H314

Hydrostatics and Properties of Fluids

User Guide

TecQuipment has taken care to make the contents of this manual accurate and up to date. However, if you find any errors, please let us know so we can rectify the problem.

TecQuipment supply a Packing Contents List (PCL) with the equipment. Carefully check the contents of the package(s) against the list. If any items are missing or damaged, contact TecQuipment or the local agent.

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TecQuipment

Contents

SECTION 1.0 INTRODUCTION AND DESCRIPTION

1.1 Introduction

The TecQuipment H314 Hydrostatics and Properties of Fluids apparatus provides a comprehensive range of experiments and demonstrations to give the student a thorough understanding of the basic principles of fluid mechanics and properties of fluids. The apparatus helps students to determine properties such as density, viscosity and surface tension. It also helps to demonstrate basic principles such as Pascal's Law and Archimedes' Law. From these, the student can progress to a wide range of practical applications of hydrostatic principles, including:

- buoyancy
- centre of pressure
- flotation and stability of floating bodies
- operation and calibration of a Bourdon pressure gauge
- manometry

1.2 General Description

Figure 1 H314 Hydrostatics and Properties of Fluids Apparatus

Figure 1 shows the TecQuipment H314 Hydrostatics and Properties of Fluids apparatus. It consists of an integral plastic moulding mounted on lockable castors. TecQuipment supply it complete with all the necessary equipment for a wide range of experiments. Much of the equipment is rigidly mounted on the bench, with the remainder being free-standing items suitable for use with the bench top. The water required for the experiments is supplied from a reservoir tank via a lift pump. An additional tank is mounted on the unit and this can be filled from the reservoir for experiments which require a free water surface. A large drain tray is fitted in the top for collecting and returning water to the reservoir.

The right-hand side of the unit has moulded features to locate a number of experiments, such as centre of pressure, Archimedes and so on, together with storage for loose items. The back panel supports a set of U-tubed manometers (pressurised by an air pump), a pressure gauge, and Pascal's tubes. This is covered in an easy-to-clean plastic sheet. The left-hand side of the unit provides covered storage for viscosity jars and small items.

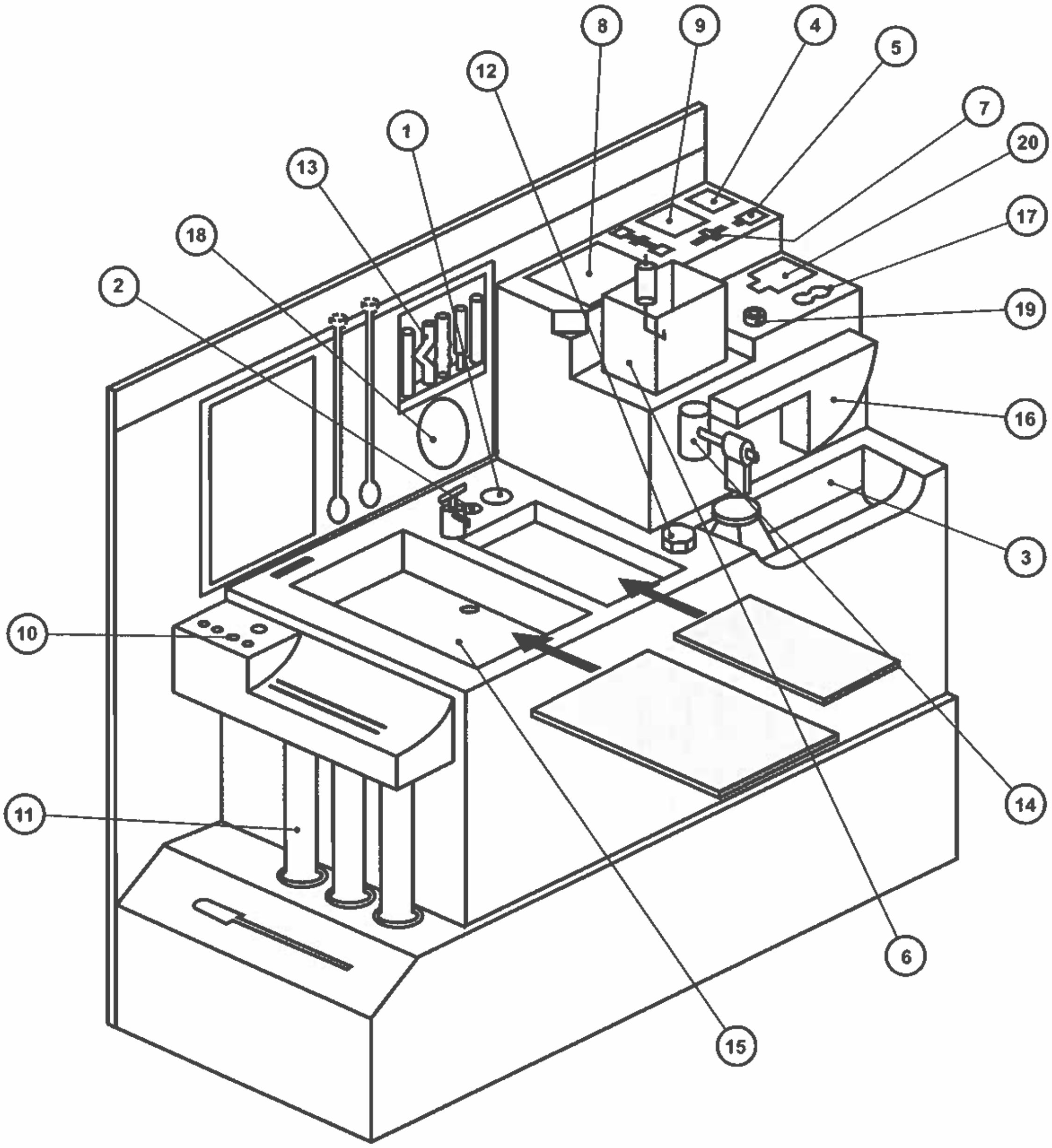
A portion of the working surface can be removed to access a reservoir which stores a rectangular stability pontoon with adjustable weights, and can be filled to float the pontoon for experiments.

Apparatus supplied for determining a variety of fluid properties includes a Eureka can, a specific gravity bottle, a hydrometer capillarity apparatus, a falling sphere viscometer and a point gauge for fluid level measurement.

The range of experiments that can be undertaken are:

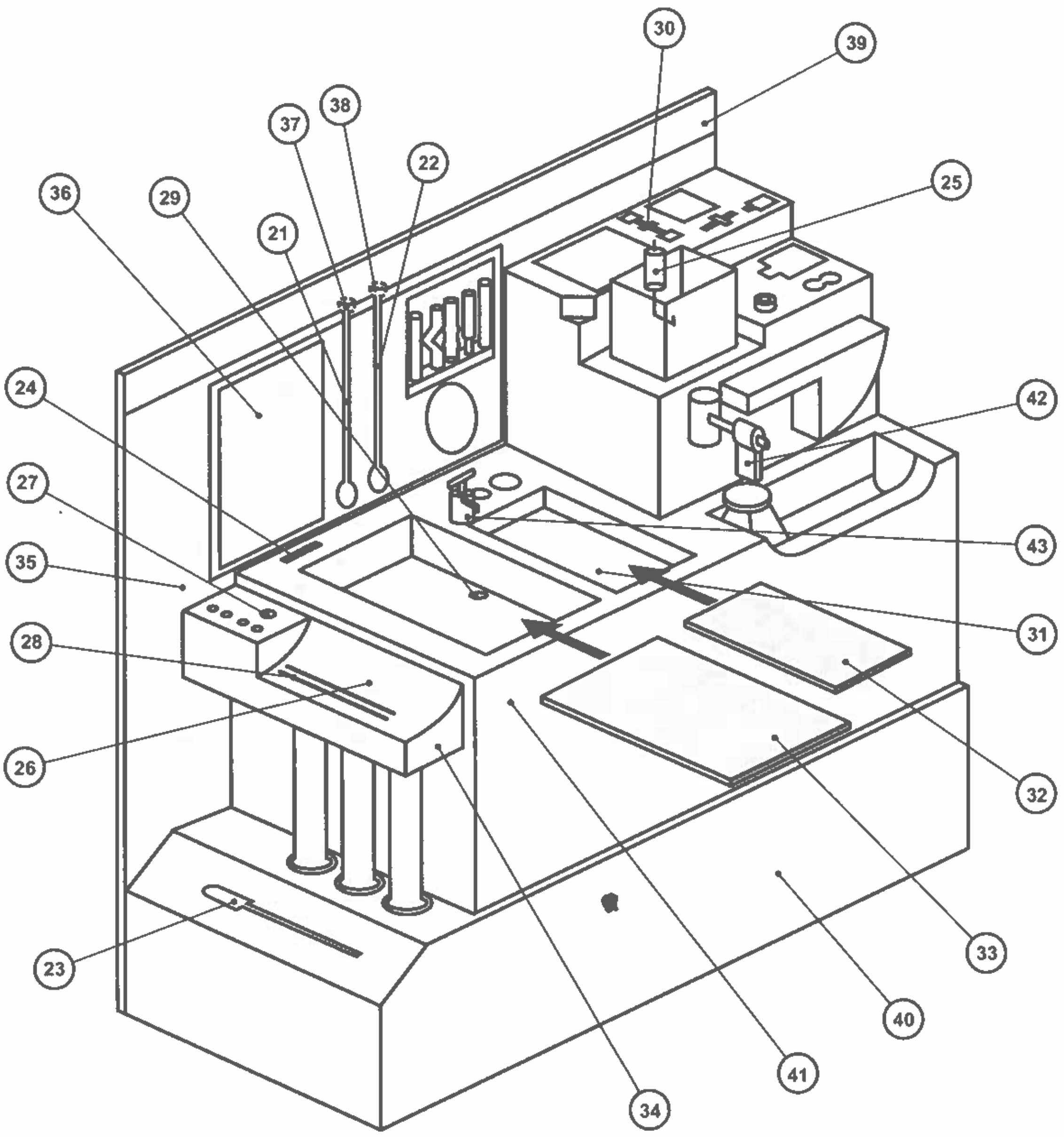
- Determination of fluid density and specific gravity
- Principles and use of a hydrometer
- Capillarity (capillary action) in tubes and between plates
- Measurement of viscosity by falling sphere method
- Demonstration of Pascal's Law
- Measurement of fluid levels by hook gauge
- Fluid flow head relationship
- Verification of Archimedes' Law and demonstration of the principles of flotation
- Stability of a floating body and determination of metacentric height
- Measurement of force and centre of pressure on a plane surface
- Operation and calibration of a Bourdon pressure gauge
- U-tube manometers

1.3 Item List



1	Measuring Beaker – 800ml	11	Graduated Jars
2	Measuring Beaker – 100ml	12	Stopwatch
3	Beam Balance	13	Pascal's Tubes
4	Eureka Can	14	Archimedes
5	Density Bottle	15	Pontoon
6	Header Tank	16	Toroidal Segment
7	Capillary Tubes	17	Weights (10 g)
8	Capillary Plate	18	Bourdon Gauge
9	Shims	19	Calibration Cylinder
10	Spheres	20	Weights (Iron)

Figure 2 Item List 1



21	Fluid Manometer	32	Right Hand Sink Cover
22	Water Manometer	33	Left Hand Sink Cover
23	Cycle Pump	34	Side Moulding
24	Valve (V1)	35	Schrader Valve (V4)
25	Depth Gauge	36	User Guide
26	Hydrometer	37	Fluid Manometer Trap
27	Ball Guide	38	Water Manometer Trap
28	Pipette Tube	39	Top Moulding
29	Rubber Bung	40	Main Unit
30	10 g Weight Hangers	41	Sump Tank (Internal)
31	Drain Cover	42	Vertical Scale
		43	Bilge Pump

Figure 3 Item List 2

NOTE **Items 1 to 28 in Figures 2 and 3 are not the same as the numbers on the Packing Contents List (PCL). Use the descriptions to match items on the apparatus with those on the PCL.**

1.4 Fluid Circuit Layout

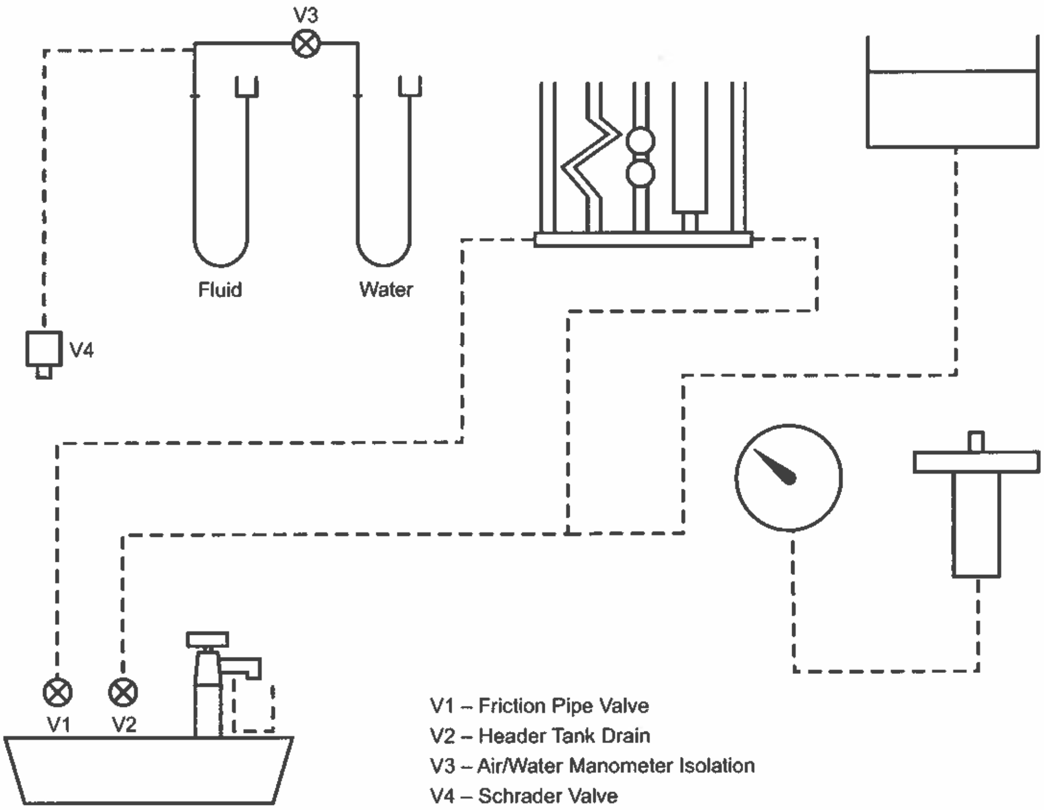


Figure 4 H314 Fluid Circuit Diagram

Figure 4 shows a fluid circuit diagram of the apparatus for reference.

1.5 Technical Details

Item	Details
Nett Dimensions and weight	1700 mm long x 1700 mm high and 750 mm front to back. 120 kg
Coloured Dye supplied	Non-toxic food colouring (refer to datsheet supplied) Colour: Red or blue
Manometer fluid supplied	Specific gravity 1.99 (~2) 10 mm water ~ 5.0 mm fluid

SECTION 2.0 ASSEMBLY AND INSTALLATION

2.1 Unpacking

TecQuipment supply the H314 Hydrostatics and Properties of Fluids apparatus in a partially-assembled condition.

Before you start assembling, examine and thoroughly clean out any dust and packing materials from all parts. Particularly the inside of the sump tank, as foreign bodies can cause blockages in the pump and the valve.

2.2 Assembly

Refer to Figure 2 and Figure 3 for a list of the various parts and their numbers which are used below.

a) Put all loose items in their correct moulded storage areas on the unit.

b) Fill the sump tank (41) to within approximately 25 mm of the drain hole of the left-hand reservoir. Add a little water colouring.

c) Remove the cover (39) and fill the manometers via the manometer traps. The right-hand side manometer is air/water, the left-hand side manometer is for the manometer fluid supplied in a small bottle (specific gravity 1.99). Approximately half full on both manometers gives best results.

WARNING

The manometer fluid is non hazardous, but do drink or ingest it.

Refer to the datasheet supplied for details.

d) Carefully unpack the pressure gauge calibration cylinder (19) and place into the moulded recess provided. Connect the length of clear plastic tube from the rear of the pressure gauge to the base of the cylinder. The cylinder may now be filled with water and bled at the gauge end to remove all traces of air.

e) Use the bilge pump (43) and the 800 ml beaker (1) to fill the header tank (6).

f) Screw the depth gauge (25) to the block on the header tank using the stainless steel screws provided.

g) Assemble the Stability of a Floating Body apparatus by fitting the sail into its housing on the pontoon and tightening the clamp screws. Check that the plumb bob hangs vertically downwards on its cord and is free to swing across the lower scale.

The unit now ready for use.

2.3 Magnets

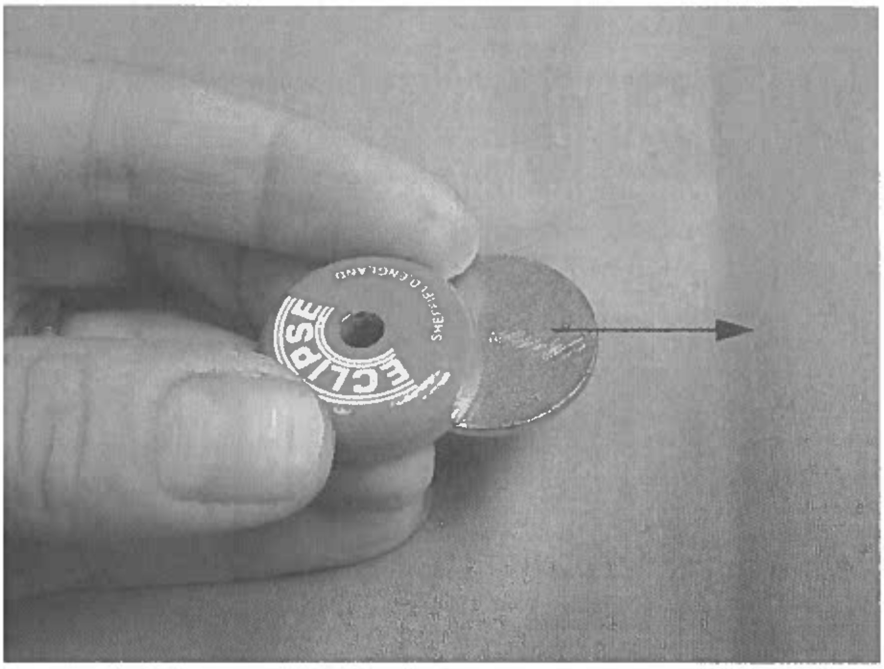


Figure 5 Remove Keep

TecQuipment supply two small magnets with the equipment to help 'trim' the balance of the pontoon on the 'Stability of a Floating Body' Experiment. These magnets have a metal 'keep' that helps keep their magnetism when they are not being used or when packed for transport. Remove the keeps before you use the magnets or they will not stick to the metal parts on the equipment. Replace the keeps when you have finished with the magnets or need to repack them.

WARNING

This equipment uses powerful magnets - always put the protective metal plates ('keeps') back on the magnets when they are not in use. This helps to contain and keep the magnetism strong for several years.

Keep any sensitive mechanical watches or instruments away from the magnets.

Always slide the magnets onto the metal surface of the pontoon. Never allow them to impact against it, as you may trap the skin of your fingers or damage the paintwork.

SECTION 3.0 THEORY AND EXPERIMENTS

3.1 Notation

A	Area
d, D	Diameter
F	Force
g	Acceleration due to gravity
h	Height of depth of fluid
Δh	Height difference (e.g. differential head of manometer)
M	Moment
p	Pressure
R	Radius
u	Velocity
W and ω	Weight
m	Mass
ρ	Density of fluid
σ	Density of solid, surface tension
θ	Angle
τ	Shear stress
μ	Coefficient of viscosity
ν	Kinematic viscosity

3.2 Properties of Fluids

The term fluid relates to both gases and liquids (for example, air and water) and, although there are differences between them, they both have the same essential property that when acted upon by any unbalanced external force, an infinite change of shape will occur if the force acts for a long enough time. Alternatively, one may say that if acted on by a force, a fluid will move continuously, while a solid will distort only a fixed amount. If a shear force is applied to one surface of a volume of fluid, the layers of fluid will move over one another, so producing a velocity gradient in the fluid. For a given shear stress, a property called the viscosity determines the velocity gradient and hence the velocity of the fluid in the plane of the applied stress. The viscosity is a measure of the fluid's resistance to motion. Viscosity is a very important property in fluid mechanics since it determines the behaviour of fluids whenever they move relative to solid surfaces.

Liquids and gases both share the property of fluidity described previously, but they differ in other respects. A quantity of liquid has a definite volume and, if in contact with a gas, it has a definite boundary or free surface. Gases, on the other hand, expand to fill the space available and cannot be considered as having a definite volume unless constrained on all sides by fixed boundaries, such as a totally enclosed vessel. The volume of a liquid changes slightly with pressure and temperature, but for a gas these changes can be very large. For most engineering purposes, liquids can be regarded as incompressible, by which we mean that volume and density do not change significantly with pressure, whereas gases usually have to be treated as compressible. Similarly, the effects of varying temperature can often be ignored for liquids, except in certain special cases, but must be taken into account with gases.

The engineer is often concerned with determining the forces produced by static or moving fluid and, when doing this, the above differences between liquids and gases can be very important. Generally, it is much easier to deal with liquids because, for most purposes, it can be assumed that their volume and density do not change with pressure and temperature. In the study of hydrostatics, we are primarily concerned with the forces due to static liquids. The forces result from the pressure acting in the liquid and, at a given point, this depends on the depth below the free surface. Density, or mass per unit volume, is a basic property which must be known before any calculation of forces can be made.

When considering the interfaces between liquids, solids and gases there is a further property which can produce forces and this is called the surface tension. When a liquid/gas interface is in contact with a solid boundary, the edge of the liquid will be distorted upwards, or downwards, depending on whether the solid attracts or repels the liquid. If the liquid is attracted to, or 'wets' the solid, it will move upwards at the edge and the surface tension will cause a small upwards force in the body of the liquid. If the liquid is in a tube, the force will act all round the periphery and the liquid may be drawn up the tube by a small amount. This is sometimes called the capillarity effect or capillary action. The forces involved are small and the effect need only be considered in a limited number of cases.

3.3 *Determination of Density*

To determine the density of a liquid it is necessary to measure the mass of a known volume of liquid. The volume is the more difficult quantity to determine, and an outline of three methods follows. Any liquid may be used but, for demonstration purposes, water is the most convenient.

Measuring Beaker

a) Weigh the empty measuring beaker (1) using the triple-beam balance (3) and record the mass.

b) Fill the beaker with water and read the volume as accurately as possible.

c) Weigh the beaker plus water and record the mass. The mass of water can then be determined by subtraction and the density ρ obtained as:

$$\rho = \frac{\text{Mass in grammes}}{\text{Volume in ml}} \times \frac{10^6}{10^3} \ (\text{kg/m}^3)$$

The density of pure water at 20°C is 998.2 kg/m^3 and this is often rounded up to 1000 kg/m^3 for engineering purposes. The experimental result should be within 1% of this value. The measurement of volume is not very precise and depends on the accuracy of the graduations on the beaker and this cannot be checked.

Eureka Can

The Eureka can (4) is a container with a fixed spout. If filled until liquid overflows from the spout, the final level when the liquid has stopped flowing will always be the same, provided the can is level and the liquid is not contaminated. If the can is initially full and a solid object is placed in it, a volume of liquid will be displaced equal to the volume of the object. This gives us a basic method of obtaining a known volume of liquid.

a) Take a solid object which will fit in the can (for example, a cylinder or cube) and accurately measure its dimensions and calculate its volume.

b) Place the Eureka can at the edge of the working surface and fill it with liquid until it overflows.

c) Weigh an empty beaker (2) and place this under the spout.

d) Gently lower the object into the can until fully immersed and collect the liquid in the beaker. Now re-weigh the beaker plus liquid.

The mass of liquid displaced can be obtained by subtraction and the density calculated as before. The result may be less accurate than with the measuring beaker, but it demonstrates a more fundamental way of determining the volume of liquid. The errors might be reduced if the can and the solid object were much larger. A good question for discussion might be whether the best accuracy would be obtained with a narrow deep can, or a wide shallow can.

Density Bottle

The problem of accurately measuring a volume of liquid can be overcome by using a special vessel with a known volume, such as a density bottle (5). This is accurately made and has a glass stopper with a hole in it through which excess liquid is expelled. When the liquid is level with the top of the stopper, the volume of liquid is 50 cm^3 (ml).

a) Dry and weigh the bottle and stopper.

b) Fill the bottle with liquid and replace the stopper.

c) Carefully dry the outside of the bottle with a cloth or tissue paper and remove any excess liquid from the stopper, such that the liquid in the hole is level with the top of the stopper.

d) Re-weigh the bottle plus liquid and determine the mass of liquid and hence the density.

This method should give an accurate result and is limited more by the accuracy of the balance than by the volume of liquid.

Density of Solids

Having determined the density of a liquid, such as water, it is interesting to note that the methods used can be adapted to measure the density of irregular solids, for example sand. If a measured weight of sand is put into the Eureka can instead of a solid object (as described in the Eureka can experiment above), we can determine the volume of sand from the mass of water displaced (since we now know the density of water). The density of the sand is its mass divided by the volume of water displaced. The density bottle could also be used to determine the density of sand and the student could be asked to work out how to do this as a further exercise.

3.4 Specific Gravity

Specific gravity, or relative density as it is sometimes called, is the ratio of the density of a fluid to the density of water. Typical values are 0.8 for paraffin, 1.6 for carbon tetrachloride and 13.6 for mercury. Specific gravity should not be confused with density, even though in some units (for example, the c.g.s. system) it has the same numerical values.

Similarly, specific weight should not be confused with density or specific gravity. Specific weight is used in some text books in place of density and is the weight force per unit volume of a fluid. It only has a fixed value when the gravitational acceleration is constant. In determining density, we have used a beam balance to 'weigh' quantities of liquid and this is calibrated in grammes (i.e. units of mass). The quantity to be weighed is balanced by sliding weights along the lever arms. A useful question for discussion could be:

> *"Would the density of water be the same on the Moon, where gravity is one-sixth that on the Earth, and would you obtain the same result for density if you used the methods in Section 3.3 on the Moon?"*

Specific gravity can be determined directly from the density of a liquid as measured, for example, by using a density bottle. The value is simply divided by the density of water to obtain the specific gravity. A convenient alternative method is to use a specially-calibrated instrument called a hydrometer (27). This takes the form of a hollow glass float which is weighted to float upright in liquids of various densities. The depth to which the stem sinks in the liquid is a measure of the density of the liquid and a scale is provided which is calibrated to read specific gravity. The sensitivity of the hydrometer depends on the diameter of the stem. A very sensitive hydrometer would have a large bulb and a thin stem (see Figure 6).

To determine the specific gravity of any liquid, place one of the tall glass cylinders (11) on the measuring surface and fill with a liquid and allow the air to rise to the top. Carefully insert the hydrometer and allow it to settle in the centre of the cylinder. Take care not to let it touch the sides, otherwise surface tension effects may cause errors. When the hydrometer has settled, read the scale at the level of the free water surface at the bottom of the meniscus, as in Figure 6.

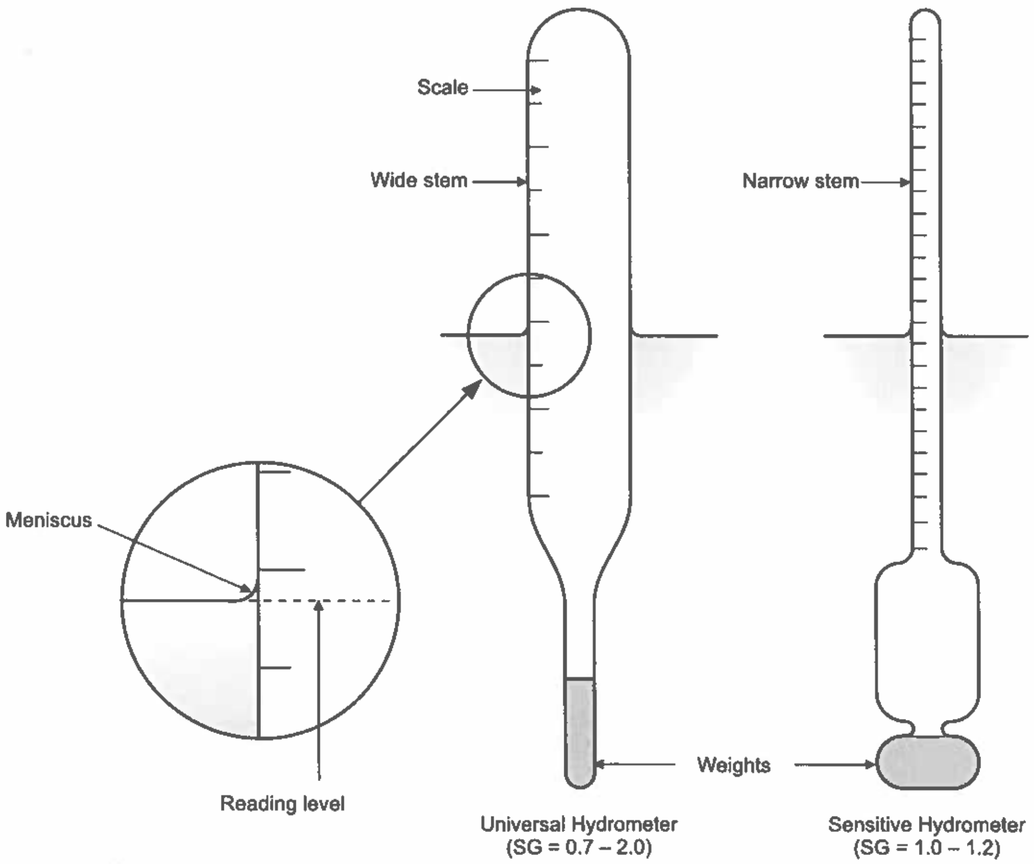


Figure 6 Types of hydrometer

3.5 Capillarity (Capillary action)

The capillarity apparatus is provided with three glass capillary tubes having bores of 0.4 mm, 0.8 mm and 1.6 mm (7). Glass plates (8) are provided, together with plastic shim material (from which strips can be cut to hold the plates a fixed-distance apart). The thicknesses are as follows:

Dark blue	0.050 mm
Green	0.075 mm
Amber	0.100 mm
Slate	0.125 mm
Natural	0.190 mm
Black	0.250 mm
Red	0.400 mm
Yellow	0.500 mm

For demonstration purposes, it is recommended that a single thickness of the yellow shim should be used to give a plate separation of approximately 0.5 mm. One strip 5 to 10 mm wide should be placed down two edges of a plate and the second plate clamped to it using the clips. The plate assembly is then placed in the header tank (6) in the slot provided, and supported by the extended clips (Figure 7). If necessary, adjust the water height in the header tank by means of the drain valve. The water will creep up the tubes and between the glass plates. The levels can be measured and compared. As a simple demonstration, this shows firstly that capillarity (capillary action) does in fact take place, and secondly that the height to which the water rises depends on the size of the tube. The effect is clearly only significant if the gap is small and is generally ignored for tubes with a bore larger than about 5 mm.

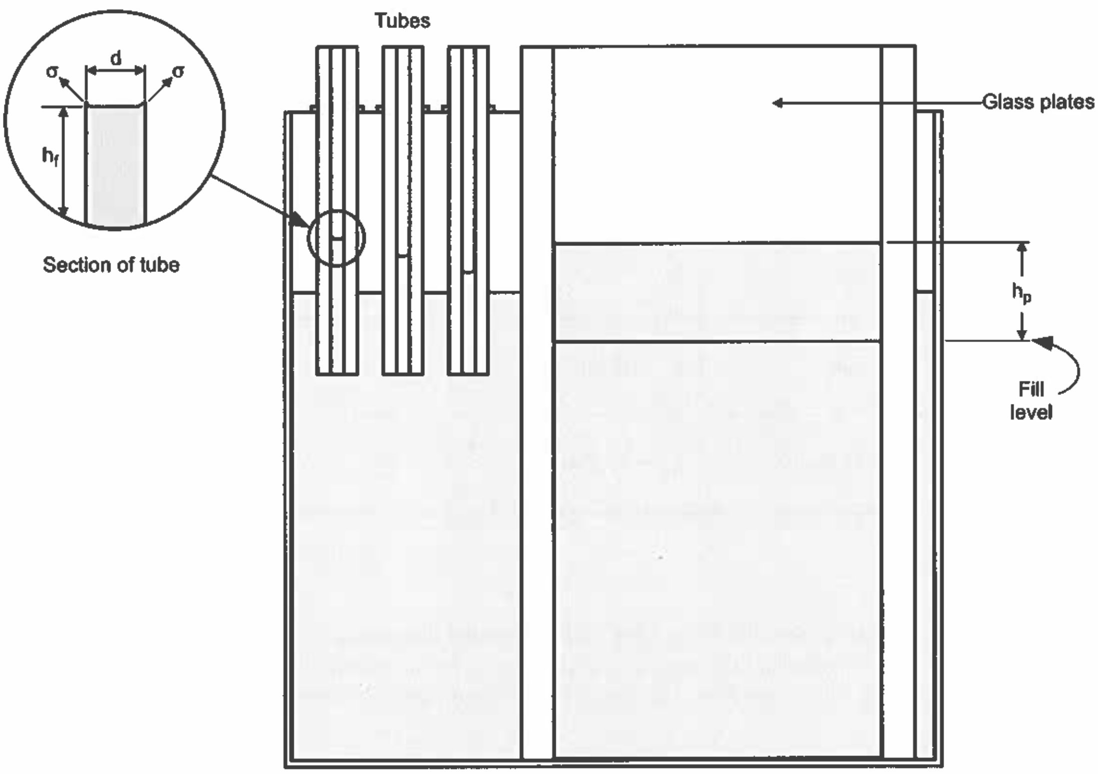


Figure 7 Capillarity Apparatus

A quantitative analysis can be carried out as follows.

An enlarged section of a tube is shown in Figure 7. The surface tension σ (force per unit length) produces an upwards force around the periphery of the tube. We will assume that the water is drawn up at the edges, such that it forms a tangent to the surface, and the force acts vertically on the water. The total force F is:

$$F = \pi d \sigma \qquad (1)$$

For equilibrium, this force is balanced by the weight W of the column of water which is approximately:

$$W = \frac{\pi d^2}{4} \rho g h_t \qquad (2)$$

Solving for h_t between Equations (1) and (2) we obtain:

$$h_t = \frac{4\sigma}{\rho g d} \qquad (3)$$

Similarly, for capillary action between plates distance b apart, we obtain:

$$h_p = \frac{2\sigma}{\rho g b} \qquad (4)$$

The actual heights obtained in an experiment will depend very much on the cleanliness of the tubes or plates and on whether any impurities are present in the water. The effect can be very variable and it is not worth calculating values of height from an accepted value of σ as the heights are unlikely to agree with observations. However, it is worth checking that the heights are in the correct proportions. If σ and ρ are constant, we should find that $\frac{h_t d}{4}$ and $\frac{h_p b}{2}$ are constant (i.e. equal to $\frac{\sigma}{\rho g}$) for various tubes and various plate separations.

A typical set of results is as follows:

1.6 mm tube:	$h_t = 7$ mm	$\frac{h_t d}{4} = 2.8$
0.8 mm tube:	$h_t = 12$ mm	$\frac{h_t d}{4} = 2.4$
0.4 mm tube:	$h_t = 23$ mm	$\frac{h_t d}{4} = 2.3$
Plates 0.35 apart:	$h_p = 14$ mm	$\frac{h_p b}{2} = 2.5$

Table 1 Typical Results

The results in Table 1 demonstrate that the levels vary in the predicted manner and that σ was roughly constant. In most hydrostatic calculations, the effect of surface tension can be ignored, but in cases concerning liquid in small tubes it may need to be taken into account. This is referred to in detail in the experiments on manometry later in this section.

3.6 Viscosity

As explained in the introduction to this section, viscosity is one of the most important properties of fluids since it determines the behaviour whenever relative movement between fluids and solids occurs. In a simple case in which a section of fluid is acted on by a shear stress τ, it can be shown that a velocity gradient is produced which is proportional to the applied shear stress. The constant of proportionality is the coefficient of viscosity μ and the equation is usually written:

$$\tau = \mu\frac{du}{dy} \qquad (5)$$

where $\frac{du}{dy}$ is the velocity gradient normal to the plane of the applied stress.

Equation (5) is derived in most text books and represents a model of a situation in which layers of fluid move smoothly over one another. This is termed **viscous** or **laminar** flow. For such conditions, experiments show that Equation (5) is valid and the μ is constant for any given temperature. For other conditions at higher velocities, when turbulent eddies are formed and mixing takes place between the layers, the behaviour cannot be represented so simply and we will not consider these cases here.

Equation (5) shows that if fluid flows over an object, there will be a velocity gradient in the flow adjacent to the surface, and a shear force transmitted to the fluid which tends to resist its motion. Similarly, if an object moves through a fluid, velocity gradients will also be set up and a force generated on the object which tends to resist its motion. In all such cases, a knowledge of μ is required to calculate the forces involved. It should be noted that μ varies with temperature, so values for a given fluid are usually tabulated for various temperatures. In the SI system μ has units of Ns/m^2.

In fluid mechanics the term μ/ρ often appears and this is called the **Kinematic Viscosity** and is denoted by:

$$\nu = \frac{\text{Coefficient of Viscosity } \mu}{\text{Density } \rho} \qquad (6)$$

Kinematic viscosity is very often more convenient to use and has units of m^2/s which are often easier to work with.

There are many experimental methods which can be used to determine μ and these are generally less direct than measuring the parameters in Equation (5). One common method is to consider the rate at which a smooth sphere will fall through a liquid for which it is required to determine the viscosity. Under equilibrium conditions, the shear or 'friction' forces on the sphere will equal its weight, and the sphere will fall at a constant velocity u, called the **terminal velocity**. An equation due to Stokes defines the terminal velocity and this is called **Stokes' Law**.

The equation can be written:

$$u = \frac{gd^2}{18\nu}\left(\frac{\sigma}{\rho} - 1\right) \qquad (7)$$

where:

- d is the diameter of the sphere
- σ is the density of the sphere
- ρ is the density of the fluid
- ν is the kinematic viscosity of the fluid.

This equation is only applicable for viscous flow, for which a variable called **Reynolds Number** is below a certain value where:

$$\text{Reynolds Number Re} = \frac{\rho u d}{\mu} = \frac{ud}{\nu} \qquad (8)$$

The limiting value of Re is often taken as 0.2 and, above this value, the errors in applying Equation (7) becomes significant.

In considering Equation (7), it is clear that the velocity decreases as ν increases, and this can be demonstrated for a range of different liquids. It is also possible to determine ν (or μ) from Equation (7) and this can be done using the falling sphere viscometer supplied with the apparatus.

Demonstration of Varying Viscosity of Liquids

For this simple demonstration, the three graduated jars can be used, together with the set of steel balls supplied. The cylinders should be filled with three different liquids, for example, water, oil and glycerine. Insert the ball guide (28) into the top of each cylinder in turn. Comparisons can be made by dropping balls (10) of the same size into each cylinder and observing the time taken to reach the bottom. By comparing different sized balls, it can be shown that the velocity depends on diameter as shown in Equation (7).

Determination of Viscosity

The viscosity of relatively high viscosity fluids, such as oil, glycerine, castor oil and so on, can be determined. Fill each of the three graduated jars with different fluids.

NOTE: The oil supplied with the H314 is for maintenance of the piston of the pressure measurement instruments, not for the viscosity experiments.

Test each fluid in turn by:

a) Inserting the ball guide.

b) Set the upper timing band marker approximately 20 mm below the level of the base of the ball guide.

c) Set the lower timing band marker to approximately 200 mm below the first.

d) Drop the ball into the fluid and time the descent between the markers using the stopwatch (12).

e) Measure the distance between the markers.

f) Measure the temperature of the liquid.

Note:

a) Moveable timing band markers are used to allow practical timings for very viscous fluids where less than a 200 mm fall is required.

b) A vertical reference for the timing band markers is provided by the volume scale on the jar.

Liquid	Specific gravity at 200°C	Kinematic viscosity ($\nu \times 10^5$) m^2/s at 20°C	Typical time to fall 200 mm(s)	
			1.6 mm ball	3.2 mm ball
Water	1.0	0.1	0.02	0.005
Medium oil	0.89	12	2.8	0.7
Thick oil	0.90	30	6.8	1.7
Glycerine	1.26	65	10	2.5
Caster oil	0.96	100	20	5

Table 2 Viscosity Data for Typical Liquids

It can be seen that thick oils, glycerine and castor oil are the most suitable and that the best accuracy (i.e. longest times) is obtained with the smallest balls.

Typical results obtained with fairly thick lubricating oil, using a 1.6 mm ball, are as follows:

Actual ball diameter	= 1.59 mm
Temperature of oil	= 18°C
Time to fall 200 mm	= 4.2 secs

The density of the ball was taken as 7800 kg/m^3 and that of the oil as 900 kg/m^3. Hence, $\frac{\sigma}{\rho} = 8.7$.

The velocity was $\frac{0.2}{4.2} = 0.048$ m/s.

From Equation (7):

$$\nu = \frac{gd^2}{18\mu}\left(\frac{\sigma}{\rho} - 1\right) = \frac{9.81 \times 1.59^2 \times 10^{-6} \times (8.7 - 1)}{18 \times 0.048}$$

Therefore:

$$\nu = 22.1 \times 10^{-5} \text{ m}^2/\text{s}$$

These results are in reasonable agreement with those expected from the data given in Table 2.

3.7 Hydrostatic Principles

In the study of hydrostatics, we are primarily concerned with the pressures and forces produced on solid boundaries by static fluids and, in particular, liquids. It can generally be assumed that the density of fluid does not vary significantly with pressure. Density does vary with temperature, but for most purposes this variation can also be ignored. For water, it can be assumed that the density is constant and equal to 1000 kg/m^3. In order to determine the effects of forces produced by static liquids, we need to know the pressure at each point in the liquid and the direction of the forces produced.

Consider the column of liquid in Figure 8. The cross-sectional area is constant and equal to A, the height is h, and the liquid is homogeneous and therefore of constant density ρ. The downward force at plane 2 is the sum of the pressure p_1 acting over area A and the weight of water in the column. For equilibrium, this must be balanced by pressure p_2 acting upwards over area A, so we may write:

$$p_2 A = p_1 A + \rho g h A$$

or

$$p_2 = p_1 + \rho g h \qquad (9)$$

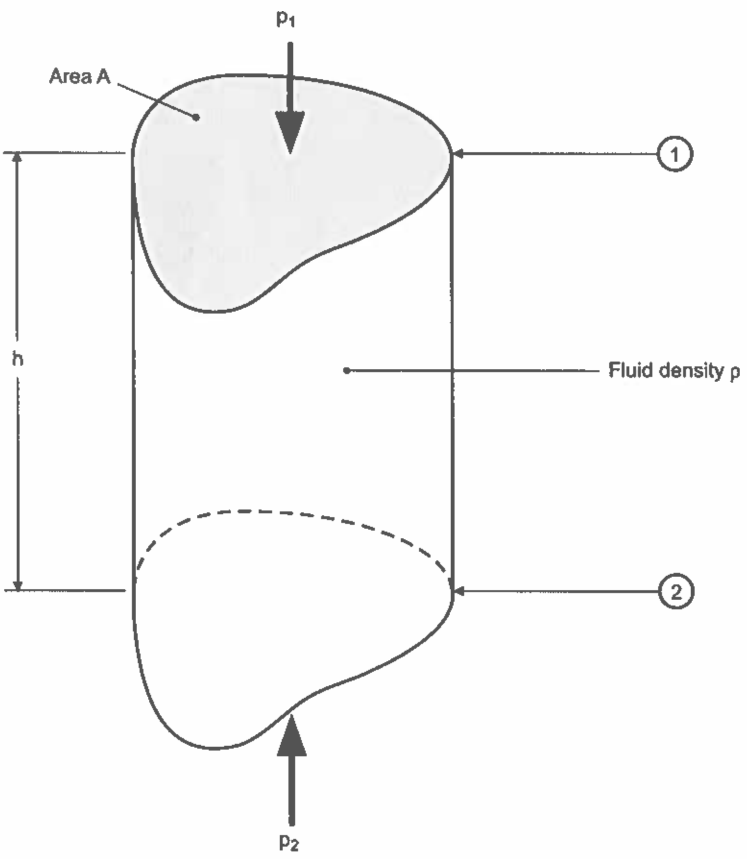


Figure 8 Hydrostatic Pressure due to a Column of Fluid

Notice that the area cancels out and plays no part in determining p_2 so, if the area is very small, we can consider p_2 as the pressure at a point in the liquid. Also note that we have considered p_2 as a pressure acting on the fluid at plane 2. If the liquid column extends downwards, then p_2 must be the pressure exerted upwards by the liquid just below plane 2. Similarly, the liquid at plane 2 must exert a pressure p_2 in the downward direction. We may therefore deduce that the pressure at a point acts equally upwards and downwards. In fact, the pressure at a point in a liquid acts equally in all directions and this is known as **Pascal's Law**. Most text books give proof of this by considering the pressure forces acting on a triangular prism of fluid. The derivation need not be given here.

There are two further important facts about pressure forces in fluids which are related to Pascal's Law.

a) Pressure forces acting between liquids and solid boundaries always act normal to the plane of the boundary if the liquid is at rest. If they did not, shear forces would be produced and, as discussed in Section 3.2, the liquid would then move.

b) The pressure is the same at all points in any horizontal plane in a liquid at rest. If this were not the case, there would be a sideways force on an element of liquid and the liquid would move.

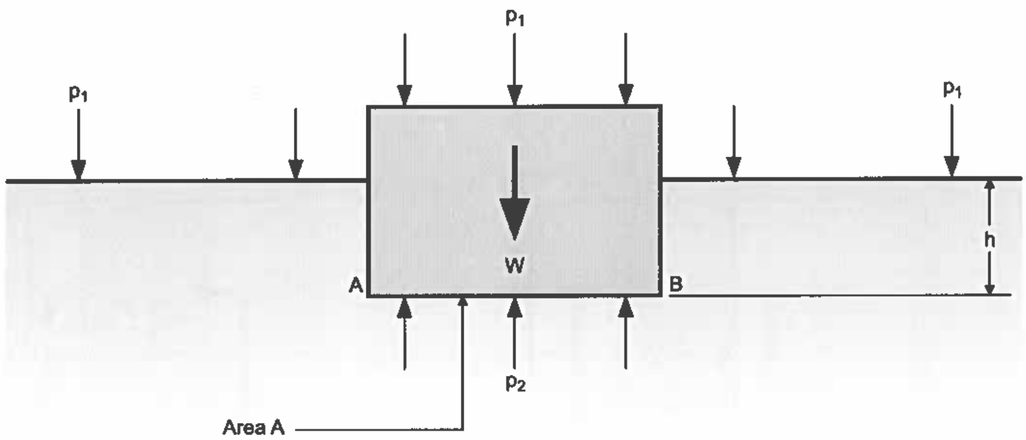


Figure 9 Upthrust on a Floating Body

We may now consider the case of a body immersed in a liquid. Figure 9 shows a rectangular body of a plan area A floating in a liquid with its bottom horizontal. The pressure p_2 acting upwards on the bottom is given by Equation (9) and is equal over area A. For equilibrium, the net upwards force must balance the weight W, hence:

$$W = (p_1 + \rho g h)A - p_1 A = \rho g h A \qquad (10)$$

We may also note that the volume of water displaced is h × A and its weight is ρghA. This is equal to the net upwards force of upthrust given by Equation (10). In fact, this is a simple case of a general rule known as **Archimedes' Law** which states that: *"The upthrust is equal to the weight of water displaced."* This is true for any body, irrespective of its shape, provided that the body and the liquid are at rest.

Liquid Level Apparatus (Pascal's Law)

The apparatus (13) consists of vertical tubes of different sizes, shapes and cross-sections. The tubes are joined by a horizontal pipe at the bottom. The apparatus is permanently connected to the header tank and will thus be filled as the header tank is filled. The header tank is filled using the bilge pump (44) and the 800ml beaker (1). Ensure that the drain valve is closed.

Before filling the apparatus, students should be asked what the levels might be in each of the tubes. Some may well suggest that the levels will be different due to the different cross-sectional areas. Filling the apparatus to various levels will soon show that the levels are always the same in all the tubes. The only slight variation which may occur is due to surface tension and capillary action in the two thinner tubes. This can form a separate point for discussion. Various conclusions can be drawn by considering the conditions in the apparatus.

a) There is no flow along the horizontal pipe between the tubes, so the pressure in the horizontal pipe must be constant.

b) The pressure at the bottom of each tube is the same, and the height of water in each is the same. Therefore, a given height of liquid always produces the same pressure, irrespective of the area of the tube and the weight of water contained in it.

c) The same pressure is produced by a certain height of liquid, irrespective of the shape of the tube containing the liquid.

d) Pressure is transmitted down the bent tube in the same way as in the other tubes. Since the tube is bent, the pressure must act at different angles, following the shape of the tube, and this indicates that pressure acts equally in all directions.

Fluid Upthrust (Archimedes' Law)

"Every body experiences an upthrust equal to the weight of liquid displaced." The validity of Archimedes' Law can be demonstrated using the cylindrical body (14) attached to moulding above the three-beam balance.

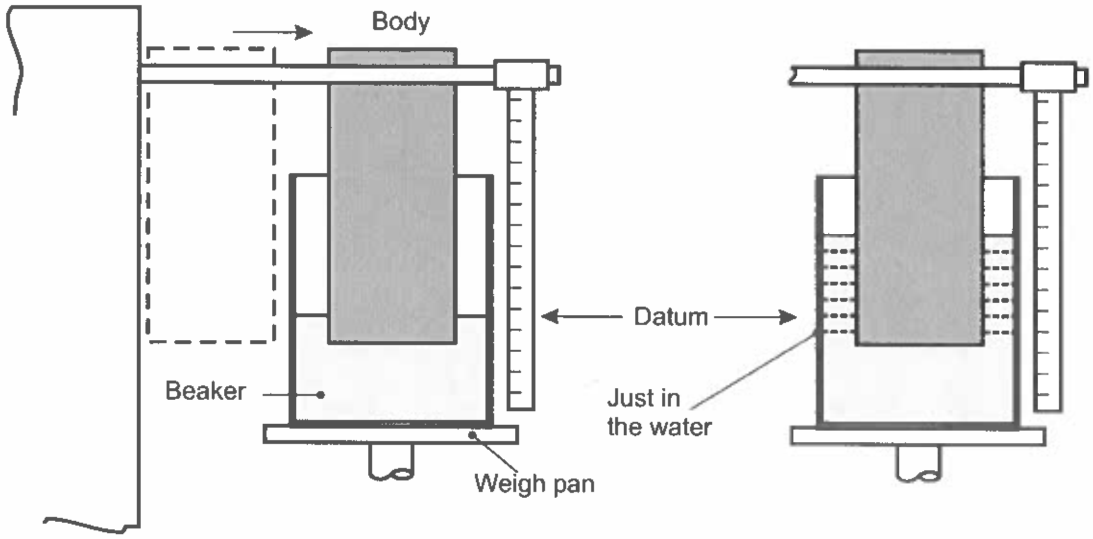


Figure 10 Apparatus for Determination of Fluid Upthrust

Measure the diameter of the body to find its area. Measure the internal diameter of the beaker to find its area. The difference between the two will be the area of the water surface that rises during the experiment. When used with the height change, this may be more accurate than using the (possibly coarse) volume scale printed on the beaker.

Slide the body out from its parked position until it is over the weigh pan of the scale and measure its diameter. Place the body in a beaker by rotating it through 90°, fitting the beaker, and then letting the body and beaker come back to the vertical, allowing the beaker to rest on the pan, as shown in Figure 10.

a) Fill the beaker with water until the body is ***just*** in the water, then balance the scale. The water level will rise slightly.

b) Record the weight needed for balance, and the new height of the water. These are ***the datum values***.

c) Add a small amount of water. Again, balance the scale, record the weight and new height of water ***above the datum values***.

d) Repeat to give at least six steps up to somewhere near the maximum volume of the beaker.

e) Convert the height into metres and weights into Newtons for direct comparison with theory.

Note that the weights you apply to balance the scale should be equal to the increase in weight of water ***plus*** the value of upthrust - which is equal to the displaced water. Alternatively, half the applied weight must equal the weight of the displaced water.

Using the area of the water and its changes in height, you can calculate the volume of water displaced by the cylinder in the beaker, for a given increase in weight on the balance. Showing the principle of 'Archimedes'.

f) Plot a chart of Displaced Weight of Water and 0.5 x the Applied weight above datum (vertical axis) against height of water above datum. Compare the two sets of results.

To drain the beaker after the experiment, slide the body and beaker together off the support and pour water through the working surface.

Datum water height:			Datum weight for balance:		
Water Height on scale (mm)	Height h above datum (m)	Applied Weight for balance above datum (g)	Applied Weight for balance above datum (N)	Displaced Volume of water (m^3)	Weight of displaced water (N)

Table 3 Blank Results Table

Typical calculation:

Body diameter = 70 mm, giving an area of 0.00385 m^2

Beaker internal diameter = 96 mm, giving an area of 0.0072 m^2

Area (A) of water surface = 0.0072 - 0.00385 = 0.00335 m^2

Datum height = 37.5 mm (0.0375 m) with a ***datum*** balance of 472 g (4.63 N).

Adding some water gave a height of 60 mm, which is 0.0225 m above datum.

The weight needed for balance was 621 g (6.09 N), which is 1.46 N above datum.

The water volume increase (h x A) was therefore 0.0225 x 0.00335 = 0.000075 m^3

The water weight increase was therefore 1000 kg.m^3 x 9.81 x 0.000075 = 0.736 N

Weight for balance (1.46 N) is therefore roughly twice that of the water weight (0.736 N).

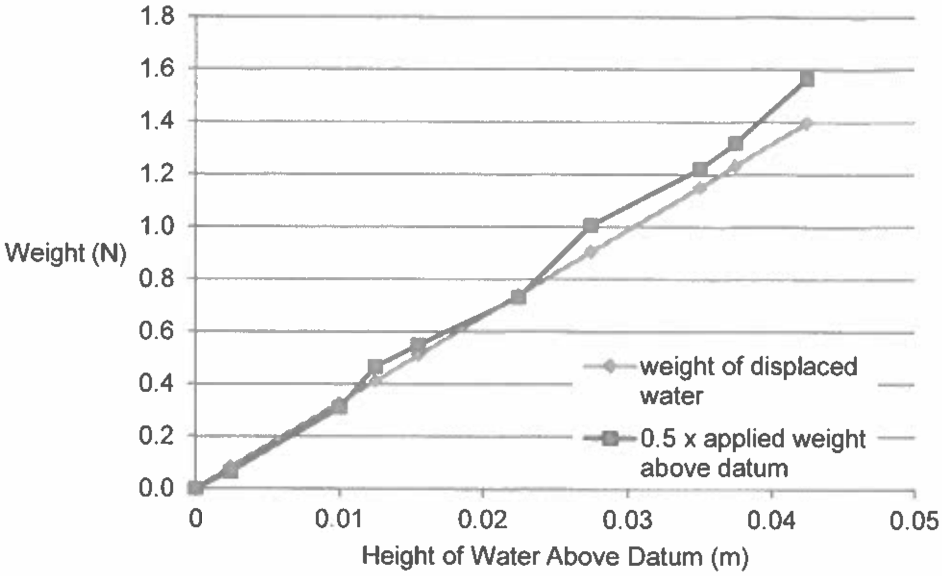


Figure 11 Typical Results