FUNDAMENTAL QUANTITIES AND BASE UNITS

SPECIFIC OBJECTIVES A (1.1-1.4)

Candidates should be able to:

1.1 recall fundamental properties quantities of the International Systems (S.I)

1.2 explain the significance of units in measurements

1.3 recall that the value of a quantity is usually expressed as the product of a number and a unit

1.4 recall the base units of the fundamental quantities in the SI systems;

CONTENT

The fundamental quantities are those physical properties from which all others are derived.

FUNDAMENTAL QUANTITY		**BASE SI UNIT**	
Name	**Symbol**	**Name**	**Symbol**
mass	m	kilogram	kg
length	*l*	metre	m
time	t	second	s
current	I	ampere	A
temperature	T	kelvin	K

Note: temperature ($^{\theta}$) is usually measured in degrees Celsius (^{0}C). This is NOT an SI unit but is however, acceptable for use in expressing “common temperatures, together with SI unit.

SIGNIFICANCE OF UNITS

What are units? Units are needed to give meaning to the expressed values of physical quantities. They are useful in comparing physical quantities and are also necessary as a means of standardization.

THE VALUE OF A QUANTITY IS EXPRESSED AS THE PRODUCT OF A NUMBER AND A UNIT.

Example: F = 100 N   m= 50 g

It should be noted however, that some quantities, like RATIOS OF LIKE QUANTITIES, have NO UNITS.

Example: Relative density of mercury = 13.6

Refractive Index of glass = 1.5

A quantity divided by its unit gives a pure number.

Example: F = 100 N therefore F/N = 100

Tables and graphs are therefore headed with QUANTITY/UNIT

Example :

F/N	x/cm
100	100
150	150

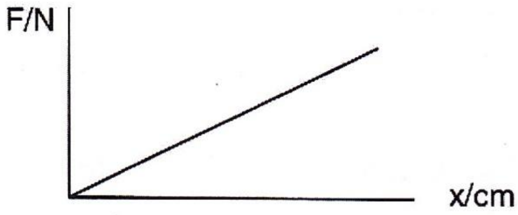


Fig. 2.1 ***Typical Heading of Table & labelling of Axes of Graph***

MULTIPLES AND SUB-MULTIPLES

Specific Objectives A 1.5

Candidates should be able to:

1.5 recall the meaning and uses of the prefixes mega, kilo, milli, micro.

CONTENT

In making measurements in the laboratory, the experimenter may need to measure very large or very small quantities. In recording and using the values of such quantities the use of standard units may not be convenient or appropriate as the use of multiples or submultiples, the syllabus requires the students to know the meaning of the four prefixes below.

Prefix	Meaning	Symbol
Mega	10^6(1 million)	M
Kilo	10^3(1 thousand)	k
Milli	10^{-3}(1 thousandth)	m
micro	10^{-6}(1 millionth)	μ

SCIENTIFIC NOTATION

Candidates should be able to:

1.6 use numbers expressed in standard form

CONTENT

In the scientific notation you express a number in the standard form that is, as a product of a power of 10 and a (mixed number consisting of a) whole number part with a decimal part with the appropriate number of decimal places. Two examples below illustrate this:

i. the decimal number 0.007346 may be expressed in standard form as 7.346×10^{-3}
ii. 734.6 will be 7.346×10^2 in standard form.

When you express a number in standard form you simplify any mathematical operation using that number since the powers of 10 are very easily manipulated. The majority advantages to powers of 10 is that it allows for conciseness when dealing with large or very small numbers and so facilitates the performance of mathematical operations.

The terms "standard form notation" and "scientific notation" both mean the same thing and are used interchangeably.

DERIVED QUANTITIES AND INDEX NOTATION

SPECIFIC OBJECTIVES (1.7-1.9)

1.7 Recall that base quantities with their units may be multiplied or divided to produce derived quantities with their units.
1.8 Use the index notation for derived units
1.9 Recall that some derived units are given special names

CONTENT

When you multiply or divide base units (magnitude and unit) by one another, the results represent both magnitudes and units of new quantities. These quantities are called derived quantities. You can also multiply or divide combinations of base and derived quantities to produce other derived quantities. The examples below illustrate this:

Derived Quantity		**Defining Equation**	**S.I Unit From Defining Equation**	**Special Name And Symbol For S.I Unit**
Name	**Symbol**			
Speed or velocity	v	V = x/t	m/s	-
Acceleration	a	A = v/t	m/s^2	-
Force	F	F = ma	$kg\ m/s^2$	Newton(N)
Work	W	W = Fx	Nm	joule(J)

The index notation is a convenient and elegant means of expressing derived units. Use this notation to express units solely as products, with the sign of the index indicating whether the term in the expression is a numerator or a denominator. The student should be able to explain the sign of the index, that is, a negative index means a division and a positive index means a multiplication. The examples below illustrate this:

1. m/s written as m s^{-1}

2. m/s^2 written as m s^{-2}

3. kg m/s^2 is written as kg m s^{-2}

4. kg/m^3 is written as kg m^{-3}

5. J/(kg x K) is written as J $kg^{-1}K^{-1}$

The index notation makes it easier to manipulate derived units.

SCALES, ERRORS AND GRAPHS

SCALES

Candidates should be able to:

2.1 calibrate a scale

CONTENT

The scale reading of any instrument is meaningless unless the instrument or its scale has been calibrated. Calibration essentially involves the checking of the scale of an instrument against some accepted standard to ensure accuracy of its reading. There are at least two steps involved in calibration:

Step 1: Dividing the scale into an appropriate number of intervals by use of graduation marks.

Step 2: Setting or fixing the scale in its proper position or location to ensure the correctness of the absolute values indicated by its reading. This may be essentially the same as setting the scale so as to eliminate any zero reading (i.e. “zero error”).

ANALOGUE AND DIGITAL- LINEAR AND NON LINEAR SCALES

SPECIFIC OBJECTIVES A (2.2-2.5)

2.2 differentiate between linear and non-linear scales

2.5 differentiate between analogue and digital scales

CONTENT

A linear scale is one in which equal changes in the value of the physical quantity being measured are indicated by equal changes on the scale of the measuring instrument (e.g. meter rule).

A non-linear scale is one in which equal changes in the value of the physical quantity being measured are indicated by unequal changes on the scale of the measuring instrument.

An analogue scale is one in which the pointer continuously deflects over a calibrated scale.

A digital scale is one which has a digital decimal light emitting diode (LED) or liquid crystal display (LCD). The reading displays on a digital scale cannot change continuously from one to the next but does so by making small "jumps" from one to the next.

The difference between linear and non-linear can be demonstrated using volumes. Ask the students to calibrate a cylinder in a given unit (say cm^3) and to observe the regular graduations in the scale produced. For the non-linear scale use a conical flask. Ask them to calibrate it in the same units and observe the graduations obtained. From their observations the students should be able to identify both types of scales and state the differences between them.

CHOOSING SUITABLE INSTRUMENTS

SPECIFIC OBJECTIVE

Candidates should be able to:

A 2.3 assess the suitability of instruments on the basis of sensitivity, accuracy and range.

CONTENT

ACCURACY is "the extent to which errors inherent in the apparatus or procedures adopted are appreciated and reduced in the final result"

Example: In the experiment to calculate the density of mercury, the result 13.6 g/cm^3 would be more than the result 14.8 g/cm^3.

The ACCURACY of an INSTRUMENT is dependent on the instrument's calibration in the sense of its correct ABSOLUTE VALUE.

PRECISION is "the intention to make observations with the greatest possible exactitude":

Example: A length measured as 17.42 cm would be more precise than the same length measured as 17.4 cm.

The precision of a reading depends on:

i. The precision of the instrument's calibration (i.e. the smallness of the interval between two adjacent graduations).
ii. The precision with which a SCALE is read i.e. estimating readings for pointer positions between two adjacent graduations.

The SENSITIVITY of an instrument is its response to a unit change in input. The larger the response, the more the sensitive the instrument.

For example, the sensitivity of an AMMETER is the DEFLECTION per unit CURRENT ($^{\theta}/I$), so a micrometer is more sensitive than a milliammeter.

The RANGE of an instrument is defined by the interval between the maximum and minimum values of a quantity than the instrument can measure.

ESTIMATING READINGS

SPECIFIC OBJECTIVE

Candidates should be able to:

2.4 estimate scale readings for pointer positions between adjacent graduations;

CONTENT

When a pointer is between two adjacent graduations marks on a scale, the experiment will have to rely to some extent on his/her judgment in taking a reading. Hence some inaccuracy in the reading may result. However, this reading is often better than one to the nearest graduation mark.

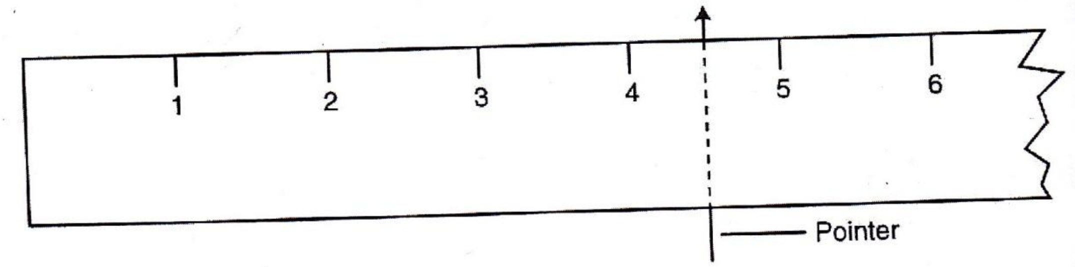


Fig. 2.2. Scale Reading Estimation (Horizontal Scale exaggerated for emphasis)

SCIENTIFIC PRECISION AND SIGNIFICANT FIGURES

SPECIFIC OBJECTIVE 2.6

Candidates should be able to:

2.6 express the result of a measurement or calculations to an appropriate number of significant figures.

CONTENT

The number of significant figures in a number is the number of digits in the number (excluding zeros) counting from the left, with a couple of important exceptions concerning zeros. Some examples given below should help to make it clear.

i. 301.6 – this number has four significant figures. Since the zero comes between two other digits which are themselves significant.

ii. 0.032 – this number has two significant figures. The zeros are not significant since they do not fall between other digits which are significant. It can be written be written in standard form as 3.2×10^{-2} which makes it clear that these are only two significant figures.

When performing multiplication or division the number of significant figures in the result should not be more than that in the least precise quantity.

For example, calculate the volume of a rectangular slat 1.236m x 0.551m x 0.063m

$V = l \times b \times h$

$= 0.042905268 \text{ m}^3$

Since the least precise measurement has two figures the volume is least written as 0.043 m^3 (or $4.3 \times 10^{-2} \text{ m}^3$).

The number of significant figures used in recording a measurement depends on precision of the instrument used. When performing mathematical operations using these measurements students will often report an unrealistic number of decimal places that bear no relationship to the precision of the instrument used. Therefore the students should be able to correct a value to an appropriate number of significant figures.

ERRORS

SPECIFIC OBJECTIVE

Candidates should be able to:

2.7 discuss possible sources or errors in any measurement, including those made with digital instrument, and the ways in which such errors may be reduced.

CONTENT

Sources of Error

These are to be treated at the qualitative level only. Students are required to identify sources of errors, but not to quantitatively estimate amounts or calculate errors although some awareness of their relative importance may reasonably be expected.

Errors are generally unavoidable in physical measurements. They arise from various sources including:

a) the environment
b) the instrument/s
c) the experimenter
d) the procedure or method used.

Environmental errors may be due to:

i) draughts
ii) temperature and pressure conditions
iii) corrosion of the instrument
iv) magnetic effects in electrical instruments
v) humidity
vi) vibration

Sometimes you can avoid these errors by taking suitable precautions to control the conditions.

Instrumental errors may be due to:

i) the calibration of the instrument
ii) the zero of the instrument (not being taken into account)

iii) faults due to the manufacture of the instrument (this is particularly true with cheap equipment).

iv) pivots due to friction

Methods of minimizing instrumental errors:

i) calibration can be checked by comparing it with another instrument

ii) zero the instrument or include zero in readings

iii) tapping the instrument may release a pivot which is sticking.

Experimenter's error may be due to:

i) personal factors as impairments to vision or hearing

ii) uncertainty (or random error) in taking readings

iii) setting errors such as the uncertainty in judging the most focused image in a lens experiment

iv) "slow" reaction time

v) When timing repetitive processes:

(a) miscounts

(b) Uncertainty in the reference point at which to start and stop the stop watch (uncertainty in starting and stopping point being the same).

(c) Uncertainty about which point of swing to time.

(vi) Mistakes or a built in error in the method or a false assumption

(vii) Errors in reading the scale;

1. Errors in reading an ANALOGUE scale:
   a) Misreading the scale
   b) Not using or misusing the multiplication factor
   c) Incorrectly estimating pointer positions between adjacent graduations
   d) Parallax
2. Errors in reading a GIGITAL scale:
   a) The last digit FLUCTATES easily. The uncertainty in the value is therefore in LAST DIGIT.
   b) If the range chosen is too small for the quantity being read, the number '1' comes on the screen.

Example: 2.6 V on a (0 to 2) V scale

c) If the range chosen is too large, the instrument becomes insensitive.
   Example: 2.6 V on a 0 to 1000 V scale reads 2 V.

d) Reading the wrong scale. Example: mA instead of A

Methods of minimizing experimenter's errors

i) Setting errors (in optics) can be reduced by moving the screen backward and forward until the sharpest image is seen and/or by use of the average of the two setting.

ii) 'Slow' reaction time can only be reduced in a repetitive process. This is done by using the countdown method and timing may oscillations.

iii) Miscounts and uncertainty in timing point can be reduced by taking a reading several times, discarding readings which are off and averaging the rest.

iv) Uncertainty in point of swing can be avoided by MARKING the point of fastest motion (rest point) and timing as it passes this mark.

v) Looking for a pattern in the measurements to identify the odd reading/s. a graph helps in doing this.

vi) Reduction of errors in reading digital scales:
   (a) Zero the instrument before use
   (b) Ensure that the correct scale is being read
   (c) Start with the highest range and work down to the most suitable one.
   (d) If the last digit fluctuates (by 1) choose either one of the digits.

PARALLAX ERRORS

SPECIFIC OBJECTIVE A 2.8

Candidates should be able to:

2.8 take readings so as to minimize parallax errors

CONTENT

Parallax results when objects occupying different positions appear to change positions relative to each other when viewed from different directions. Therefore an experimenter needs to take precautions to avoid parallax errors when making measurements.

Parallax errors can arise in reading scales, in locating images or in any situation where two or more objects must be viewed simultaneously. The illustration below shows how parallax errors may be avoided when reading scales.

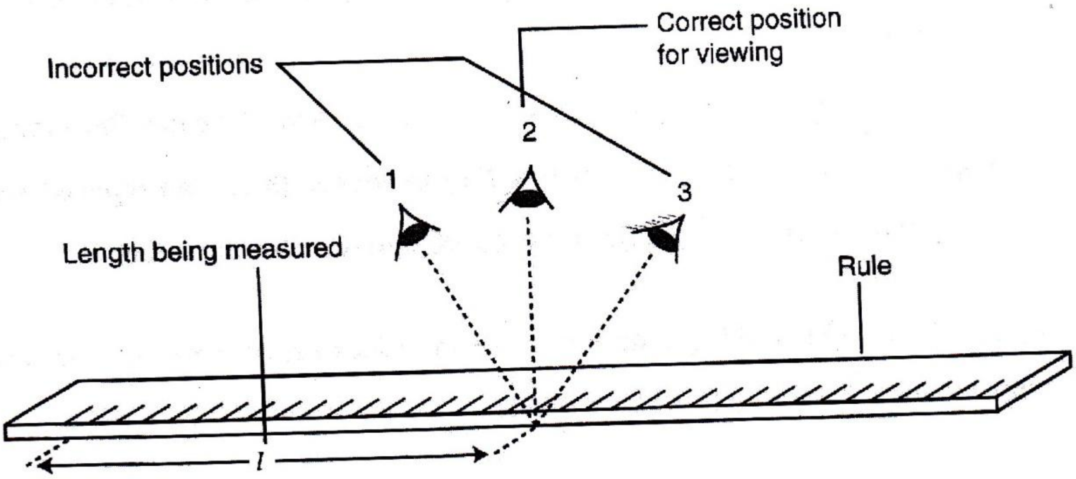


Fig 2.3 ***Avoiding Parallax Error***

MEASURING LENGTH

SPECIFIC OBJECTIVE A 2.9

Candidates should be able to:

2.9 use rulers, verniers calipers and micrometer to measure length

CONTENT

Length can be measured using the following common laboratory instruments rulers, vernier calipers and micrometer. The range of each instrument indicates its suitability for measuring particular lengths. For example, a ruler would be more suitable for measuring the width of a book than for measuring the diameter of a wire.

MEASURING MASS

SPECIFIC OBJECTIVE A (2.10-2.11)

Candidates should be able to:

2.10 use balances to measure mass
2.11 Use spring balances or other force measurers to measure force.

CONTENT

To measure mass, you can use various types of balances, the lever balance, the beam balance and the top-pan balance.

Mass is a measure of the quantity of matter in a body. Mass indicates inertia and hence is a constant value for a given body. It will not change with the body's location or physical conditions. On the other hand, weight is the force or pull of the earth on a body. Hence, its value will be dependent on the distance of the body from the center of the earth. Therefore, the weight depends on the location of the body. Thus, the weight of a particular body on the moon will be different from what it is on earth. Balances measure mass by comparing the weights of bodies at the same location. A force measurer may be used to measure mass by comparing a body's weight with some other standard force e.g. another weight.

A top pan balance and a beam balance are shown below.

MEASURING TIME

SPECIFIC OBJECTIVE 2.13

Candidates should be able to:

2.12 use clocks and stop watch or stop watches to measure time intervals

CONTENT

The measurement of time is one of the most fundamental determinations in Physics. A variety of devices and associated apparatus are in current use for timing everyday occurrences and unusual phenomena. Devices which use atomic and electronic oscillations for measuring time and inherently more precise than those which use mechanical processes such as the rotational oscillation of a balance wheel. Modern wrist watches are increasingly electronic in their operations and generally give a more precise display than common clocks.

Electronic or electrical triggering for starting and stopping are also recognized as being more reliable than manual triggering.

More school laboratories may have (mechanical) analogue clocks, stop clocks, stop watches and access to students' own wrist watches and it is desirable and expected than stop-watch precision would be available for such processes as:

i) the freefall of a body

ii) oscillations of pendula and/or mechanical systems of various types

iii) travel or transit times of trolleys, balls etc. in speed determinations

For cooling experiments and determinations involving electrical and other means of heating, stop clock precision of timing may be just satisfactory.

INVESTIGATING THE SIMPLE PENDULUM

SPECIFIC OBJECTIVE 2.14

Candidates should be able to:

2.14 investigate the factors which might affect the period of a simple pendulum

CONTENT

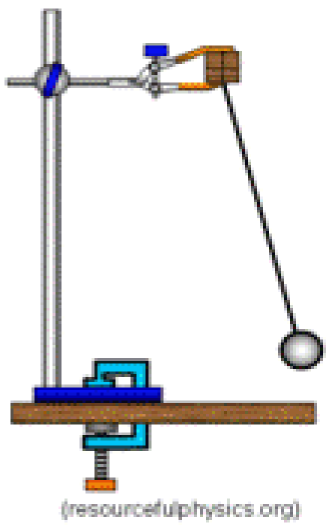
The period of an (ideal) pendulum depends only on its length and the acceleration due to gravity, g. for practical purposes; g can be regarded as a constant, although it varies slightly with location on the earth's surface. The relationship between the period and the length is not a direct one.

From the expression: $T = 2p \sqrt{l/g}$

$$T \alpha \sqrt{l}$$

Because of its basic simplicity, this type of pendulum readily recommended itself as the basis for designing clocks i.e. instruments of measuring time.

Figure 2.5 ***A Simple Pendulum***



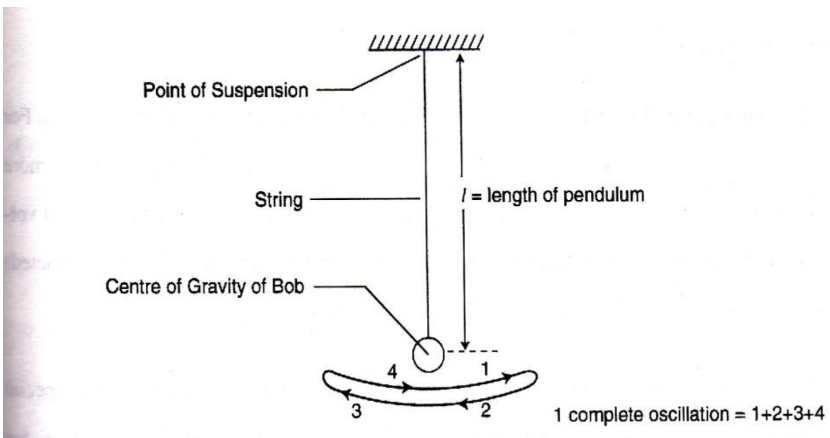


Fig. 2.5 ***A Simple Pendulum***

MEASURING LENGTH-DERIVED QUANTITIES: AREA AND VOLUME

SPECIFIC OBJECTIVE (2.12: 2.15-2.16)

Candidates should be able to:

Instruments

2.13 use measuring cylinders and burettes to measure volumes

Area A

2.15 measure the area of both regular and irregular shapes

Volume

2.16 measure the area of both regular and irregular solids which
(a) Float (b) sink in water

CONTENT

Area and volume are both length-derived quantities having SI units of m^2 and m^3 respectively. For regular shapes, the measurements of area and volume may be accomplished by making one or more measurements of length and by use of an appropriate formula or formulae. Length, area and volume are all scalars, so that measurements of any one may be easily combined (added or subtracted) to give the value of the (like) quantity which is being determined.

The measurement of irregular areas and that of the volume of liquids requires the use of special techniques and/or instruments and generally cannot be done to the same high precision as for example, either the measurement of mass, or that of time or that of length itself.

DENSITY AND RELATIVE DENSITY

SPECIFIC OBJECTIVE (2.17-2.20)

Candidates should be able to:

2.17 define density

2.18 Determine density using $p = m/v$

2.19 Use the concept of relative density

2.20 Recall relative density as an example of a quantity that has no unit

CONTENT

Density is a common property of matter frequently used in scientific descriptions of physical systems and also useful as an everyday concept for the ordinary citizen. The concept of density may be summarized by the statement "Density is a measure of how heavy or light a body made of some material is for its size". Density is a property of the material of which a body is made and is not a parameter of the body as such. Density is defined as the mass per unit volume of a substance. It is determined by measuring both the mass and the volume of a body made of the material or substance concerned. It is calculated by dividing the mass by the volume. The SI unit of density, the usual symbol for which is p is kg m^{-3} as can be described from its defining equation $p = m/v$.

In everyday speech the statement "Aluminum is lighter than iron" is to be understood to mean that "the density of aluminum is less than that of iron"

Density determinations require the use of a large enough sample of the substance or material, the mass and volume of which can be found to the required precision and accuracy.

A difficult but closely related concept to density is the concept of "relative density". As its name suggests, relative density is a quantity which compares the density of a substance with that of another common substance, water. Thus relative density is a measure of how many times the substance is as dense as water and is defined by the equation.

$$\text{Relative density (RD)} = \frac{\text{density of substance}}{\text{density of water}}$$

$$= \frac{\text{mass of substance/volume of substance}}{\text{mass of water /volume of water}} = \frac{m_s/v_s}{m_w/v_w}$$

$$= \frac{m_s}{m_w} \quad \text{if } v_s = v_w$$

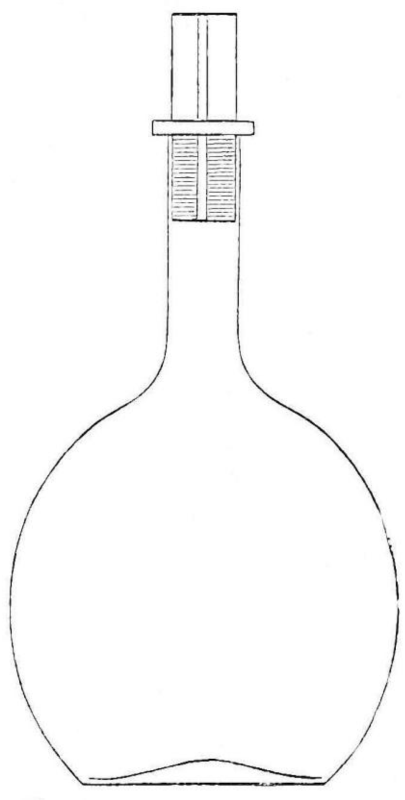
So we can see that

i) Relative density, is a quantity, has no units i.e. it is a pure number, just as mechanical advantage, velocity ratio and refractive index, are

ii) That it can be determined by comparing the mass (or weight) of a substance with that of an equal volume of water.

Determining the R.D of a liquid is, there, a relatively straightforward affair involving the comparison of the masses (of weights) of equal volumes of that liquid and water.

Specially engineered vessels called "relative density bottles" with prescribed and proper handling are capable of being filled and refilled repeatedly always to contain the same volume of liquid. These are especially suitable for determinations of relative density.



A Relative Density Bottle