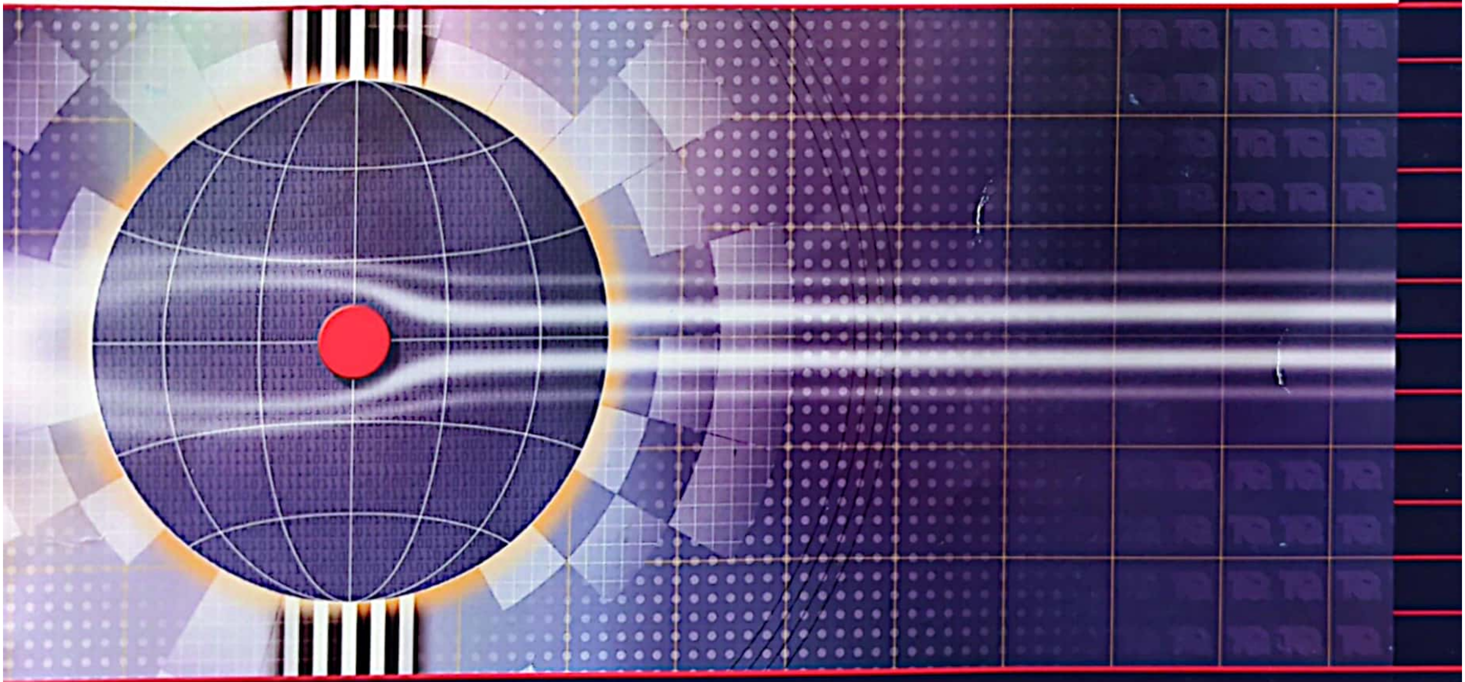
TecQuipment

H314

Hydrostatics and Properties of Fluids

User Guide



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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.

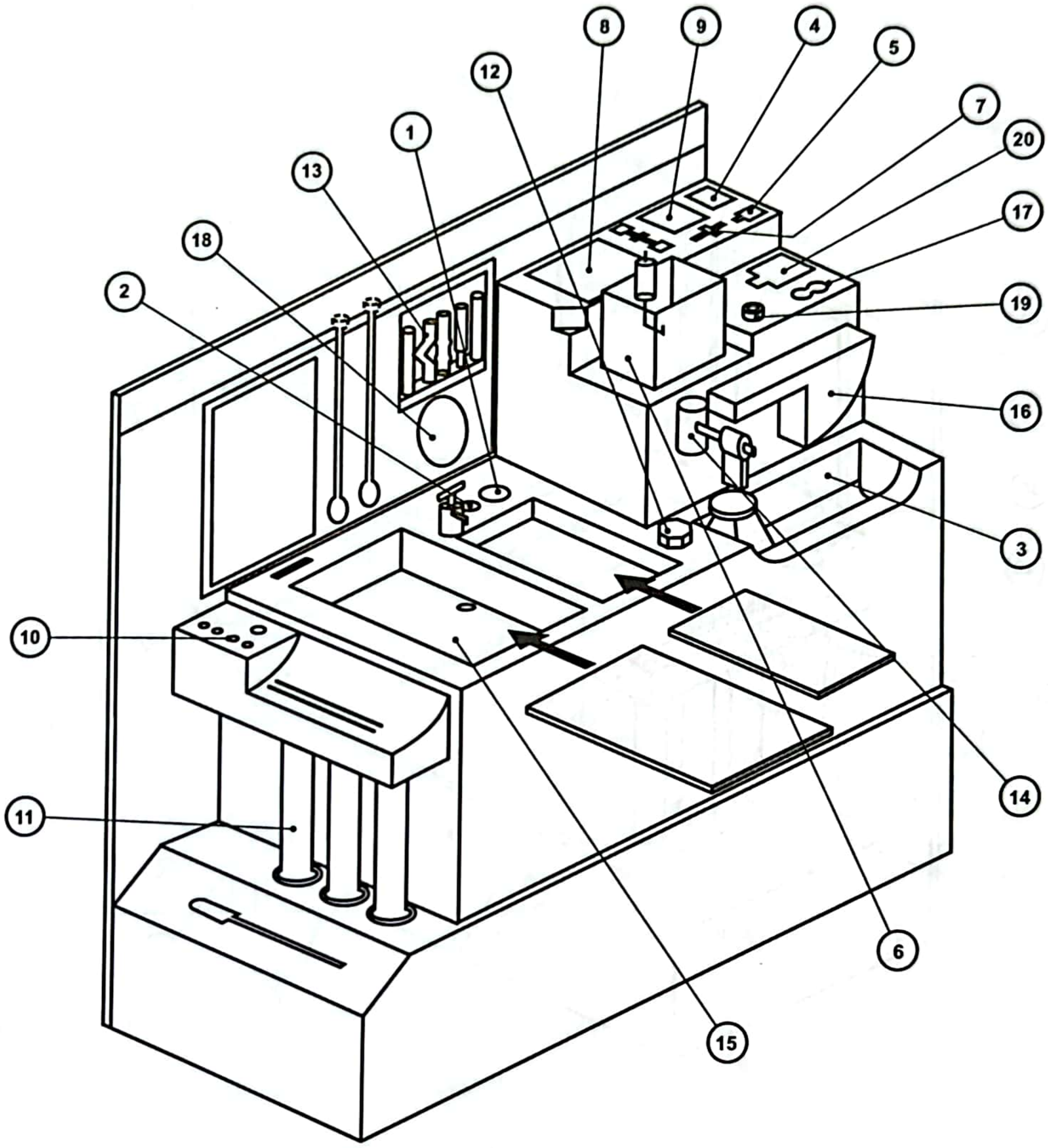
A portion of the working surface can be removed to access a reservoir which stores a rectangular stability pontoon with adjustable weights, and can be filled to float the pontoon for experiments.

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:

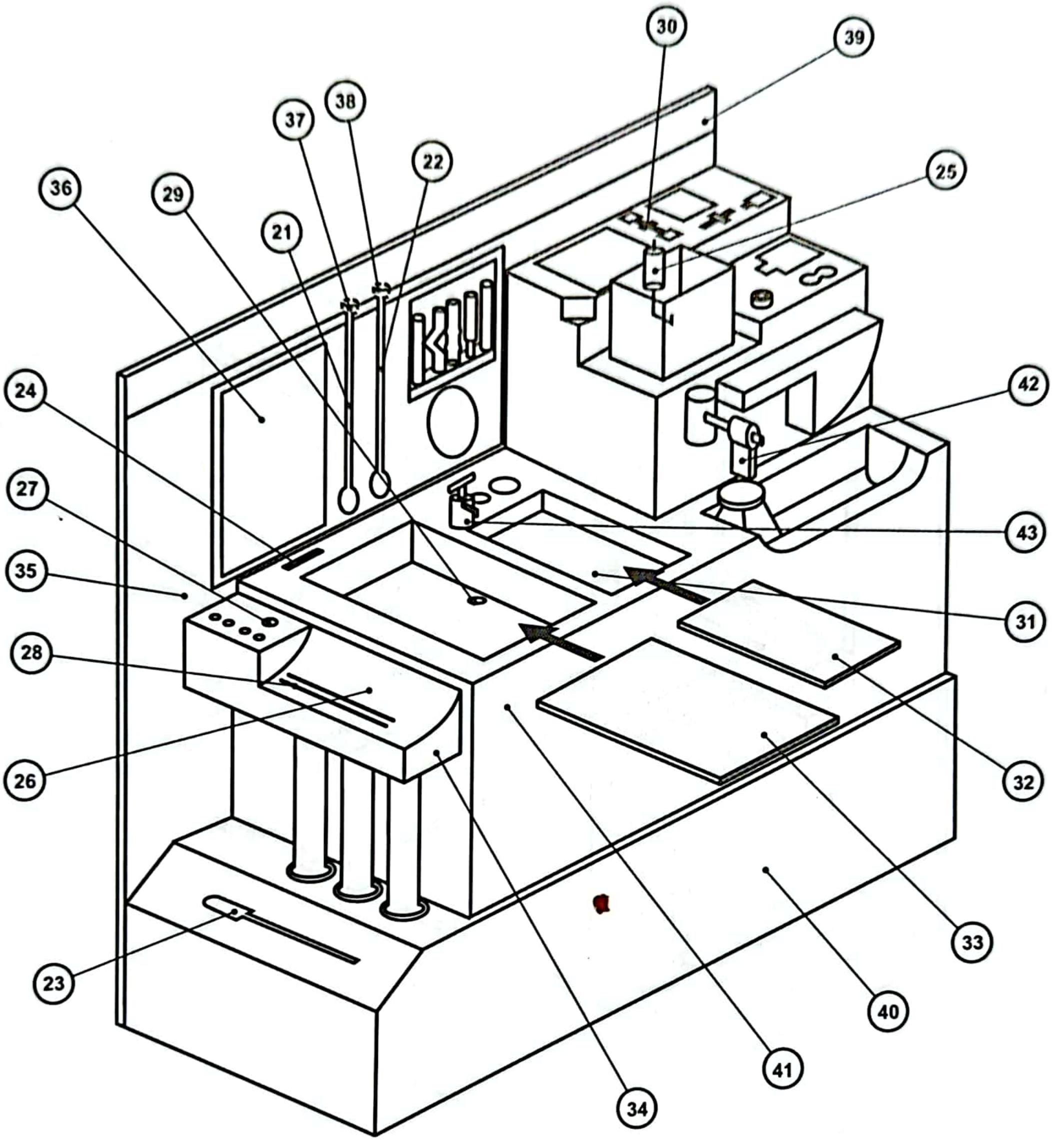
- Determination of fluid density and specific gravity
- Principles and use of a hydrometer
- Capillarity (capillary action) in tubes and between plates
- Measurement of viscosity by falling sphere method
- Demonstration of Pascal's Law
- Measurement of fluid levels by hook gauge
- Fluid flow head relationship
- 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

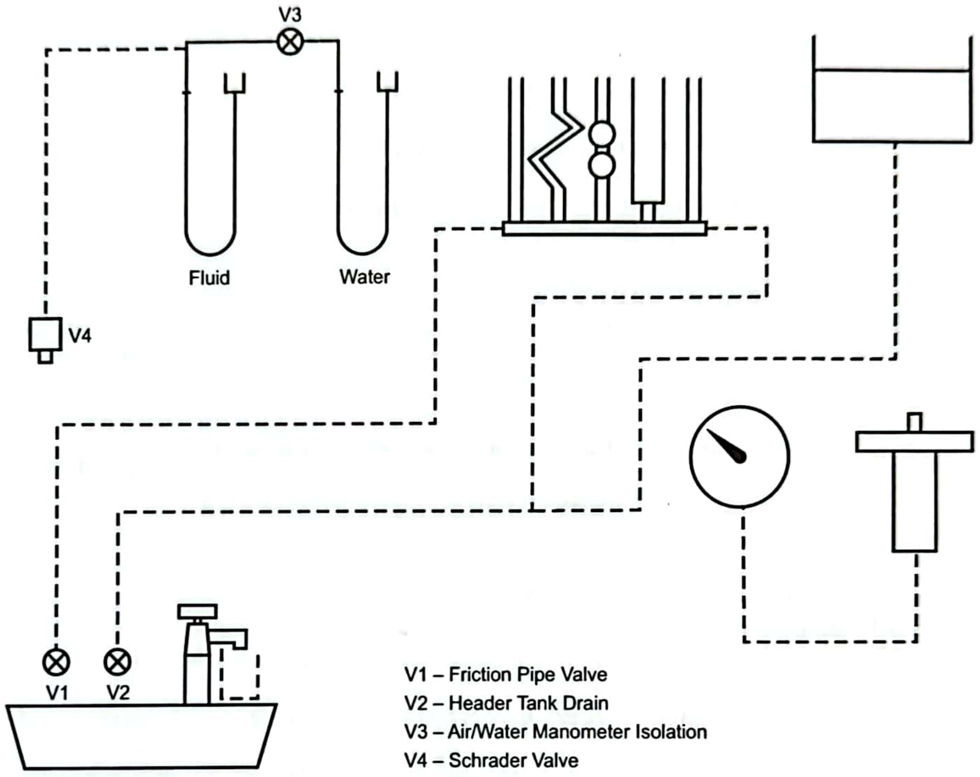


Figure 4 H314 Fluid Circuit Diagram

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

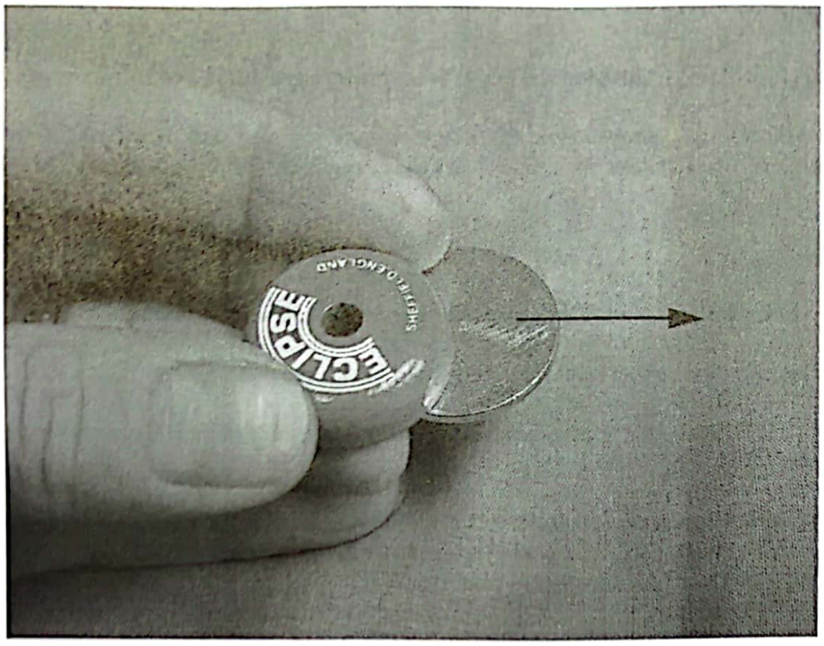


Figure 5 Remove Keep

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.

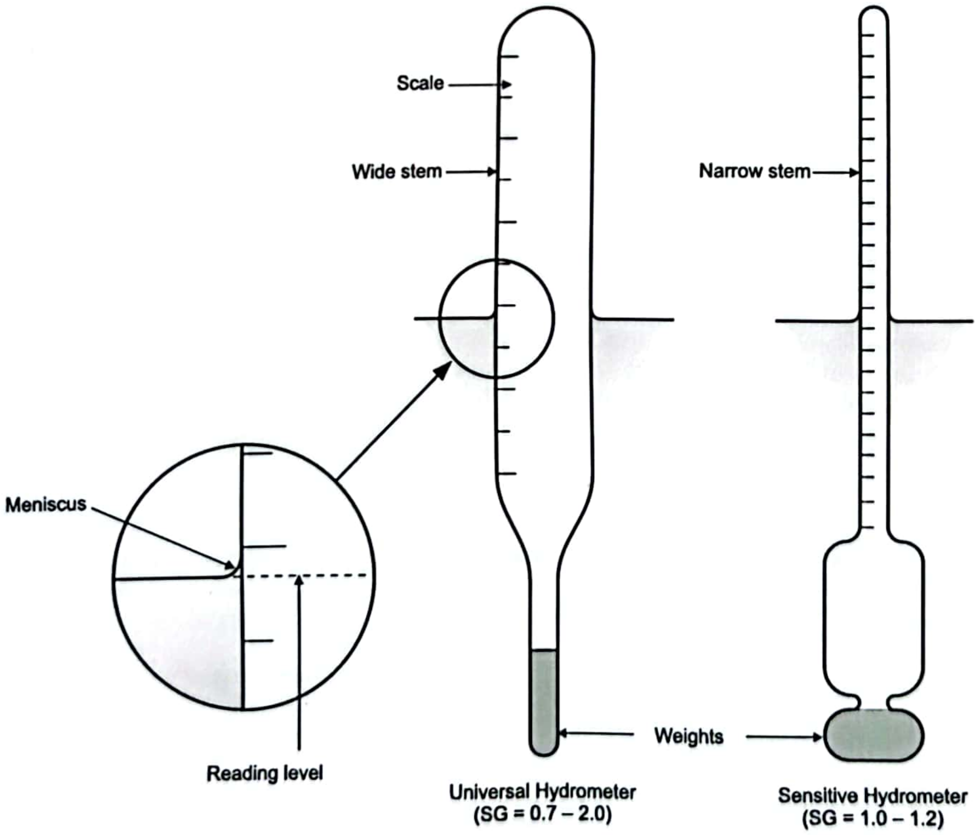


Figure 6 Types of hydrometer

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.

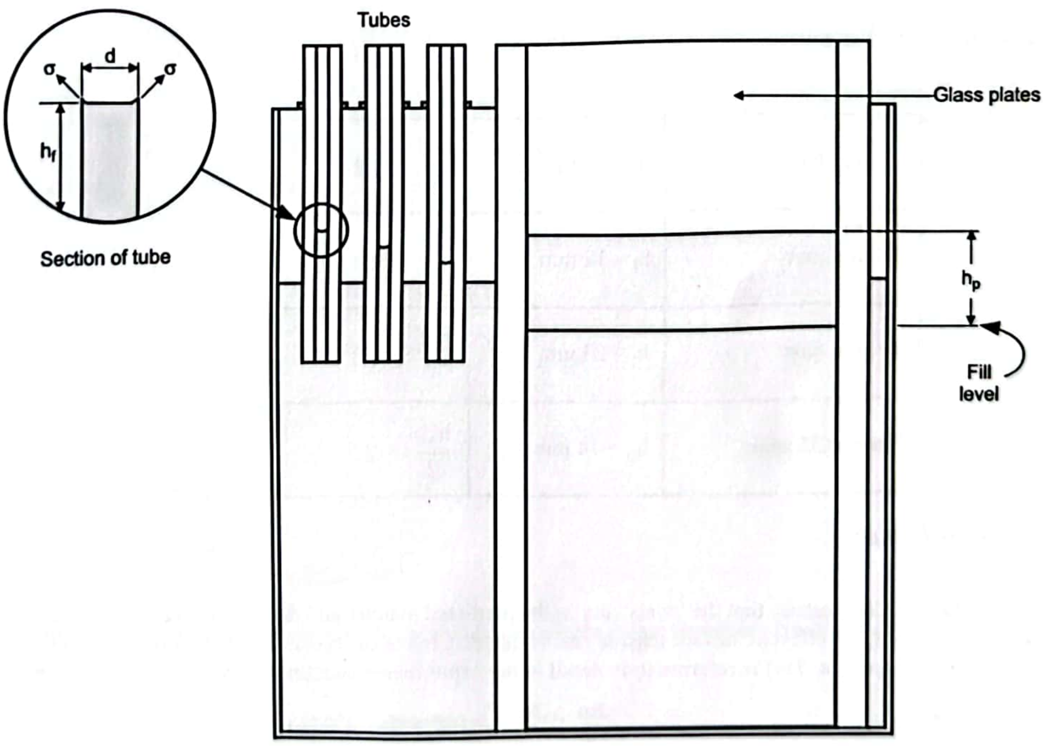


Figure 7 Capillarity Apparatus

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:

$$F = \pi d \sigma \tag{1}$$

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

$$W = \frac{\pi d^2}{4} \rho g h_t \tag{2}$$

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

$$h_t = \frac{4\sigma}{\rho g d} \tag{3}$$

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

$$h_p = \frac{2\sigma}{\rho g b} \tag{4}$$

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:

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

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

$$p_2 = p_1 + \rho g h \tag{9}$$

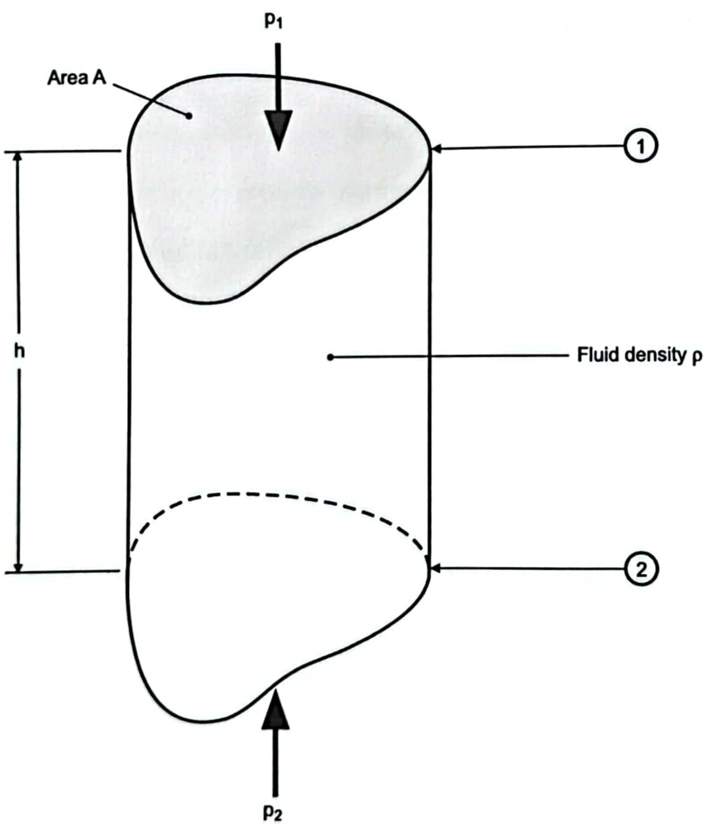


Figure 8 Hydrostatic Pressure due to a Column of Fluid

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.

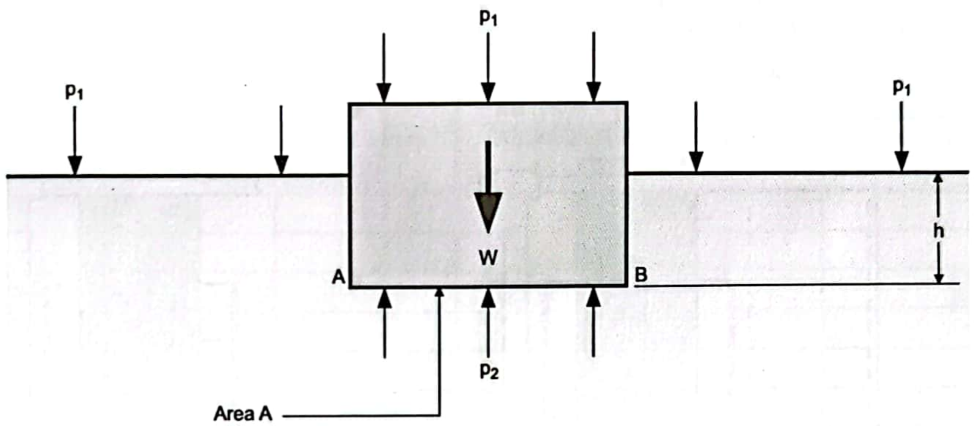


Figure 9 Upthrust on a Floating Body

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:

$$W = (p_1 + \rho gh)A - p_1 A = \rho ghA \qquad (10)$$

We may also note that the volume of water displaced is $h \times A$ 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.

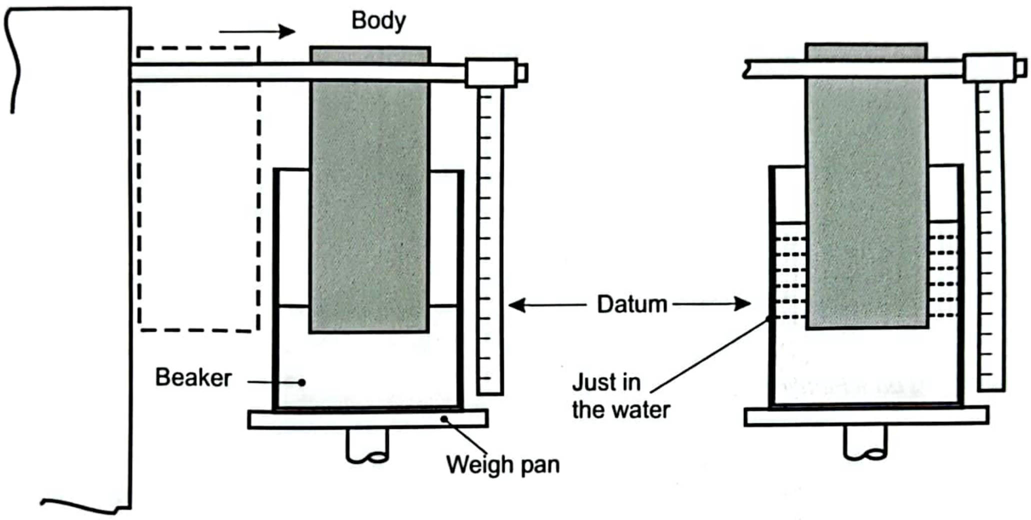


Figure 10 Apparatus for Determination of Fluid Upthrust

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).

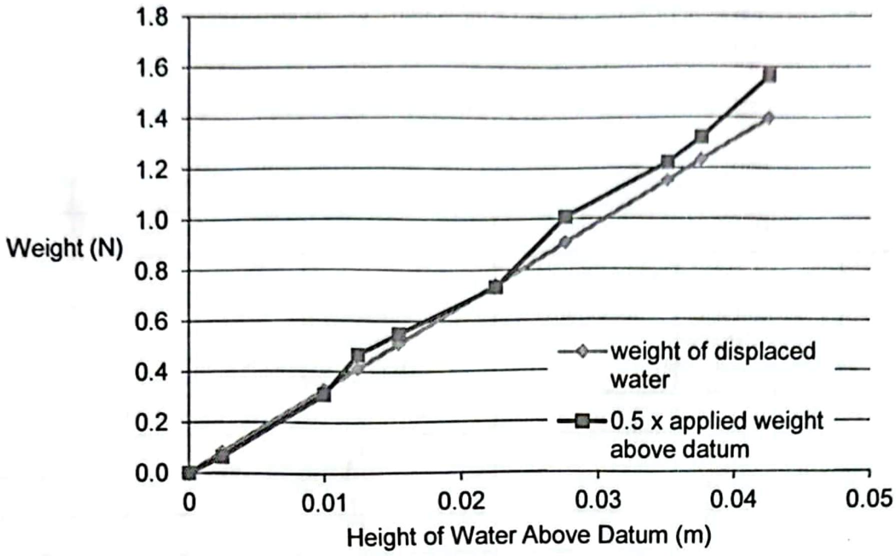


Figure 11 Typical Results

3.8 Buoyancy, Flotation and Stability of Floating Bodies

In the preceding experiment we have seen that the upthrust, or buoyancy force, is equal to the weight of water displaced. It should be noted that this depends only on the immersed volume of the body and not on its density or weight. However, the question of whether a body will float or sink does depend on these factors. The maximum buoyancy force is produced when the body is fully immersed and if this is less that its total weight it will sink. Conversely, if it is greater, the body will find an equilibrium position with only parts of its volume immersed, such that the buoyancy force just balances the weight of the body, i.e. the body will float. The criterion for floating, therefore, is that the average density must be less than that of water.

Simple Demonstrations

Various simple demonstrations can be carried out using one of the plastic beakers and the weights supplied with the apparatus.

a) Attempt to float the beaker in the upper tank by placing it in the water, bottom downwards. It is unstable and tips over, and will float or sink depending on whether water gets into it or not. The beaker is 'top heavy' and will not float in the upright position.

b) Place a few weights in the centre of the bottom of the beaker and again place it in the water. It is now more stable and will float in a more upright position, although it is lower in the water due to the extra weight. The extra stability is produced by lowering the centre of gravity.

c) If further weights are added, the stability will further improve and the beaker will float lower down in the water.

d) If sufficient weights are added, the beaker will sink. The volume is approximately 450 ml, so approximately 450 g should be required to make it sink. Note that at this point, the average density of the beaker is equal to that of water, even though much of the volume is filled with air.

Stability of a Floating Body

Note: SECTION 4.0 includes alternative theory for this experiment.

The type of behaviour demonstrated above can be quantified and analysed using the Stability of a Floating Body apparatus (15) supplied with the bench. The stability will be found to depend on the position of the centre of gravity and, in particular, its position in relation to the centre of buoyancy. This leads to a definition of the metacentric height as a measure of stability.

The question of the stability of a body, such as a ship, which floats in the surface of a liquid, is one of obvious importance. Whether the equilibrium is stable, neutral or unstable is determined by the height of its centre of gravity, and, in this experiment, the stability of a pontoon may be determined with its centre of gravity at various heights. A comparison with calculated stability may also be made.

The arrangement of the apparatus is shown in Figure 12. A pontoon of rectangular form floats in water and carries a plastic sail, with five rows of V-slots at equally-spaced heights on the sail. The slots' centres are spaced at 7.5 mm intervals, equally disposed about the centre sail line. An adjustable weight, consisting of two machined cylinders which can be screwed together, fits into the V-slots on the sail; this can be used to change the height of the centre of gravity and the angle of list of the pontoon. A plum bob is suspended from the top centre of the sail and is used in conjunction with the scale fitted below the base of the sail to measure the angle of list.

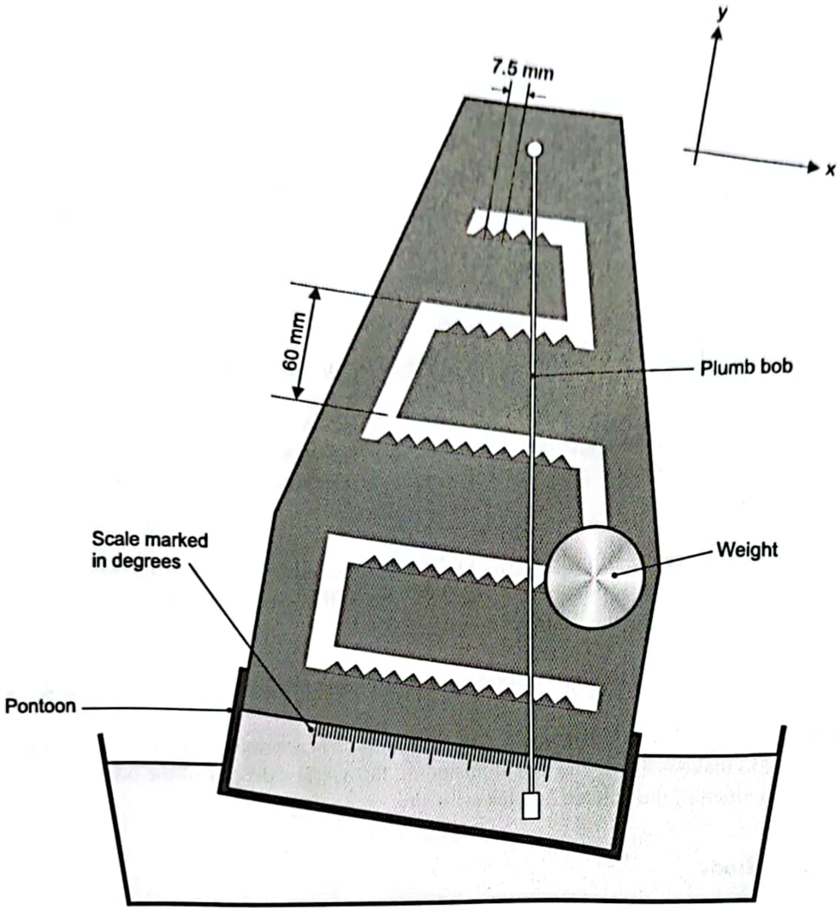


Figure 12 Arrangement of the Floating Pontoon

Consider the rectangular pontoon shown floating in equilibrium on an even keel, as shown in the cross-section of Figure 13(a). The weight of the floating body acts vertically downwards through its centre of gravity G and this is balanced by an equal and opposite buoyancy force acting upwards through the centre of buoyancy B, which lies at the centre of gravity of the liquid displaced by the pontoon.

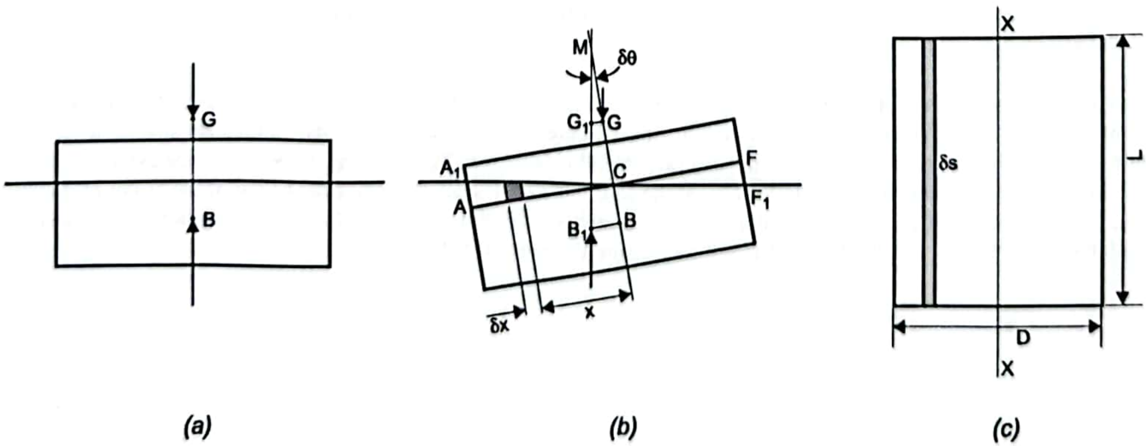


Figure 13 Derivation of the Stability of a Floating Pontoon

To investigate the stability of the system, consider a small angular displacement $\delta\theta$ from the equilibrium position as shown in Figure 13(b). The centre of gravity of the liquid displaced by the pontoon shifts from B to B_1. The vertical line action of the buoyancy force is shown in the diagram and intersects the extension of line BG at M, the metacentre.

The equal and opposite forces through G and B_1 exert a couple on the pontoon, and provided that M lies above G, as shown in Figure 13(b), this couple acts in the sense of restoring the pontoon to even keel, i.e. the pontoon is stable. If, however, the metacentre M lies below the centre of gravity G, the sense of the couple is to increase the angular displacement and the pontoon is unstable. The special case of the neutral stability occurs when M and G coincide.

Figure 13(b) shows clearly how the metacentric height GM may be established experimentally using the adjustable weight (of mass ω) to displace the centre of gravity sideways from G.

Suppose the adjustable weight is moved a distance δx_1 from its central position. If the weight of the whole floating assembly is W, then the corresponding movement of the centre of gravity of the whole, in a direction parallel to the base of the pontoon, is $\frac{\omega}{W}\delta x_1$. If this movement produces a new equilibrium position at an angle of list $\delta\theta$, then in Figure 13(b), G_1 is the position of the centre of gravity of the whole, i.e.

$$GG_1 = \frac{\omega}{W}\delta x_1 \qquad (11)$$

Now, from the geometry of the figure:

$$GG_1 = GM \cdot \delta\theta \qquad (12)$$

Eliminating GG_1, between these equations we derive:

$$GM = \frac{\omega}{W} \cdot \frac{\delta x_1}{\delta\theta} \qquad (13)$$

or in the limit:

$$GM = \frac{\omega}{W}\left(\frac{dx_1}{d\theta}\right) \qquad (14)$$

The metacentric height may thus be determined by measuring $\left(\frac{dx_1}{d\theta}\right)$ knowing ω and W.

Quite apart from experimental determinations, BM may be calculated from the mensuration of the pontoon and the volume of liquid which it displaces. Referring again to Figure 13(b), it may be noted that the restoring moment about B, due to shift of the centre of buoyancy to B_1, is produced by additional buoyancy represented by triangle AA_1C to one side of the centre line, and reduced buoyancy represented by triangle FF_1C to the other. The element shaded in Figure 13(b) and Figure 13(c) has an area δs in plan view and a height $x\delta\theta$ in vertical section, so that its volume is $x\delta s\delta\theta$. The weight of liquid displaced by this element is $wx\delta s\delta\theta$, where w is the specific weight of the liquid, and this is the additional buoyancy due to the element. The moment of this elementary buoyancy force about B is $wx^2\delta s\delta\theta$, so that the total restoring moment about B is given by the expression:

$$w\delta\theta\int x^2 ds$$

where the integral extends over the whole area s of the pontoon at the plane of the water surface. The integral may be referred to as I, where:

$$I = \int x^2 ds \qquad (15)$$

the second moment of area of s about the axis XX.

The total restoring moment about B may also be written as the total buoyancy force, wV, in which V is the volume of liquid displaced by the pontoon, multiplied by the lever arm BB_1. Equating this product to the expression for total retiring moment derived previously:

$$wV \cdot BB_1 = w\delta\theta \int x^2 ds$$

Substituting from Equation (15) for the integral and using the expression:

$$BB_1 = BM \cdot \delta\theta \qquad (16)$$

which follows from the geometry of Figure 13(b), leads to:

$$BM = \frac{I}{V} \qquad (17)$$

This result, which depends only on the mensuration of the pontoon and the volume of liquid which it displaces, will be used to check the accuracy of the experiment. It applies to a floating body of any shape, provided that I is taken about an axis through the centroid of the area of the body at the plane of the water surface, the axis being perpendicular to the plane in which angular displacement takes place. For a rectangular pontoon, B lies at a depth below the water surface equal to half the total depth of immersion, and I may readily be evaluated in terms of the dimensions of the pontoon as:

$$I = \int x^2 ds = \int_{-D/2}^{D/2} x^2 L dx = \frac{1}{12} L D^3 \qquad (18)$$

Experimental Procedure

The total mass of the apparatus (including the two magnetic weights, but not the jockey weight) is written on a label affixed to the sail housing.

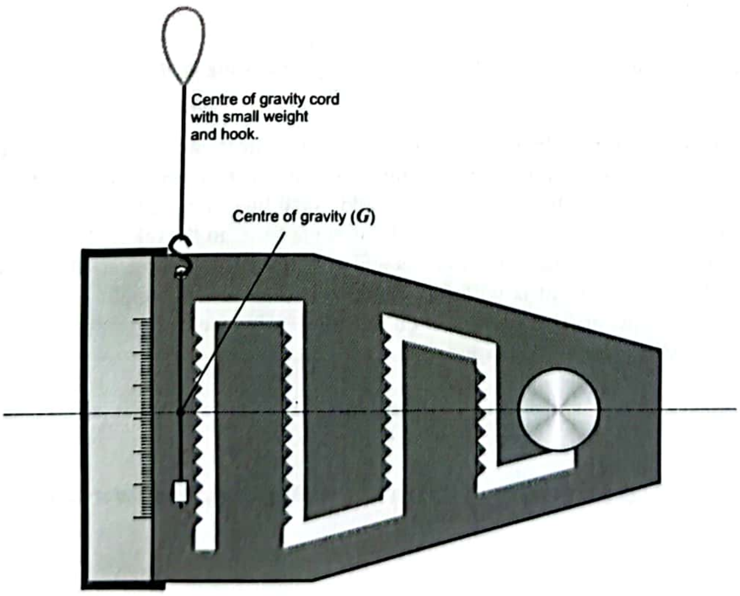


Figure 14 Method of Finding the Centre of Gravity

With reference to Figure 14, the height of the centre of gravity may be found as follows:

a) Fit the two magnetic weights to the base of the pontoon. Refer to 'Magnets' on page 8.

b) Fit the hook of the centre of gravity cord, through the hole in the sail, ensuring that the plumb weight is free to hang down on the side of the sail which has the scored centre line.

c) Clamp the adjustable weight into the V-slot on the centre line of the lowest row and suspend the pontoon from the free end of the thick cord. Mark the point where the plumb line crosses the sail centre line (for example, with typist's correcting fluid or a similar marking fluid).

d) Repeat step c) for the other four rows.

With the adjustable weight situated in the centre of one of the rows, allow the pontoon to float in water and position the two magnetic weights on the base of the pontoon to trim the vessel. When the vessel has been trimmed correctly, the adjustable weight may be moved to positions either side of the centre line for each of the five rows. At each position, the displacement can be determined by the angle the plumb line from the top of the sail makes with the scale on the sail housing.

Results and Calculations

Total weight of floating assembly (W)	=	N
Adjustable weight (ω)	=	N
Breadth of pontoon (D)	=	mm
Length of pontoon (L)	=	mm
Second moment of area $I = \frac{LD^3}{12} \times 10^{-12}$	=	m^4
Volume of water displaced $V = \frac{W}{10^3 \rho}$	=	m^3
Height of metacentre above centre of buoyancy $BM = \frac{I}{V}$	=	m
Depth of immersion of pontoon $= \frac{V \times 10^6}{LD}$	=	m
Since L and D are in mm depth of centre of buoyancy $CB = \frac{V \times 10^6}{2LD}$	=	m

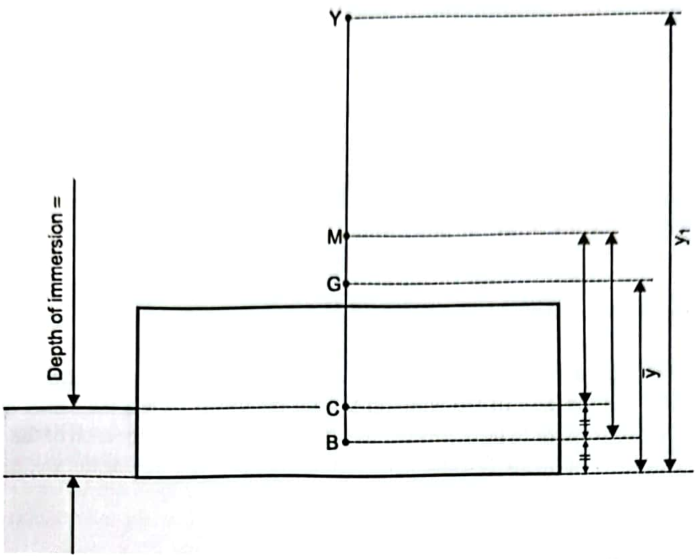


Figure 15 Standard Dimensions of the Pontoon

It is recommended that Figure 15 is marked up appropriately and referred to each time the apparatus is used. Note that when measuring the heights $\bar{y}$ and y_1, as it is only is convenient to measure from the inside floor of the pontoon, the thickness of the sheet metal bottom should be added to $\bar{y}$ and y_1 measurements. The position of G (and hence the value of $\bar{y}$) and a corresponding value of y was marked earlier in the experiment when the assembly was balanced.

The height of $\bar{y}$ of G above the base will vary with the height y of the adjustable weight above the base, according to the equation:

$$\bar{y} = y_1\frac{\omega}{W} + A \qquad (19)$$

where A is a constant, which pertains to the centre of gravity of the pontoon and the height of the adjustable weight.

Using one set of results for the centre of gravity of the pontoon and the height of the adjustable weight, $\bar{y}$ and y_1 can be measured and the constant A calculated. This can then be used in calculations for subsequent heights of $\bar{y}$ and y_1 which can be checked against the markings.

Values of angles of list produced by lateral movement of the adjustable weight height y_1 should be recorded in the form of Table 4. A graph (Figure 16) for each height y_1, of lateral position of adjustable weight against angle of list, can then be plotted.

Note: Decide which side of the sail centre line is to be termed negative and then term list angles on that side negative.

Height of jockey weight y_1 mm (i)	Angles of list for adjustable weight lateral displacement from sail centre line x_1 mm														
	-52.5	-45	-37.5	-30	-22.5	-15	-7.5	0	7.5	15	22.5	30	37.5	45	52.5

Table 4 Values of List Angles for Height and Position of Adjustable Weight

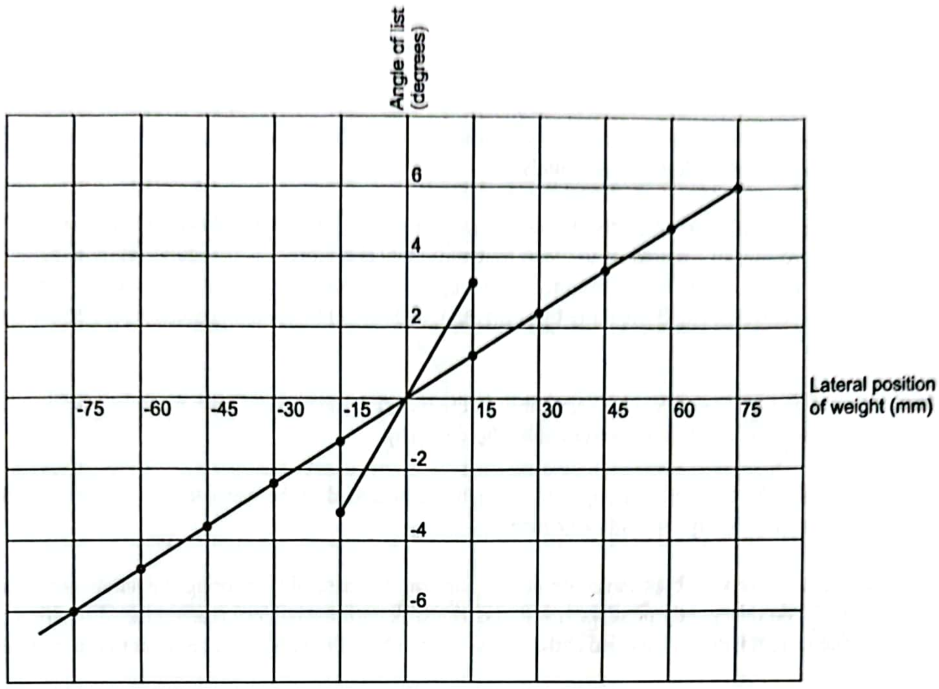


Figure 16 Variation of Angle List with Lateral Position of Weight

From Figure 16, for the five values of y_1, the corresponding values of $\frac{dx_1}{d\theta}$ can be extracted. Using Equation (14), values of GM can be obtained. Using Equation (19) and knowing the immersion depth, values of CG can be derived. Also, since CM = CG + GM, values of CM can be calculated. These values should be calculated and arranged in tabular form as shown in Table 5.

Height of adjustable weight y_1 (mm)	Height of G above water surface CG (mm)	$\frac{dx_1}{d\theta}$ (mm/°)	Metacentric height CM (mm)	Height of M above water surface CM (mm)

Table 5 Derivation of Metacentric Height from Experimental Results

The values of $\frac{dx_1}{d\theta}$ can now be plotted against CG, the height of G above the water line. Extrapolation of this plot will indicate the limiting value of CG above which the pontoon will be unstable (i.e. when $\frac{dx_1}{d\theta}$ is zero and CG = M).

3.9 Forces on Plane Surfaces: Centre of Pressure

The centre of pressure may be defined as: "*The point in a plane at which the total fluid thrust can be said to be acting normal to that plane.*"

The apparatus permits the moment due to the total fluid thrust on a wholly or partially submerged plane surface to be measured directly and compared with theoretical analysis.

Water is contained in a quadrant tank assembly (16) as part of a balance. The cylindrical sides of the quadrant have their axes coincident with the centre of rotation of the tank assembly, and therefore the total fluid pressure acting on these surfaces exerts no moment about that centre. The only moment present is that due to the fluid pressure acting on the plane surface. This moment is measured experimentally by applying weights (17) to a weight hanger mounted on the opposite side to the quadrant tank.

A second tank, situated on the same side of the assembly as the weight hanger, provides a trimming facility. A scale on the quadrant tank measures the level of the water below the pivot (h).

TecQuipment supply coloured dye with the apparatus, which can be added to the water to help see its level during the experiments. Only a few drops of dye should be needed.

Before each experiment, make sure both tanks are empty and trim the assembly to bring the submerged plane to the vertical (0° position). To do this, gently pour water into the trim tank until the balance reaches the 0° position. You may need to add one of the weight hangers supplied and a few masses to help (hook it to the bar next to the trim tank).

TecQuipment supply a pipette (29) to help remove excess water. To use it, dip it into the tank and put a finger on the top of the pipette to hold the water then lift the pipette and transfer the water to the reservoir.

Now add the second weight hanger and additional weights. Pour water into the quadrant tank until a 0° balance is restored. Note the additional weight (not the trim weight) and the level of the water (h). Repeat the procedure for the full range of weights.

Now you can investigate the readings for $\theta = 0°$.

Readings should be tabulated in the form outlined in Table 6 and the results calculated in line with the theory given.

ω (g)	$M = \dfrac{W \times 9.81 \times R_3}{10^3}$ (Nm)	h (mm)	h (m)	h^3 (m^3)	$M + \dfrac{\omega B R_2^2 h}{2}$ (Nm)

Table 6 Format of Results Table – Centre of Pressure for the Particular Case of θ = 0°

The following analysis is applied to the general condition of a plane surface at various angles when it is wholly or partially submerged in a fluid.

Note: SECTION 4.0 includes alternative theory for this experiment.

Let breadth of quadrant = B
and weight per unit volume = ω

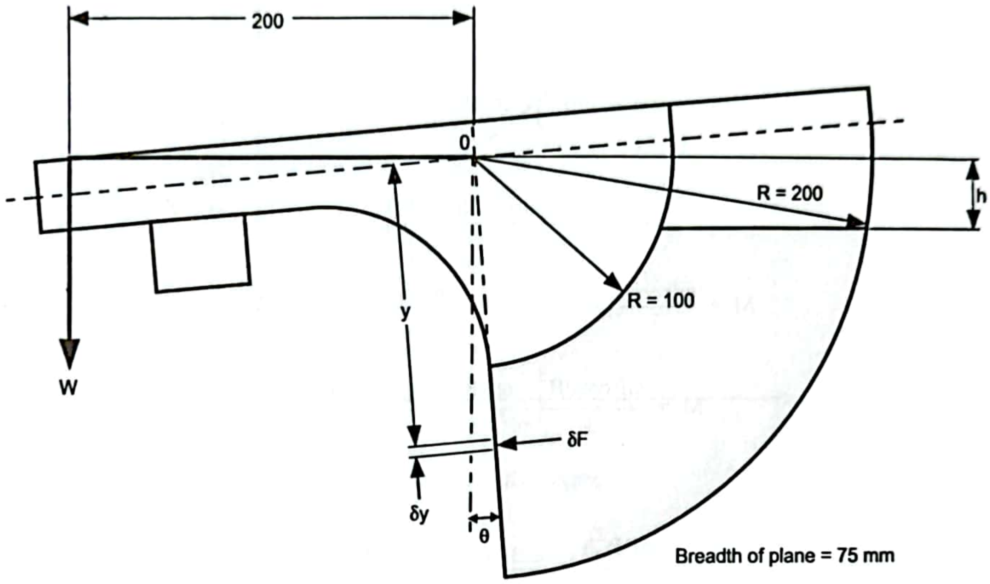


Figure 17 Pressure Forces on a Plane Surface

Referring to Figure 17, consider an element at start depth y, width δy.

Therefore, force on element $\delta F = \omega(y\cos\theta - h)B\delta y$ and moment of force on element about $0 = \omega B(y\cos\theta - h)y\delta y$. Therefore:

$$\text{Total moment about } 0 = M = \omega B\int(\cos\theta y^2 - hy)dy$$

Case 1: Plane Fully Submerged

Limits R_1 and R_2

$$M = \omega B\int_{R_1}^{R_2}(\cos\theta y^2 - hy)dy$$

$$M = \omega B\left[\frac{\cos\theta^3}{3} - \frac{hy^2}{2} + c\right]_{R_1}^{R_2}$$

$$M = \frac{\omega B\cos\theta}{3}(R_2^3 - R_1^3) - \frac{\omega B}{2}(R_2^2 - R_1^2)h \qquad (20)$$

This equation is of the form of $y = mx + c$

A plot of M against h will yield a straight line graph of gradient $-\frac{\omega B}{2}(R_2^2 - R_1^2)$. The value of ω can now be calculated.

Case 2: Plane Partially Submerged

Limits R_2 and $h\text{Sec}\theta$

Hence:

$$M = \omega B \int_{h\sec\theta}^{R_2} (\cos\theta y^2 - hy)dy$$

$$M = \left[\frac{\omega B\cos\theta y^3}{3} - \frac{hy^2}{2} + c\right]_{h\sec\theta}^{R_2}$$

$$M = \frac{\omega B\cos\theta}{3}(R_2^3 - h^3\sec^3\theta) - \frac{\omega Bh}{2}(R_2^2 - h^2\sec^2\theta)$$

$$M = \frac{\omega B\cos\theta R_2^3}{3} - \frac{\omega BR_2^2h}{2} + \frac{\omega B\sec^2\theta h^3}{6}$$

Rearranging:

$$M + \frac{\omega BR_2^2h}{2} = \frac{\omega B\sec2\theta h^3}{6} + \frac{\omega B\cos\theta R_2^3}{3}$$

Obtain ω from Case 1 and plot h^3 against $M + \dfrac{\omega BR_2^2h}{2}$

Figure 18 and Figure 19 show the general form of the graphs expected from this experiment.

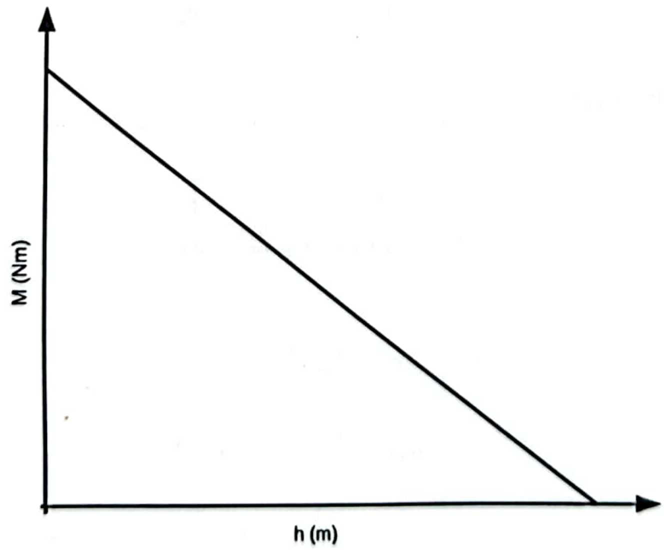


Figure 18 Centre of Pressure Graph: Plane Fully Submerged

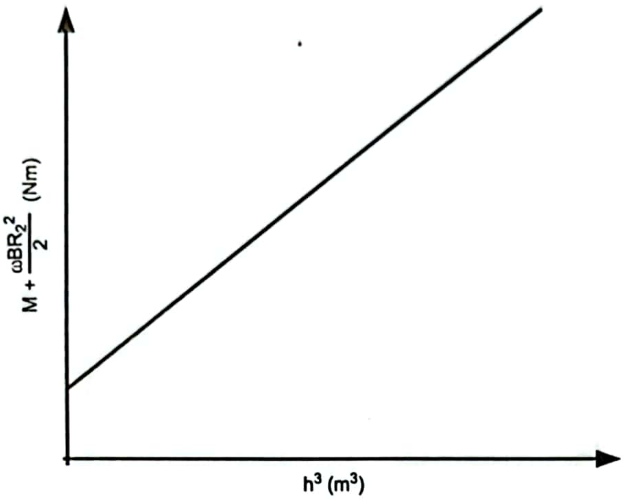


Figure 19 Centre of Pressure Graph: Plane Partially Submerged

3.10 Pressure Measurement

Pressure measurement is important, not only in fluid mechanics but in virtually every branch of engineering. There is a wide range of methods for measuring pressure and many of these employ hydrostatic principles. The following experiments illustrate some of the methods and, in particular, how columns of fluid can be used in various forms to measure pressure.

Bourdon Pressure Gauge

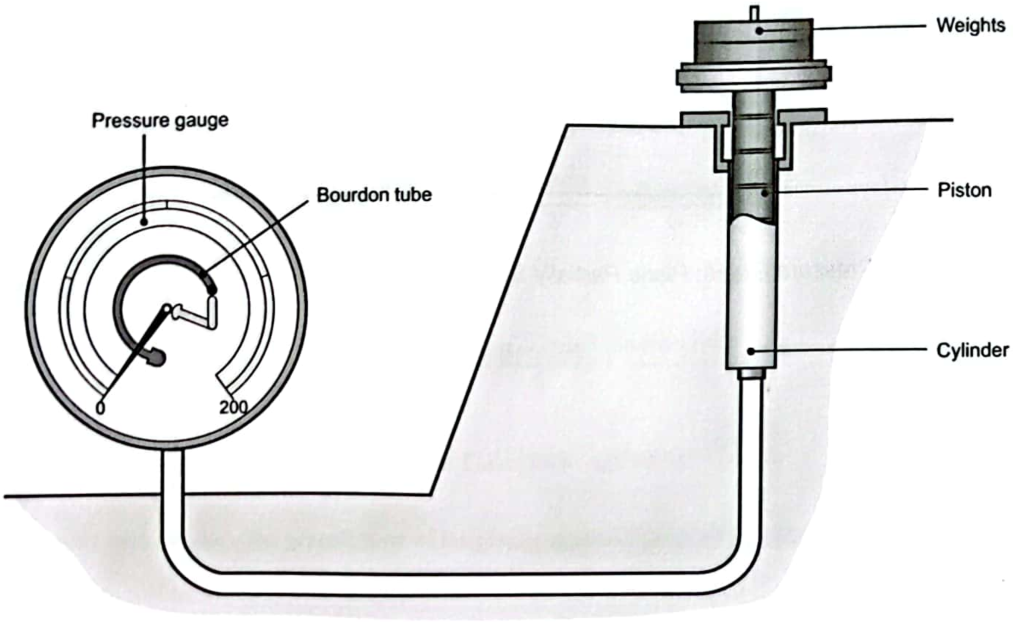


Figure 20 Principle of the Bourdon Pressure Gauge Calibrator

The pressure gauge apparatus has a large Bourdon pressure gauge and facilities for calibrating the gauge using dead weights.

The mechanism of the gauge may be seen through the transparent dial of the instrument, as illustrated in Figure 20. A tube, having a thin wall of oval cross-section, is bent to a circular arc encompassing about 270 degrees. It is rigidly held at one end, where the pressure is admitted to the tube, and is free to move at the other end, which is sealed. When pressure is admitted, the tube tends to straighten, and the movement at the free end operates a mechanical system which moves a pointer round the graduated scale – the movement of the pointer being proportional to the pressure applied. The sensitivity of the gauge depends on the material and dimensions of the Bourdon tube; gauges with a very wide selection of pressure ranges are commercially available.

To check the accuracy of a Bourdon gauge, the procedure is to load it with known pressures by a dead weight tester using oil to transmit the pressure. This experiment, however, works satisfactorily with water instead of oil.

a) Remove the piston from the unit. The piston is delivered lightly oiled and should be wiped only when the unit is to be used.

b) Fill the cylinder with water, and remove air trapped in the transparent tube by gently tapping the unit. A small amount of air left in the system will not affect the experiment.

c) Top up with water and insert the piston into the cylinder, allowing air and excess water to escape through the top hole in the side of the cylinder. Allow the piston to settle.

CAUTION

Always smear the whole piston surface lightly with oil (supplied) after use. Do not attempt to polish the piston rod with emery cloth, or any harsh abrasive. Use only a mixture of powdered chalk and oil to remove discoloration.

Do not add more than the supplied masses.

Experimental Procedure

Create a blank results table similar to Table 7. Note the mass and cross-sectional area of the piston.

Ensure the cylinder is vertical. Add masses in approximately eight increments up to a maximum of 5.2 kg taking readings of mass and pressure as you add each mass. Always load the masses gradually and carefully. Do not drop them onto the platform. To prevent the piston sticking, rotate the piston gently as each mass is added. Reverse the procedure, taking readings as the masses are removed.

Results and Calculations

The actual hydrostatic pressure (p) in the system due to a mass of M kg (including the piston mass) applied to the piston is given by:

$$p = \frac{M \times 9.81}{A} \times 10^{-3} \text{ kN/m}^2$$

where A is the piston area in m^2.

			Increasing Pressure		Decreasing Pressure	
Mass added to piston (kg)	Total mass on piston M (kg)	Actual presure p (kN/m²)	Gauge reading (kN/m²)	Gauge error (kN/m²)	Gauge reading (kN/m²)	Gauge error (kN/m²)

Table 7 Results for Increasing and Decreasing Pressure

Use your results to plot graphs of the gauge pressure against actual pressure, and gauge error against actual pressure.

Two different kinds of error may normally be expected in a gauge of this type. Firstly, there is the possibility of hysteresis, friction and backlash which will yield smaller gauge readings when the pressure is increasing than when it is decreasing. Typically, the gauge tested here will have an error in the range of 1 kN/m^2 of the entire range, which is acceptably small. Secondly, there is error due to the scale being marked off incorrectly. It will be found that this error increases to a maximum of around 2.5% of the full-scale reading. This is acceptably small for many engineering purposes, although gauges with an error of only 0.5% of the full-scale reading are commercially obtainable.

Liquid Column Manometers

Columns of liquid can be used in a wide range of configurations for measuring pressures in both static and moving fluids. A barometer represents a special case in which absolute pressure is measured but, in general, liquid columns are used to measure differential pressures; that is to say the difference in pressure between two points in a fluid system. Strictly speaking, the term manometer relates to all methods of measuring pressure but, in normal usage, it is taken to refer to liquid columns and particularly those in the form of U-tubes.

Figure 21 shows the general case of a U-tube manometer measuring the differential pressure between two points in a system containing fluid (liquid or gas) of density ρ_1. The U-tube is filled with a heavier fluid (liquid) of density ρ_2 and the differential pressure is measured in terms of the difference in height $\Delta h = (h_4 - h_3)$ of the two columns.

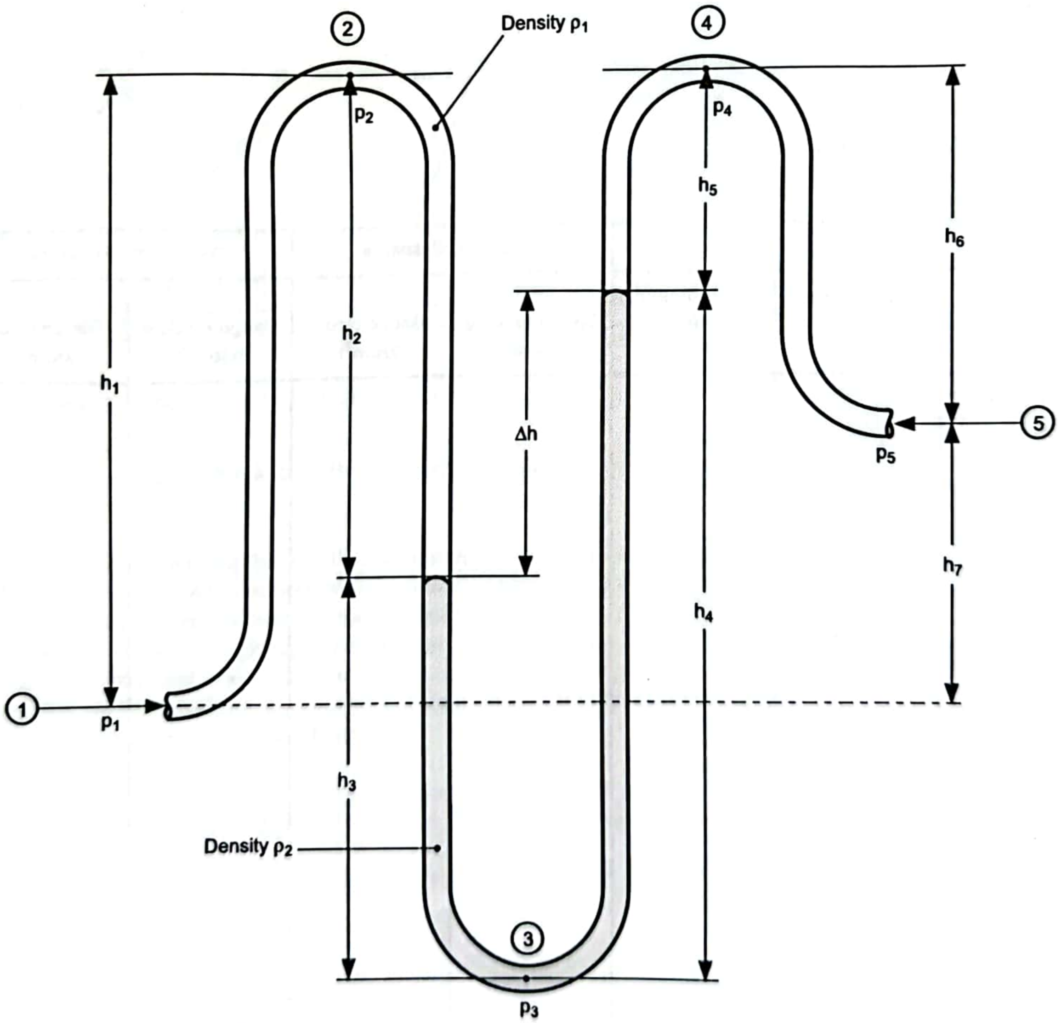


Figure 21 Pressure in a U-tube Manometer

The reminder of the U-tube and the connecting tubes are filled with the working fluid of density ρ_1. First consider the pressure at point 1 due to the column h of working fluid:

$$p_1 = p_2 + \rho_1 g h_1$$

or

$$p_2 = p_1 - \rho_1 g h_1$$

Now consider the pressure at the bottom of the U-tube due to fluid in the left-hand column:

$$p_3 = p_2 + \rho_1 g h_2 + \rho_2 g h_3 \qquad (21)$$

and substituting for p_2 we obtain:

$$p_3 = p_1 - \rho_1 g(h_1 - h_2) + \rho_2 g h_3$$

Similarly, for the right-hand column and connecting tube:

$$p_3 = p_5 - \rho_1 g(h_6 - h_5) + \rho_2 g h_4 \qquad (22)$$

Then, on equating the right-hand sides of Equations (21) and (22) and rearranging we obtain:

$$(p_1 - p_5) = \rho_2 g(h_4 - h_3) + \rho_1 g(h_1 - h_6) - \rho_1 g(h_2 - h_5) \qquad (23)$$

Finally, substituting $h_4 - h_3 = h_2 - h_5 = \Delta h$ and $h_1 - h_6 = h_7$ we obtain:

$$(p_1 - p_5) = (\rho_2 - \rho_1) g \Delta h + \rho_1 g h_7 \qquad (24)$$

This represents the general case where the pressure tappings are at different heights and the density of the working fluid is significant compared to that of the manometer fluid. It can be seen that the difference in height Δh of the manometer columns gives a measure of $(p_1 - p_5)$, but a correction has to be made for the different heights of the pressure tappings. This is most important and must be remembered whenever a manometer is used with liquid rather than gas as the working fluid in the connecting tubes.

Notice also that the apparent density of the manometer fluid is reduced by ρ_1, the density of the working fluid. A common case is a mercury under water manometer where the apparent density is $13600 - 1000 = 12600$ kg/m^3 instead of 13600 kg/m^3 for a mercury/air manometer. There are two important cases which lead to a simplification of Equation (24).

Tappings at the same height

If the tappings are at the same height, the last term in Equation (24) becomes zero giving:

$$(p_1 - p_5) = (\rho_2 - \rho_1) g \Delta h \qquad (25)$$

Thus, for this case, the pressure difference is proportional to Δh multiplied by the apparent density $(\rho_2 - \rho_1)$.

Gas as the working fluid

If a gas is the working fluid, its density can usually be taken as negligible compared to that of the manometer fluid and Equations (24) and (25) reduce to:

$$(p_1 - p_5) = \rho_2 g h \, \Delta h \qquad (26)$$

In this case, the pressure difference depends directly on Δh and the actual density of the manometer fluid.

Equations (25) and (26) are quite general. The following two cases are worthy of further discussion.

Manometers open to atmospheric pressure

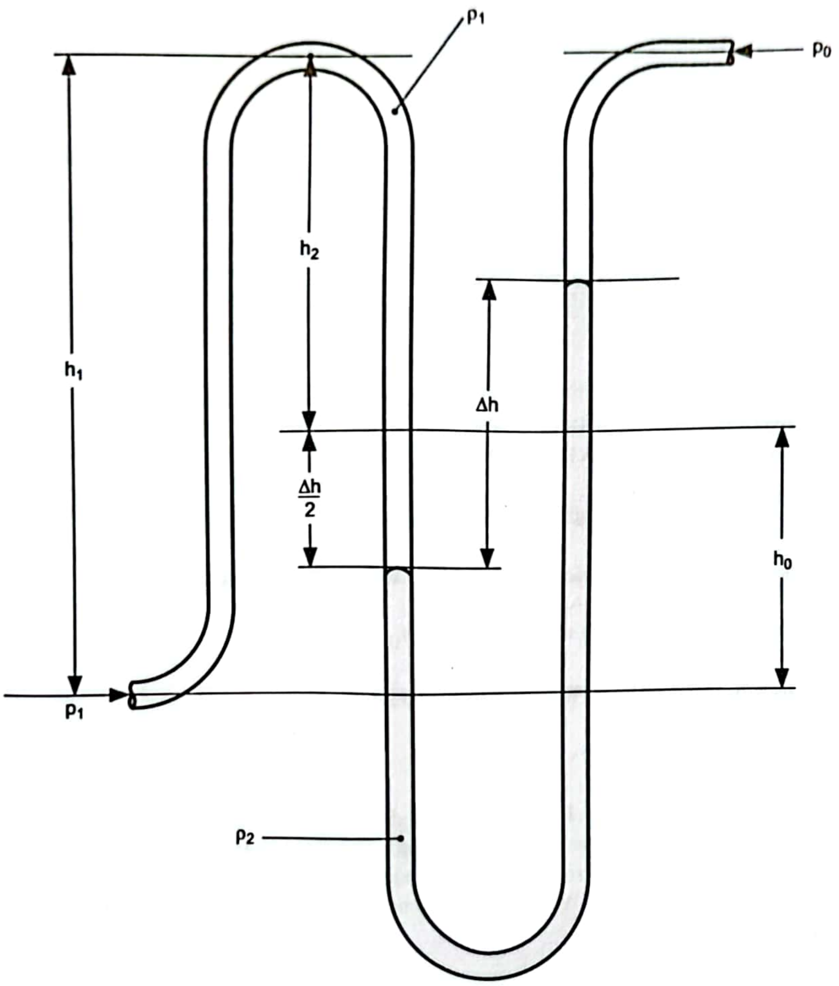


Figure 22 Manometer Open to Atmospheric Pressure

The manometers fitted to the H314 apparatus all have one column which is open to atmospheric pressure and this provides a common datum pressure. In the case of a liquid/air manometer, Equation (26) applies except that the pressure difference is measured relative to a fixed datum of atmospheric pressure p_0, rather than a varying pressure p_5. If the right-hand column is open to atmospheric pressure p_0 and there is no water in the connecting pipe as shown in Figure 22, Equation (23) becomes:

$$(p_1 - p_0) = \rho_2 g\Delta h + \rho_1 g(h_1 - h_2) \qquad (27)$$

It may be noted that the second term on the right-hand side is a correction for the varying column of water in the connecting tube. This variable correction can be eliminated by substituting $h_1 - h_2 = h_0 - \frac{\Delta h}{2}$, where h_0 is the height of the columns above the pressure tapping when the pressure difference is zero (see Figure 22). Equation (27) can then be written:

$$(p_1 - p_0) = \left[\rho_2 - \frac{\rho_2}{2}\right]g\Delta h + \rho_1 g h_0 \qquad (28)$$

where the second term on the right-hand side is now a constant.

It should be noted that this is based on the assumption that each column moves the same distance from level h_0 when displaced and this means that Equation (28) only applies if the tubes are of the same cross-sectional area. The significance of this is explained in the next case.

Manometer with limbs of different cross-sectional areas

In the preceding cases, the pressure difference is measured in terms of the height Δh, which is usually obtained as the difference between two measured heights. This is often laborious and it would be easier if the pressure difference could be obtained in terms of a single direct reading. One possible solution is to take the initial level of the columns at zero pressure difference as a datum and then measure the deflection of one column relative to this. If the limbs were of equal cross-sectional area, each column would move by $\Delta h/2$ and the reading could be doubled to obtain Δh. This is not often done in practice due to the loss of accuracy which results, but this can be overcome by using limbs of different cross-sectional areas.

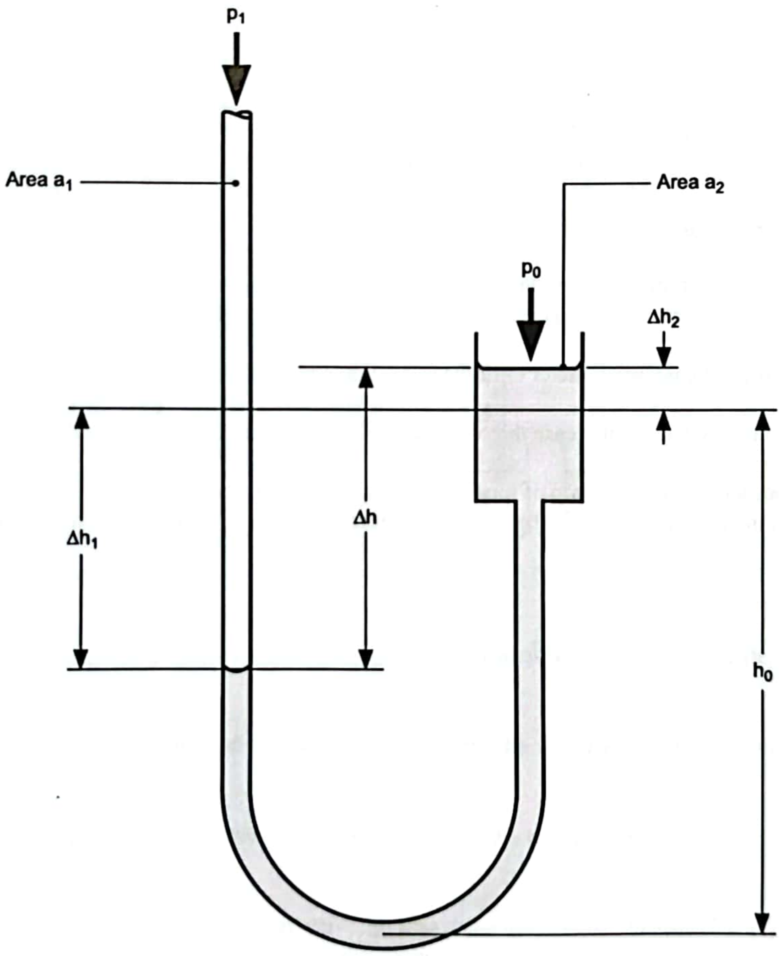


Figure 23 Manometer with Unequal Limbs

Consider the manometer shown in Figure 23 which has limbs of different cross-sectional areas. From the results of previous experiments (see page 12, Measuring Beaker) it will be appreciated that the differing areas do not affect the pressures in the columns, so for the case shown (a liquid/air manometer), Equation (26) still applies. The significant point is that the columns move different distances from the datum level h_0. The volume of liquid displaced is the same for each column so we can write:

$$\Delta h_1 a_1 = \Delta h_2 a_2$$

or alternatively:

$$\Delta h_2 = \Delta h_1 \frac{a_1}{a_2} \qquad (29)$$

If we make a_2 large compared to a_1 then nearly all of the change in height will occur in column 1 and the deflection can be measured to a greater accuracy. Since $\Delta h = \Delta h_1 + \Delta h_2$ we can obtain h by substituting using Equation (29):

$$\Delta h = \Delta h_1\left(1 + \frac{a_1}{a_2}\right) \qquad (30)$$

This arrangement is the basis of a common form of direct-reading, 'single-limb' manometer. The second limb is in the form of a reservoir tank of large cross-sectional area, such that the change in level in it is small compared to that in the narrow limb. Equation (30) can be used to define a scale for the narrow limb which is calibrated to read Δh directly from the level in that limb. Alternatively, Δh_1 can be measured and a small correction applied using Equation (30) to obtain Δh, or if a_2 is made sufficiently large, the measurement could be taken as a direct reading of h without introducing significant errors.

Manometer Experiments

The equations and underlying principles described previously can be demonstrated using the manometers fitted to the rear panel of the H314 apparatus. The manometers should be filled and all air bubbles removed from the water lines.

Comparison of different fluids

a) With the isolating valve on pipe (V3) to the air/water manometer open, attach the air pump to the Schrader valve and gently pump until a pressure is registered. This will be shown on both the fluid and water manometers.

b) Compare the readings of each manometer until the water manometer approaches the limit of its range.

c) Isolate the water manometer and increase the pressure until the fluid manometer is at full capacity.

d) To vent both manometers, insert the top of the Schrader valve cap into the centre of the valve and vent the fluid manometer. Open the isolating valve for the water manometer and again vent the air via the Schrader valve.

3.11 Hare's Tube Apparatus (Optional Ancillary H314b)

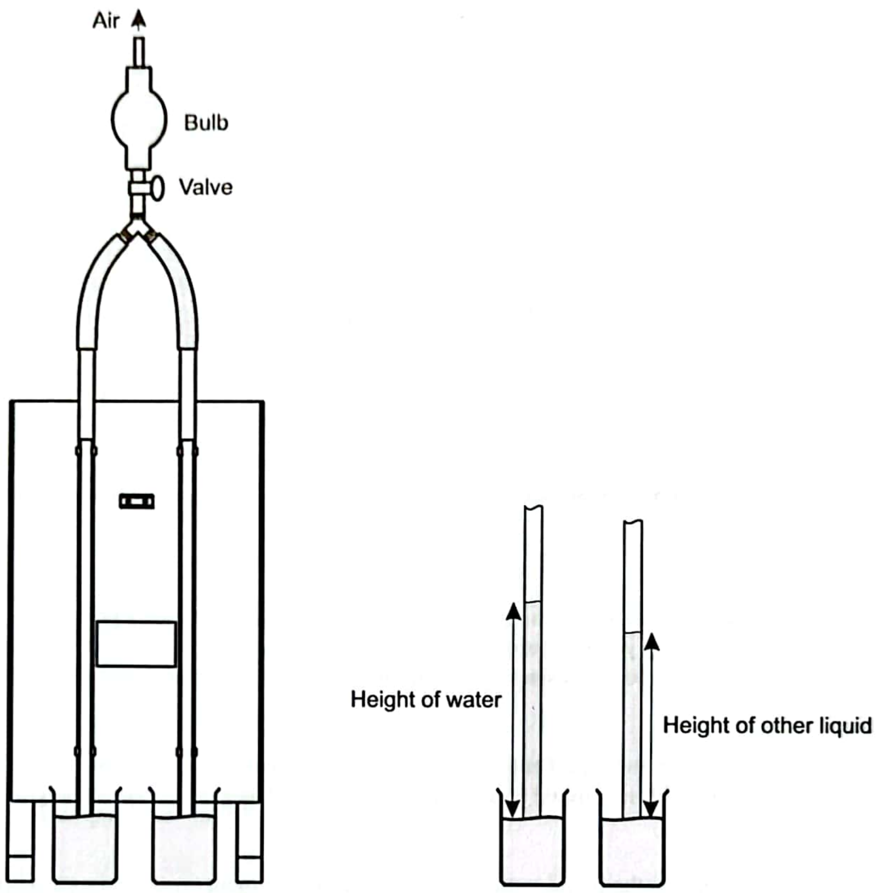


Figure 24 Using Hare's Tube

This apparatus enables the specific gravity of a liquid to be determined when compared with water. This is done as follows:

a) Fill one 100 ml beaker with water and another 100 ml beaker with the other liquid. Ensure the two liquids are at the same level.

b) Place the filled beakers under the vertical glass tubes, ensuring the tubes are at the same height, so the tube goes into the liquid.

c) The suction bulb includes a built-in one way valve, so that it can only 'suck' air from the tubes, but the equipment also includes a small hand-operated valve under the suction bulb to retain the suction when you release the bulb.

d) Fully open the small valve underneath the bulb, squeeze the bulb and slowly release it to draw the two liquids up the glass tubes. Now shut the small valve underneath to keep the fluids in the tube.

e) Record the liquid levels and then fully open the small valve again to allow the fluids to return to their containers (you may need to squeeze the bulb a few times to help).

f) Use the two liquid levels to calculate the unknown liquid's specific gravity as shown:

$$\text{Specific gravity (relative density)} = \frac{\text{Height of water}}{\text{Height of other liquid}}$$

3.12 Depth Gauge (also known as a 'Hook' Gauge)

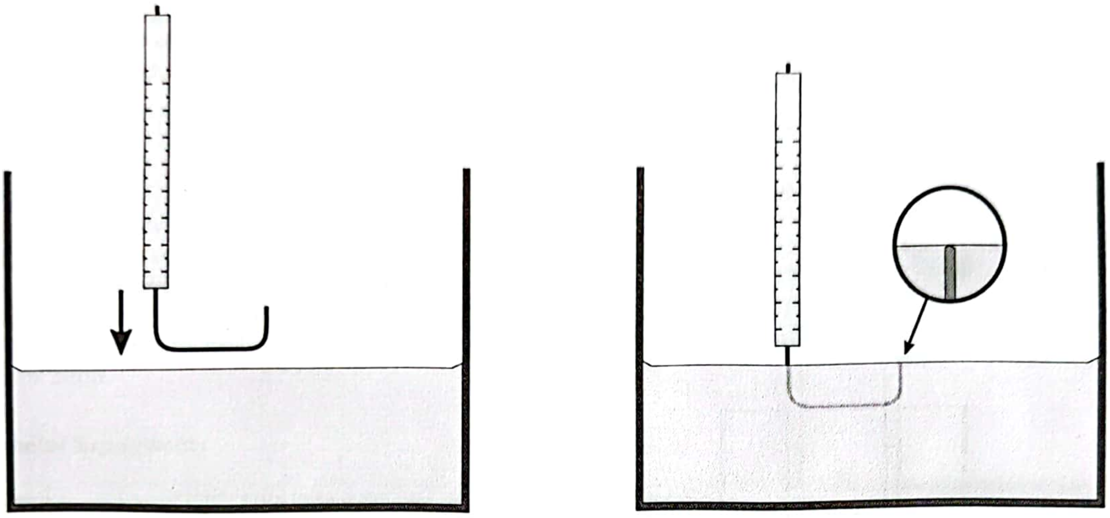


Figure 25 Using the Depth Gauge

The Depth Gauge in the header tank accurately measures changes in liquid level. It uses a pointed hook to 'touch' the surface of the liquid and a scale to help you measure differences in liquid height. To use it you must choose one of two methods and be consistent. If you are not consistent, the small meniscus of liquid that forms around the tip will affect your results.

Method 1: Gently lower the hook into the liquid and note when the tip just passes under the surface of the liquid. Note the reading on the scale. Repeat for different liquid levels and subtract the differences in scale readings to find the change in liquid level.

Method 2: Gently lower the hook into the liquid until it is completely submerged, then slowly raise it until the tip just breaks the liquid surface from underneath. Repeat for different liquid levels and subtract the differences in scale readings to find the change in liquid level.

SECTION 4.0 ALTERNATIVE THEORY

This section includes alternative but relevant theory for some parts of the product.

4.1 Alternative Theory for Buoyancy, Flotation and Stability of Floating Bodies on page 25

Introduction

When designing a vessel such as a ship, which is to float on water, it is clearly necessary to be able to establish beforehand that it will float upright in stable equilibrium.

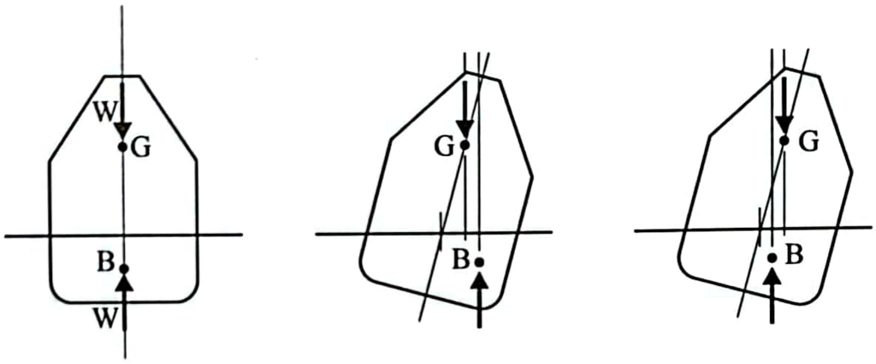


Figure 26 Forces Acting on a Floating Body

Figure 26 (a) shows such a floating body, which is in equilibrium under the action of two equal and opposite forces, namely, its weight W acting vertically downwards through its centre of gravity G, and the buoyancy force, of equal magnitude W, acting vertically upwards at the centre of buoyancy B. This centre of buoyancy is located at the centre of gravity of the fluid displaced by the vessel. When in equilibrium, the points G and B lie in the same vertical line. At first sight, it may appear that the condition for stable equilibrium would be that G should lie below B. However, this is not so.

To establish the true condition for stability, consider a small angular displacement from the equilibrium position, as shown in Figure 26 (b) and Figure 26 (c). As the vessel tilts, the centre of buoyancy moves sideways, remaining always at the centre of gravity of the displaced liquid. If, as shown on Figure 26 (b), **the weight and the buoyancy forces together produce a couple which acts to restore the vessel to its initial position, the equilibrium is stable. If however, the couple acts to move the vessel even further from its initial position, as in Figure 26 (c), then the equilibrium is unstable.** The special case when the resulting couple is zero represents the condition of neutral stability. It will be seen from Figure 26 (b) that it is perfectly possible to obtain stable equilibrium when the centre of gravity G is located above the centre of buoyancy B.

In the following text, we shall show how the stability may be investigated experimentally, and then how a theoretical calculation can be used to predict the results.

Experimental Determination of Stability

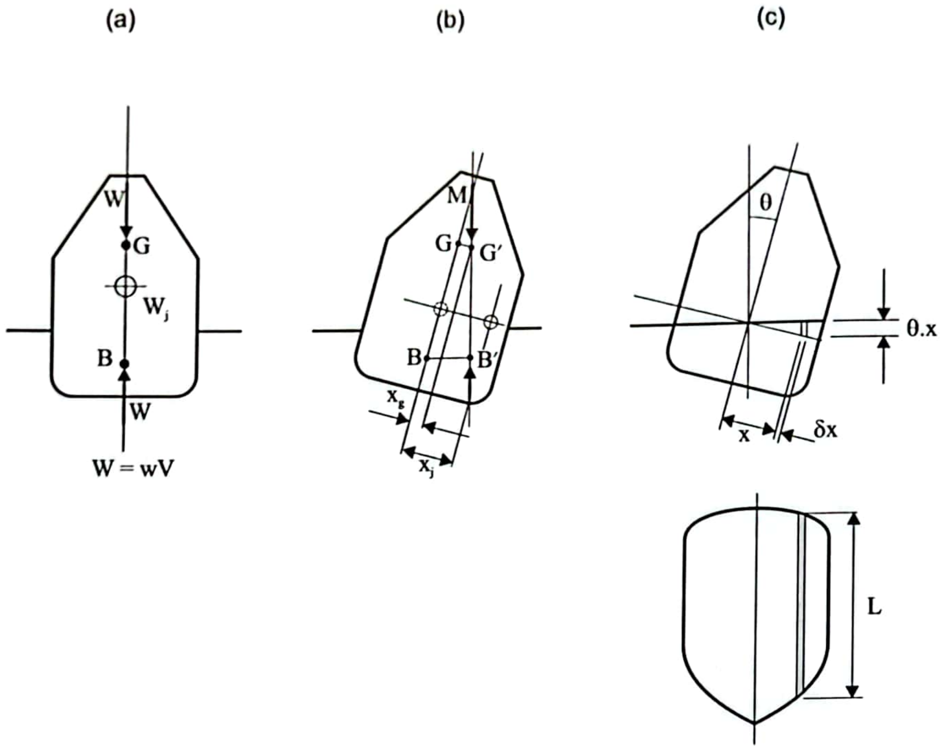


Figure 27 Derivation of Conditions for Stability

Figure 27(a) shows a body of total weight W floating on even keel. The centre of gravity G may be shifted sideways by moving a jockey of weight W_j across the width of the body. When the jockey is moved a distance x_j, as shown in Figure 27(b), the centre of gravity of the whole assembly moves to G'. The distance GG', denoted by x_g, is given from elementary statics as:

$$x_g = \frac{W_j x_j}{W} \tag{31}$$

The shift of the centre of gravity causes the body to tilt to a new equilibrium position, at a small angle θ to the vertical, as shown in Figure 27(b), with an associated movement of the centre of buoyancy from B to B'. The point B' must lie vertically below G', since the body is in equilibrium in the tilted position. Let the vertical line of the upthrust through B' intersect the original line of upthrust BG at the point M, called the metacentre. We may now regard the jockey movement as having caused the floating body to swing about the point M. Accordingly, the equilibrium is stable if the metacentre lies above G. Provided that θ is small, the distance GM is given by:

$$GM = \frac{x_g}{\theta} \tag{32}$$

where θ is in circular measure. Substituting for x_g from Equation (31) gives the result:

$$GM = \frac{W_j}{W} \times \frac{x_j}{\theta} \tag{33}$$

The dimension GM is called the metacentric height. In the experiment described below, it is measured directly from the slope of a graph of x_j against θ, obtained by moving a jockey across a pontoon.

Analytical Determination of BM

A quite separate theoretical calculation of the position of the metacentre can be made as follows.

The movement of the centre of buoyancy to B' produces a moment of the buoyancy force about the original centre of buoyancy B. To establish the magnitude of this moment, first consider the element of moment exerted by a small element of change in displaced volume, as indicated on Figure 27(c). An element of width δx, lying at distance x from B, has an additional depth $\theta.x$ due to the tilt of the body. Its length, as shown in the plan view on Figure 27(c), is L. So the volume δV of the element is:

$$\delta V = \theta.x.L.\delta x = \theta L x \delta x$$

and the element of additional buoyancy force δF is:

$$\delta F = w.\delta x = w\theta L x \delta x$$

where w is the specific weight of water. The element of moment about B produced by the element of force is δM, where

$$\delta M = \delta F.x = w\theta L x^2 \delta x$$

The total moment about B is obtained by integration over the whole of the plan area of the body, in the plane of the water surface:

$$M = w\theta \int L x^2 dx = w\theta I \qquad (34)$$

In this, 'I' represents the second moment, about the axis of symmetry, of the water plane area of the body.

Now this moment represents the movement of the upthrust wV from B to B', namely, wV.BB'. Equating this to the expression for M in Equation 34.

$$wV.BB' = w\theta I$$

From the geometry of the figure, we see that

$$BB' = \theta.BM$$

and eliminating BB' between these last two equations gives BM as:

$$BM = 1/V \qquad (35)$$

For the particular case of a body with a rectangular planform of width D and length L, the second moment I is readily found as:

$$I = \int_{-D/2}^{D/2} L x^2 dx = L \int_{-D/2}^{D/2} x^2 dx = L\left[\frac{x^3}{3}\right]_{-D/2}^{D/2} = \frac{LD^3}{12}$$

Now the distance BG may be found from the computed or measured positions of B and of G, so the metacentric height GM follows from Equation (35) and the geometrical relationship:

$$GM = BM - BG \qquad (36)$$

This gives an independent check on the result obtained experimentally by traversing a jockey weight across the floating body.

4.2 *Alternative Theory for Forces on Plane Surfaces: Centre of Pressure on page 32*

Introduction

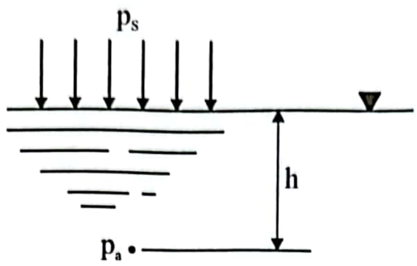


Figure 28 Hydrostatic Pressure at Depth

The hydrostatic pressure exerted by a liquid of density ρ or specific weight w, at depth h below the surface, is:

$$p = \rho g h = wh \qquad (37)$$

This is the gauge pressure, due solely to the liquid column of height h. To obtain the absolute pressure p_a at depth h, we must add whatever pressure p_s is applied at the liquid's surface, giving:

$$p_a = p_s + p$$

or

$$p_a = p^s + wh$$

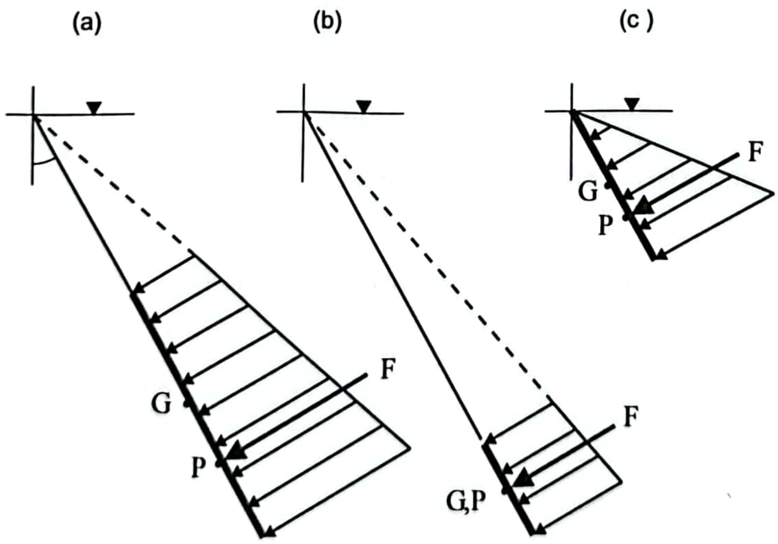


Figure 29 Hydrostatic Thrust on Plane Surfaces

Hydrostatic pressure generates thrust on any surface over which it acts. Figure 29 (a) indicates the distribution of gauge pressure over a plane surface in the liquid. The pressure acts normal to the surface, increasing linearly with depth below the water surface. The result of the pressure forces is a single force F, which of course is also normal to the surface. If the pressure were uniform, F would act through the centroid G of the plane surface. However, as the pressure increases with depth, the line of action of F is through some lower point P, called the **centre of pressure**. If the extent of the plane surface is small compared with its depth, as shown in Figure 29(b), the hydrostatic pressure is very nearly constant over it, so the centre of pressure lies nearly at the centroid. If however, the upper edge of the plane area lies in the water surface the pressure distribution is triangular, as shown in Figure 29(c), and P will lie at a significant distance below G.

The hydrostatic force on a submerged surface, such as the face of a dam or on a lock gate, can be extremely large, so it is necessary to be able to calculate such a force with certainty.

Analytical Determination of Position of Centre of Pressure

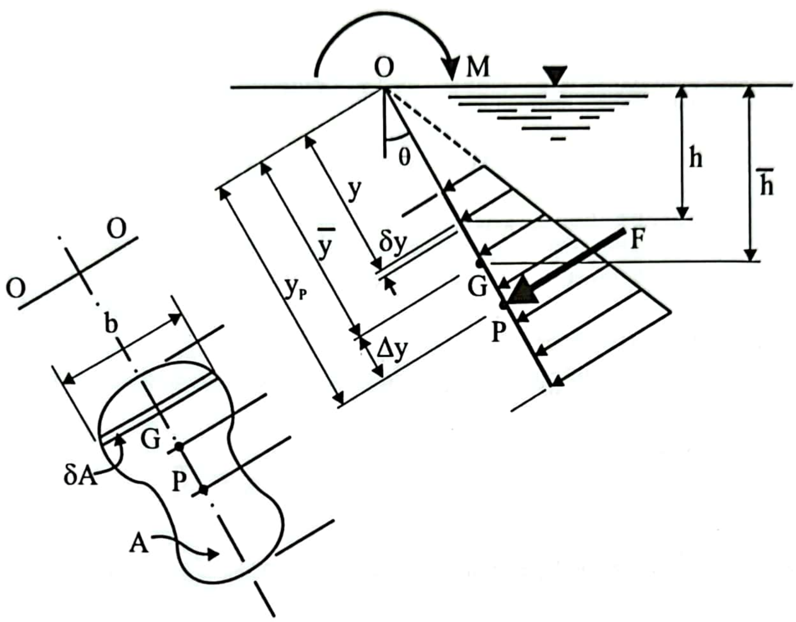


Figure 30 Determination of position of centre of pressure

Consider a plane surface A, inclined at angle θ to the vertical, as shown in edge and front view in Figure 30. For simplicity, the surface is taken to be symmetrical in front view. The area δA of the element shown at depth h, is:

$$\delta A = b\delta y$$

in which b is its width and δy its length, measured down the slope. The hydrostatic pressure on the element is

$$p = wh$$

so the element of hydrostatic force δF is

$$\delta F = p\delta A = wh\delta A$$

The resultant force F is obtained by integrating over the whole area A, and is therefore

$$F = w\int h\delta A$$

Now the depth $\bar{h}$ of the centroid G is, by definition, given by:

$$\bar{h}A = \int h\delta A$$

From these last two equations we see that

$$F = w\bar{h}A \qquad (38)$$

Writing $\bar{p}$ as the hydrostatic pressure at the centroid, then

$$\bar{p} = w\bar{h}$$

so the force F may be written as

$$F = \bar{p}A \qquad (39)$$

The **magnitude** of F is therefore simply the product of the hydrostatic pressure at the centroid, and the area of the surface. To obtain the **position** of F, we take moments about the axis through O, lying in the water surface.

The element of moment δM about O produced by the element of force δF is

$$\delta M = y\delta F$$

Integrating over the surface, the resultant moment is

$$M = w\sec\theta\int y^2\delta A$$

Now the second moment of area of A about the axis at O is, by definition,

$$I_o = \int y^2\delta A$$

so, substituting this into the previous equation,

$$M = w\sec\theta I_o \qquad (40)$$

This moment may also be expressed as

$$M = Fy_p$$

where y_p is the depth, measured down the slope, of the centre of pressure P below the water surface. Equation 38 gives F as

$$F = w\bar{h}A = w\bar{y}\sec\theta A$$

Substituting from this for F in the previous equation, and then equating the result to M as given by Equation 40 leads to

$$y_p = \frac{I_o}{A\bar{y}} \qquad (41)$$

This result may be simplified by using the "theorem of parallel axes", which relates the second moment of area I_o about the axis at O to the second moment I_g about the parallel axis through G by

$$I_o = A\bar{y}^2 + I_g = A\bar{y}^2 + Ak_g^2 \qquad (42)$$

In this,

I_o is the second moment of area A about the axis at O;

I_g is the second moment of area A about the axis at G;

k_g is the radius of gyration of A about the axis at G.

Substituting into Equation 41, we derive the result

$$y_p = \bar{y} + \frac{k_g^2}{\bar{y}} \qquad (43)$$

Finally, the slant distance, $\Delta y = y_p - \bar{y}$, between P and G is

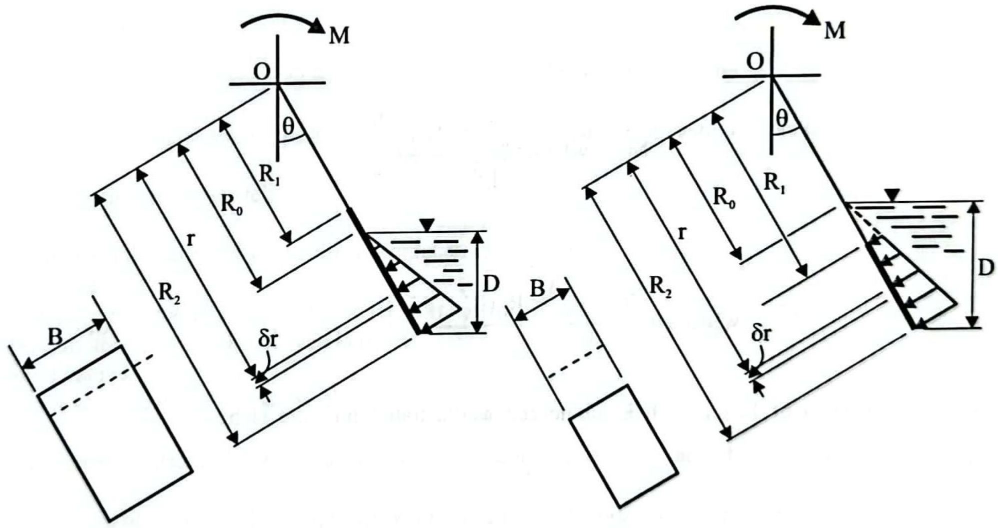
$$\Delta y = \frac{k_g^2}{\bar{y}} \qquad (44)$$

In summary, the resultant force F is $\bar{p}A$, the product of the hydrostatic pressure $\bar{p}$ at the centroid G and the area A of the surface. It acts at the centre of pressure P, which lies at the slant distance Δy below G given by:

$$\Delta y = \frac{k_g^2}{\bar{y}}$$

In the experiment described below, a plane surface is subjected to hydrostatic pressure, and measurement is made of the resultant moment about a fixed axis above the water surface. This moment is compared with a value derived from an analysis similar to that presented above.

Analytical Determination of Moment about an Axis above the Water Surface



(a) Partial Submergence (B) Full Submergence

Figure 31 Determination of Moment about an Axis above the Water Surface

Consider a rectangular plate, inclined at angle θ to the vertical, which is subjected to the action of an increasing depth of water. Figure 31 (a) shows the case where the plate is only partially submerged, and Figure 31(b) shows the case when the plate is completely submerged below the level of the water surface. We now derive expressions for the moment produced about a fixed axis at O above the water surface.

Let D be the depth of water above the lower edge of the rectangle. Let R_1 be the slant distance from the axis O to the upper edge, and R_2 be the corresponding slant distance to the lower edge. It is convenient also to define R_0 as the slant distance to the water surface. To find the moment about the axis at O, consider first the moment produced by the action of hydrostatic pressure on an element, lying at slant distance r from the axis, and of slant length δr. The width of the rectangular plate is B, so the area of the element δA is

$$\delta A = B\delta r$$

The depth of the element below the water surface is $(r-R_0)\cos\theta$, so the hydrostatic pressure p on it is:

$$p = w(r-R_o)\cos\theta$$

The hydrostatic force δF on the element is:

$$\delta F = p\delta A = wB(r-Ro)\cos\theta\delta r$$

This force acts at radius r from the axis at O, so the moment δM produced about O is:

$$\delta M = wB(r-Ro)\cos\theta\delta r$$

The total moment M, obtained by integration over the submerged area, is:

$$M = wB\cos\theta\int r(r-R_0)dr \qquad (45)$$

Now the limits of integration for the two cases shown in Figure 31 are different. For the case of Figure 31(a), where the rectangular surface is only partially submerged:

$R_0 > R_1$ and

$$M = wB\cos\theta\int_{R_0}^{R_2} r(r-R_0)dr = wB\cos\theta\int_{R_0}^{R_2}(r^2-R_0r)dr$$

which leads to:

$$M = wB\cos\theta\left[\frac{r^3}{3}-\frac{R_0r^2}{2}\right]_{R_0}^{R_2}$$

or

$$M = wB\cos\theta\left[\frac{R_2^3-R_0^{\ 3}}{3}-\frac{R_0(R_2^2-R_0^2)}{2}\right] \qquad (46)$$

For the case where the whole of the rectangle is submerged, as illustrated in Figure 31(b),

$R_0 > R_1$ and

$$M = wB\cos\theta\int_{R_1}^{R_2} r(r-R_0)dr = wB\cos\theta\int_{R_1}^{R_2}(r^2-R_0r)dr$$

or

$$M = wB\cos\theta\left[\frac{R_2^3-R_1^{\ 3}}{3}-\frac{R_0(R_2^2-R_1^2)}{2}\right] \qquad (47)$$

SECTION 5.0 MAINTENANCE, SPARE PARTS AND CUSTOMER CARE

5.1 Maintenance

Regularly check all parts of the apparatus for damage, renew if necessary.

When not in use, store the apparatus in a dry, dust-free area, covered with a plastic sheet. If the apparatus becomes dirty, wipe the surfaces with a damp, clean cloth. Do not use abrasive cleaners.

Regularly check all fixings and fastenings for tightness, adjust where necessary.

NOTE *Renew faulty or damaged parts with an equivalent item of the same type or rating.*

Pressure Measurement Apparatus

Always smear the whole piston surface lightly with oil (supplied) after use. Do not attempt to polish the piston rod with emery cloth, or any harsh abrasive. Use only a mixture of powdered chalk and oil to remove discoloration.

5.2 Spare Parts

Check the Packing Contents List to see what spare parts we send with the apparatus.

If you need technical help or spares, please contact your local TecQuipment agent, or contact TecQuipment direct.

When you ask for spares, please tell us:
- Your name
- The full name and address of your college, company or institution
- Your email address
- The TecQuipment product name and product reference
- The TecQuipment part number (if you know it)
- The serial number
- The year it was bought (if you know it)

Please give us as much detail as possible about the parts you need and check the details carefully before you contact us.

If the product is out of warranty, TecQuipment will let you know the price of the spare parts.

5.3 Customer Care

We hope you like our products and manuals. If you have any questions, please contact our Customer Care department:

Telephone: +44 115 954 0155

Fax: +44 115 973 1520

Email: **customercare@tecquipment.com**

For information about all TecQuipment products visit: **www.tecquipment.com**

TecQuipment

Air Valves

TecQuipment's

Fluid Mechanics Products

Instruction Sheets

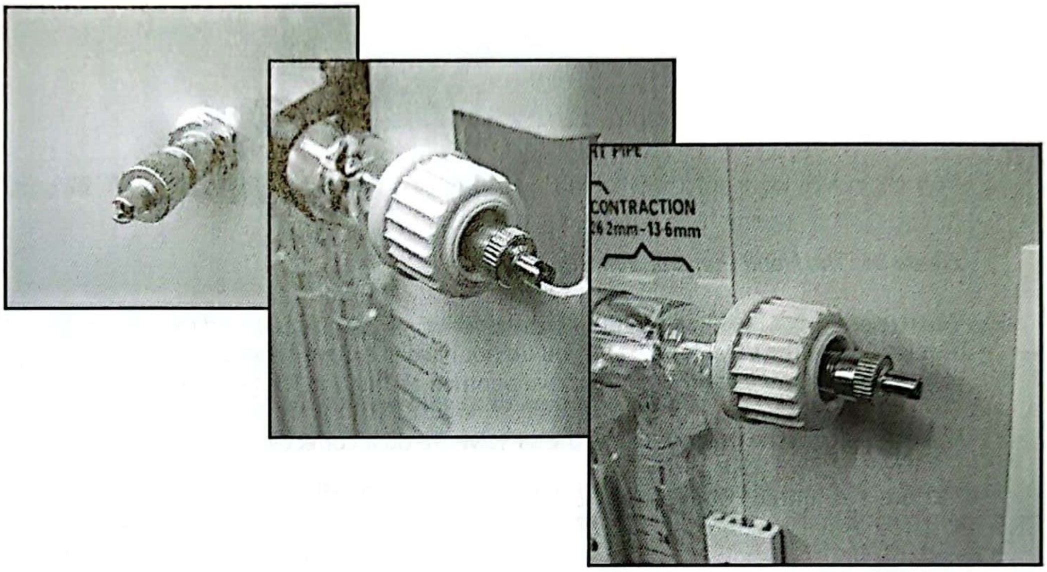


Figure 32 Typical Air Valves on Some of TecQuipment's Products

Many of the products in TecQuipment's Fluid Mechanics range use air valves at the tops of manometers or piezometers. The valves keep the air in the manometer tubes to allow you to offset the pressure range of the manometer or piezometer.

The valves are similar to valves used in vehicle tyres and include a special cap. The hand pump supplied with the equipment is similar to those used for bicycle tyres, except that TecQuipment remove the cross-shape part of the flexible pipe.

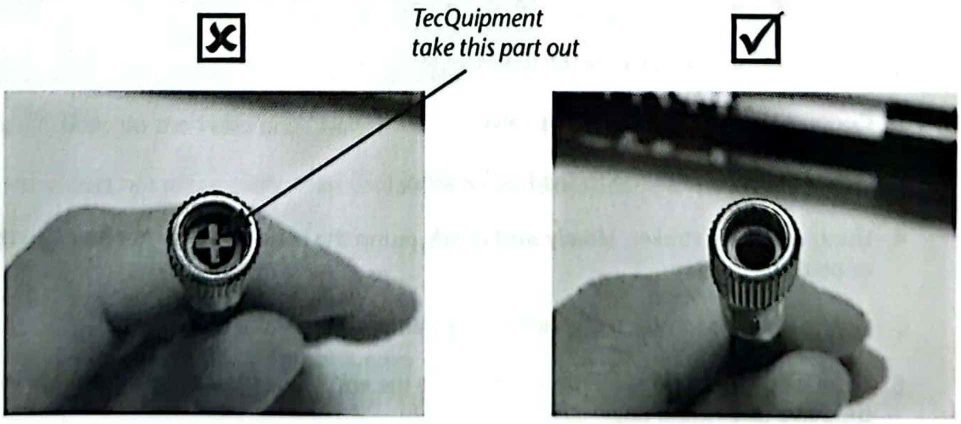


Figure 33 TecQuipment Remove the Cross-shape Part of the Flexible Pipe

Normally, when you connect the flexible pipe to an air valve, the cross-shape piece in the flexible pipe pushes open the valve as you pump air with the hand pump. With TecQuipment fluid mechanics products, this could allow water back out through the valve. For this reason TecQuipment remove the cross-shape piece. Without the cross-shape piece, only pressurised air can go through the valve in one direction, and no water can come back out.

Figure 34 The Hand Pump and Flexible Pipe

When you first use the hand pump with the air valve, you may find it hard to push air through the valve. This is because the valve is new and you do not have the cross-shape piece to help push it open. The valve will open more easily after you have pumped air through it a few times.

You may need some practice to use the air valve. To do it correctly:

1. Unscrew the cap from the valve.

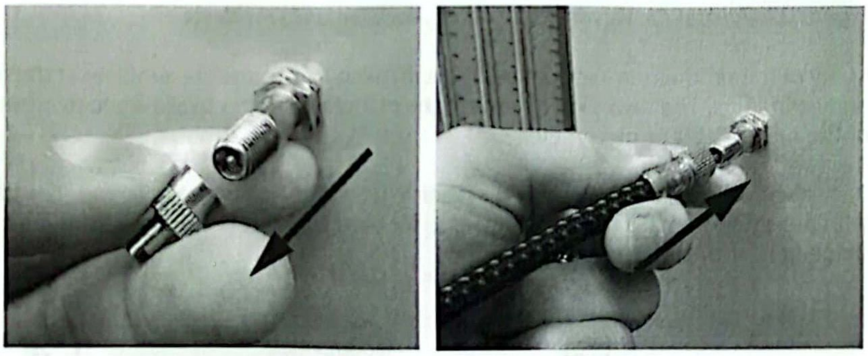


Figure 35 Unscrew the Cap and Fit the Pipe

2. Connect the flexible pipe to the valve.
3. Connect the hand pump to the flexible pipe.
4. Using complete strokes, ***slowly and firmly*** pump the hand pump to force air into the manometer or piezometer.
5. Unscrew the hand pump and flexible pipe and refit the valve cover.
6. To let air back out through the air valve, use the end of the special cap to press on the inner part of the valve (see Figure 36).

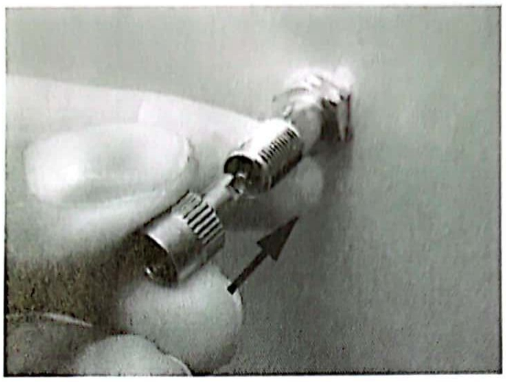


Figure 36 To Let Air Out - Use the End of the Special Cap to Press the Inner Part of the Valve

WARNING

Take care when you let air back out from the air valve. Water may come out!

Clean up any water spills immediately.

If using the hand pump is too difficult, the valve may be stuck. If you need to check the valve is working, use the special cap to unscrew the valve, then gently press the end of the valve. It should move easily and return back to its original position (see Figure 37).

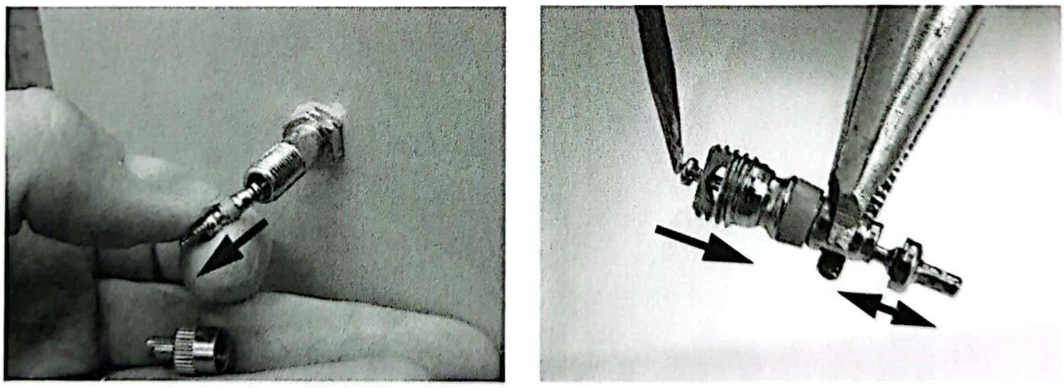


Figure 37 Unscrew the Valve and Check it

If the valve does not move easily, then contact TecQuipment Customer Services for help.

Telephone: +44 115 9722611

Fax: +44 115 973 1520

Email: **customer.care@tecquipment.com**

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