaft takes 1/30 sec to make one revolution. How many rotations does the stroboscope make?

#slits = 12

t = 20 sec

$T = \frac{1}{30}$ sec

? #rev

$\frac{\#rev}{time} \times \#slits = f_{obj}$

$f = \frac{1}{T} = 30 \frac{}{sec}$

$\#rev = \frac{ft}{\#slits}$

$\frac{30}{sec} \times \frac{20 sec}{12} = 50$ rev

4. The diameter of the wire is:

   a. Using the micrometer. .80 MM 1.65 mm .165 cm

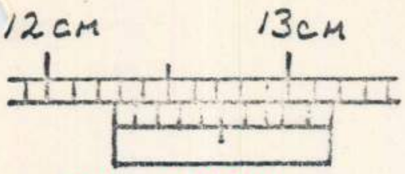
   b. Using the vernier caliper. .8 1.6 MM .17 cm

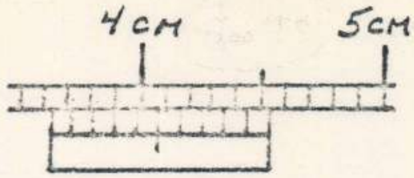
5. What possible errors might result when using the stroboscope? What would you do to minimize the errors?

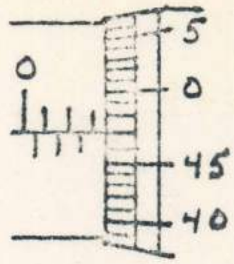
get sub multiple of true value - Stop motion at fastest possible viewing rate

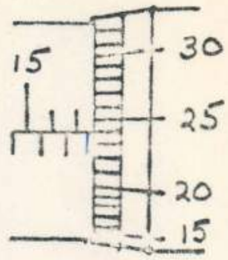
Test Introduction A Name ______________

Write the vernier readings and micrometer readings under each.









odd 1.06 MM
1.63 mm

d = 1.27 cm
[illegible] 3.02 cm

✓ 1. 12.27 CM 2 2. 3.63 CM 2 3. 3.47 MM 2 4. 17.74 MM

Give the order of magnitude of the following:

1 10^{23} 5. 5.3×10^{22}

1 10^{-6} 6. 1.7×10^{-6}

1 10^{7} 7. 3.1×10^{7}

1 10^{-4} 8. 4.2×10^{-5}

10^{-5}
3.16
10^{-6}

3/4

D%

9. What is the minimum number of turns/sec made by an eight-slit strobe if it is to 'stop' the motion of a fan turning at the rate of 50 rpm?

4 6.25/min = 0.10/sec

slits = 8

f_{obj} = 50/min

f_{strobe} = ? /sec

$f_{strobe} = \frac{f_{obj}}{\# \text{ slits}} = \frac{50}{8} \frac{1}{min} \times \frac{1 \, min}{60 \, sec}$

rev/min not RPM

10. A student obtains 50.3 Hertz for the frequency of a rotating tire which is actually rotating at 48.5 Hertz. Calculate the percent of error.

4 ~~3.71~~ % ~~3.59~~ %

11. How many points were scored by all of the high school varsity basketball teams in all of the regularly scheduled games in the 1982-1983 season in the state of Ohio. Use order of magnitude estimation only. Show all work.

4 10^{6}

$10^{2} \frac{points}{game} \times 10^{1} \frac{games}{year} \times 10^{3} \frac{teams}{state}$

12. If a teacher speaking at a normal rate gives the same one-hour lecture every period of the school day, how many words does he or she speak? Again use order of magnitude estimation only and show all work.

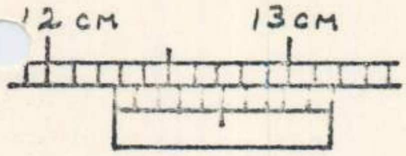
4 10^{5}

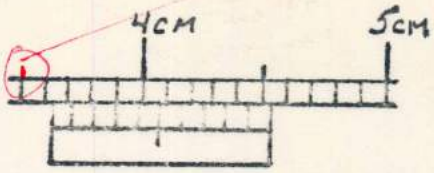
$10^{2} \frac{words}{min} \times 10^{2} \frac{min}{hr} \times 10^{1} \frac{hrs}{day}$

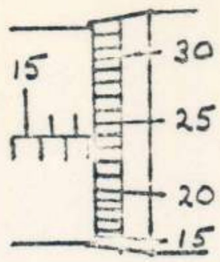
26

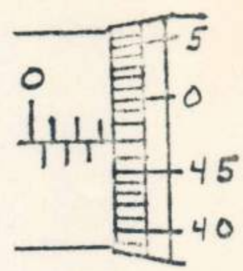
Test Introduction A Name — Correct

Write the vernier readings and micrometer readings under each.









odd (2) 1.06 mm
2.13 mm
1.63

(2) 2.55 cm odd
7.60 cm even

8

1. 12.27 cm 2. 3.63 cm 3. 17.74 MM 4. 3.47 MM

Give the order of magnitude of the following:

4

10^{24} 5. 5.3×10^{23}

10^{-7} 6. 1.7×10^{-7}

10^{6} 7. 3.1×10^{6}

10^{-4} 8. 4.2×10^{-5}

9. What is the minimum number of turns/sec made by an eight-slit strobe if it is to 'stop' the motion of a fan turning at the rate of 55 rpm?

$6.88/\text{min} = 0.11/\text{sec}$

identify info ✓
work ✓
answer ✓

$\# \text{slits} = 8$

$f_{obj} = 55 \text{ rev/MIN}$

$f_{strobe} = ?\ /\text{sec}$

$f_{strobe} \times \# \text{slits} = f_{obj}$

$f_{strobe} = \frac{f_{obj}}{\# \text{slits}}$

$= 55 \frac{\text{rev}}{\text{min}} \times \frac{1}{8 \text{ slits}} * \frac{1 \text{ MIN}}{60 \text{ sec}}$

10. A student obtains 50.8 Hertz for the frequency of a rotating tire which is actually rotating at 48.3 Hertz. Calculate the percent of error.

5.18 %

11. How many points were scored by all of the high school varsity basketball teams in all of the regularly scheduled games in the 1982-1983 season in all 50 states. Use order of magnitude estimation only. Show all work.

10^8

$10^2 \frac{\text{points}}{\text{game}} \times 10^1 \frac{\text{game}}{\text{yr}} \times 10^3 \frac{\text{teams}}{\text{state}} \times 10^2 \text{ states}$

12. If a teacher speaking at a normal rate gives the same one-hour lecture every period of the school day, how many words does he or she speak? Again use order of magnitude estimation only and show all work.

10^5

$10^2 \frac{\text{words}}{\text{min}} \times 10^2 \frac{\text{min}}{\text{lec}} \times 10^1 \frac{\text{lec}}{\text{day}}$

24

LABS 1 and 2 QUESTION SHEET Name ______________________ mod____

QUESTIONS TO CHECK WHAT YOU HAVE LEARNED:

1. What is the relation between the precision of the measuring instrument being used and the number of significant digits you can measure to?

2. As measuring instruments of increasingly greater precision are used to make a given measurement, what happens to the certain portion of the measurement?

3. When using a double-pan balance, an experimenter waits for the arm to stop swinging before taking a reading. His partner takes a reading while the arm swings equal distances on either side of the zero mark. What are the advantages of the second method?

4. The reading on a double-pan balance is 263.75 g. How many significant digits in this measurement? How many are certain?

5. State some reasons why the measurement of the length of a lab table may not be precise.

6. A meterstick (graduated in millimeters) is used to measure a length. Would a reading of 28.625 cm be acceptable? Explain.

7. Four trials are made of a given measurement: 18.20 cm, 18.21 cm, 18.19 cm, and 18.22 cm. What is the mean value of these four measurements?

8. What effect does increasing the number of trial measurements have on the mean value of the measurement?

9. If the wooden block (used in the lab) was actually a volume of water instead of wood, what would it "weigh" in grams?

length = 4.428 m   width = 3.31 m

Calculate the area of the rectangle and give the answer in the correct number of significant digits.

11. Add these measurements:

1.284 m, 1.9 m, 6.28 m, .9381m

Give the answer in the correct number of significant digits.

12. When using a meter stick (smallest division of millimeters) are these measurements possible:

	yes	no
a) 26.3 mm		
b) 2.93 cm		
c) 1.92847 m		
d) .35210 mm		
e) 1652.4278 m		
f) 372.28 cm		

EXPERIMENT S-1

Precision and Significant Digits

Purpose: *To learn how the number of significant digits in a measurement is related to the precision of the measurement*

WHAT YOU NEED TO KNOW

"I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind." Such were the words of Lord Kelvin, the great English physicist. Physics may be thought of as the science of measurement.

Measuring a physical quantity involves the use of a measuring instrument. Each measurement deals with two fundamental concepts, precision and accuracy. *Precision* refers to the extent to which a set of measurements of the same sample agrees with the mean value of the measurements. Thus, the precision of a measurement reflects its reproducibility. The number of significant digits used to record a measurement indicates the degree of precision of the measurement. This experiment is concerned with precision and significant digits. *Accuracy* refers to the extent to which a measurement agrees with the standard, or accepted, value for that measurement. Problems dealing with *accuracy* are covered in Experiment 3.

To see how precision is involved when making a measurement in the laboratory, you should know: (1) which factors affect the precision of your laboratory instrument, (2) how the instrument can be used to achieve maximum precision, and (3) how significant digits reflect the degree of precision.

The precision of an instrument depends only upon the measuring instrument itself, assuming the instrument is used properly. For example, a meterstick marked with centimeter graduations permits measurements to the nearest centimeter with an estimate to the nearest 0.1 cm. If the graduations are marked to the nearest millimeter—that is, to the nearest 0.1 cm—then the precision of the meterstick permits measurements to the nearest 0.01 cm. When several measuring instruments are used under similar conditions, the instrument containing the largest number of scale subdivisions is considered to yield the most precise results. As the precision increases, the differences between the measurements become smaller and the measurements become more alike.

The degree of precision obtained with any measuring device may be indicated by the use of *significant digits,* also called *significant figures.*

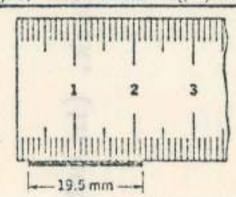


Fig. 1–1 Determining significant digits of a measurement

Measuring devices, such as a meterstick, contain a scale graduated in some specific units of measurement. Any measurement containing an integral number of these units is a *certain* measurement and the digits written to express this measurement are called *certain digits.* In Fig. 1–1, the certain digits of the measurement 19.5 mm, or 1.95 cm, are 1 and 9.

Precision in Linear Measurement

Purpose: *To learn to make precise linear measurements using the meterstick and to use these measurements to compute quantities derived from length*

WHAT YOU NEED TO KNOW

In the previous experiment, it was pointed out how precision of a measurement depended on the scale markings of an instrument. In this experiment, you will learn how the precision of a measurement depends on the competence and care taken by the person using the instrument. Recall that the *precision of a measurement* refers to how close the measurement can be reproduced. Measuring a length precisely presents difficulties. For example, if three different persons were to measure the length of this page, they might not obtain the same answers. The differences may be due to a variety of reasons, some involving the instrument itself, which we have already covered, and others involving the experimenter. When a person using the instrument applies the proper techniques and takes the care required to read the instrument properly, then the instrument yields precision measurements to the full extent of its capability.

Starting with a precision instrument, one endeavors to obtain measurements with a high degree of accuracy. Recall that accuracy in a measurement refers to the closeness of a measurement to some accepted value. When making measurements, such as the length of a table, one can only hope to obtain a precise length whose measured values are as close together as possible. Since there is no standard length for a table, the necessity to develop an accepted value for the length of a table has never arisen. Thus, it is impossible to determine whether the measurement is accurate or not. We can expect precision, but not accuracy, in such a measurement. Problems dealing with accuracy in measurement are treated in Experiment 3 and in later experiments.

STRATEGY

You will investigate the significance of the markings on a meterstick. Then you will use the meterstick to make measurements such as the length and width of your laboratory table. In doing this, you will apply various techniques to make your measurements as precise as possible. Finally, you will use these linear measurements to compute certain quantities, such as area, that are derived from length.

MAKE MEASUREMENTS AND/OR CALCULATIONS TO DETERMINE THE FOLLOWING:

1) Find the area of the lab table you are sitting behind. (in sq. cm or cm^2)

2) Calculate (using data from question #1) the diagonal of the lab table and then verify this calculation thru measurement of the diagonal. (in cm)

3) Find the mass (you probably call it the "weight") of the small wooden block. (in g)

4) Find the volume of the large wooden block. (in cubic cm or cm^3)

5) Find the diameter of the wooden cylinder.

6) Calculate the volume of the wooden cylinder.

7) Measure the width of the lecture stand to the nearest m __________ m then to the nearest cm ________ cm and then to nearest mm __________ mm.

8) (Optional) Find the thickness of this piece of paper.

Find the thickness of a hair from your head.

Is there a difference in thickness in black vs. blond hair? In male vs. female hair?

WHEN YOU'VE COMPLETED THE MEASUREMENT/CALCULATION SECTIONS ABOVE, ASK FOR THE QUESTION SHEET THAT GOES WITH THIS LAB.