The Video Encyclopedia *of* Physics Demonstrations™

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D I S C   T W E L V E

Chapter 27 Fluid Pressure

Chapter 28 Buoyancy

CHAPTER 27

FLUID PRESSURE

Demo 12-01 Same Level Tubes

This demonstration shows that water "seeks its own level" using the apparatus of *Figure 1*. The pressure in each of the tubes is proportional to its vertical height, so the pressure at the bottom of each tube is the same and the system is in equilibrium.†

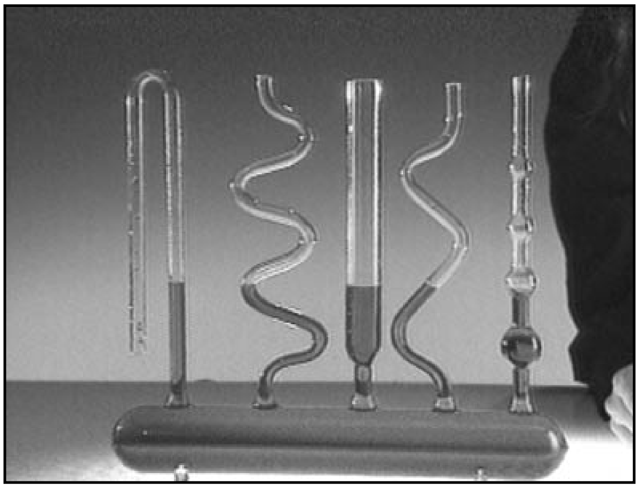

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-275, Pressure Depends on Depth.
Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Fa-3, Pascal Vases.

Here are five glass tubes connected to a common reservoir filled with water.

The heights of the water in all five tubes are the same despite the different shapes and sizes of the tubes.

Tipping the tubes shows that the water level in all the tubes always remains at the same height.

Equipment

1. Commercially available equilibrium tubes.
2. Supply of colored water.

Demo 12-02 Pressure vs. Depth

This video shows that the pressure in a liquid is proportional to the depth of the liquid.† The demonstration uses a pressure-sensitive transducer connected to an array of light-emitting diodes that make a bar graph of the pressure, shown in *Figure 1*. As the transducer is lowered into water, the number of LED's activated grows, increasing the length of the bar. When the water column is tipped the bar graph gets shorter, as shown in *Figure* 2. The length of the bar graph is always equal to the vertical depth of the sensor in water.

Figure 1

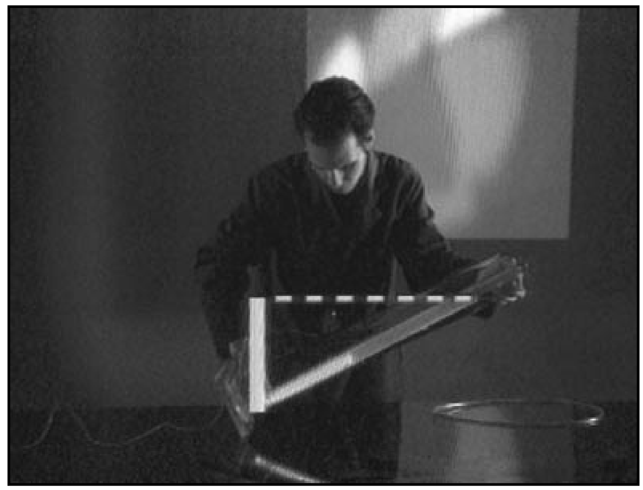

Figure 2

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-275, Pressure Depends on Depth.
Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Fa-3, Pascal Vases.

This is an electronic pressure gauge with a pressure sensor at the bottom.

Blowing into the sensor through a tube increases the pressure and drives the bar graph display, whose length is proportional to the pressure at the sensor. We'll use it to show how the pressure in a column of water changes with increasing depth.

As the sensor goes deeper into this column of water, the display shows that the pressure increases in direct proportion to the depth.

What will happen to the display if we tip the water column at an angle?

Tipping the column of water reduces the pressure reading. The length of the display is still equal to the vertical depth of water above the sensor, as shown by this line.

Equipment

1. Custom made, LED display, electronic pressure gauge with a pressure sensor located in the tip of the bar.
2. Tall cylinder of water.
3. Length of plastic tubing.

Demo 12-03 Pressure vs. Depth in Water and Alcohol

The apparatus of Disc 12 Demonstration #2 is used to compare the pressure of a column of water with the pressure of an identical column of alcohol. When the transducer is lowered into alcohol the pressure is less than that of an identical column of water, due to the lesser density of the alcohol. The pressures at the same depth in alcohol and in water, shown in *Figure 1*, are compared in the video.

Figure 1

This is an electronic pressure gauge which has a pressure sensor at the bottom.

Blowing into the sensor through a tube increases the pressure and drives a bar-graph display whose length is proportional to the pressure at the sensor.

When the pressure gauge is placed in a column of water, the display shows that the pressure increases in direct proportion to the depth of the sensor.

If we replace the water in the column with alcohol, which has a lower density than water, how will the pressure readings be affected?

The reading is lower in alcohol than at the same depth in water, but it is still proportional to the depth.

Equipment

1. Same as Demonstration 12-02.
2. Supply of alcohol.

Demo 12-04 Pressure Independent of Direction

A large membrane on the end of a tube is lowered into a tank of water, showing that the pressure in the tank increases with distance below the surface, as illustrated in *Figure 1*. When the membrane is rotated so that it faces any arbitrary direction, the pressure remains the same, verifying that the pressure at any point in a fluid is independent of direction.†

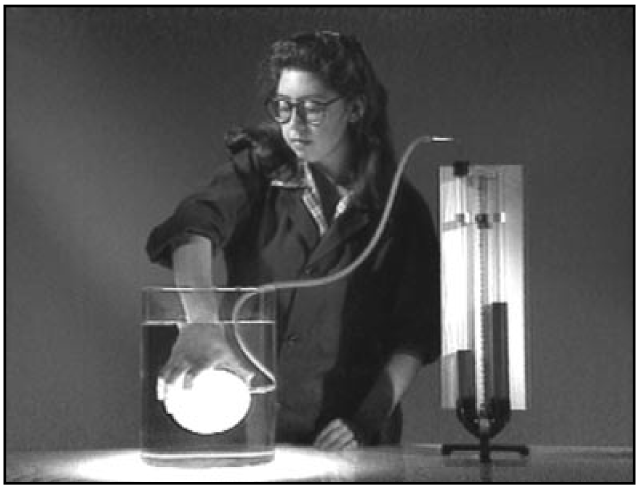

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-271, Pressure the Same in All Directions—Pascal's Law.
Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Fa-1, Pressure Independent of Direction.

We'll use this water manometer driven by a flexible rubber diaphragm to show that pressure in a fluid is independent of direction.

When the diaphragm is lowered into a jar of water, the manometer indicates the pressure increase with depth.

When the diaphragm is held at a constant depth and turned to different directions, the reading on the manometer stays constant.

The pressure in the water is the same in all directions.

Equipment

1. Manometer—glass U-shaped tube filled with colored water, and its support system (an attached meter stick section is helpful for reading water column heights).
2. Length of rubber tubing attached to a rubber stopper appropriate size to fit the manometer tube on one side while the other side remains open.
3. Clear plastic cell, one side covered by rubber dental dam sheeting, and equipped for attaching the rubber tubing—all seals need to be watertight.
4. Large clear container of water.

Demo 12-05 Water/Air Compression

A syringe filled with air as in *Figure 1* can be easily compressed by a force on the plunger of the syringe. When the syringe is filled with water, as shown in the video, it cannot be compressed.†

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-270, Compressibility of Water.

Air is compressible. If we fill this syringe with air and place it between two wooden blocks, a weight placed on the upper block can easily compress the air.

Water is not as compressible. If the syringe is filled with water instead of air and the demonstration is repeated,

even large amounts of weight do not compress the water significantly.

Equipment

1. Large syringe.
2. Support system (two custom-fitted blocks, one for the tip of the syringe, the other for the plunger cap).
3. Large weight (10 pounds).
4. Supply of colored water.

Demo 12-06 Water and Mercury U-tube

Water is poured into one side of a U-tube originally partially filled with mercury.† The equilibrium level of the water is higher than the level of the mercury in the other side of the U-tube, due to the difference in their densities, as shown in *Figure 1*. The relative densities of water and mercury can be calculated from the heights of the two columns.

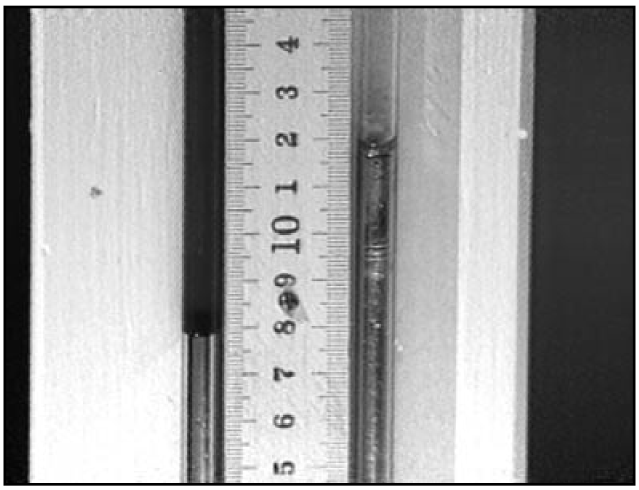

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Fh-1, Comparison of Fluid Densities.

The mercury in this U-shaped tube is in equilibrium when the surface of the mercury is at the same height in both sides of the tube.

But when colored water is added to one side, the fluids come to equilibrium with their surfaces at different heights. The pressure at the bottom of each leg must still be the same, but the amount of fluid required to produce that pressure is different on each side.

Equipment

1. Tall mercury U-shaped manometer.
2. Support system including a meter stick.
3. Squeeze bottle nozzle and colored water.

Demo 12-07 Hydraulic Press

A hydraulic press uses Pascal's law for the pressure in a confined fluid to convert a small force into a large force.† A small force is exerted on a small area piston, creating a large force on the large piston which operates the press of *Figure 1*. With this large force one can bend an aluminum bar with one hand, as shown in the figure.

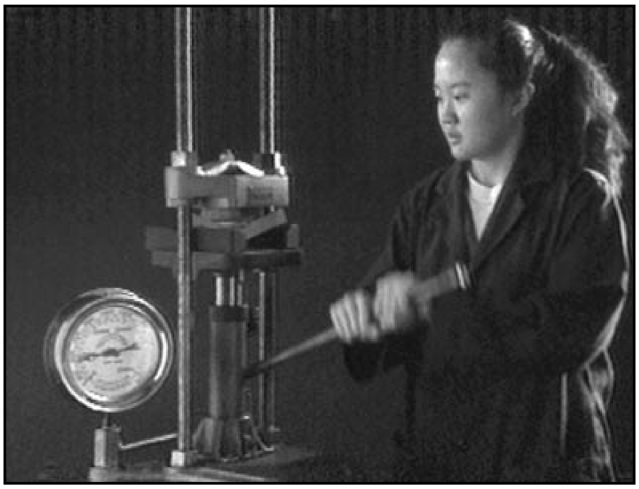

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-282, Pumps and Presses.

This hydraulic press will be used to show how fluid pressure can multiply a small input force into a large output force.

Pressing this lever down with the force of two hands is enough to break a piece of wood

or bend a thick piece of metal.

This animation shows how it works.

Two oil-filled cylinders with different diameters are connected by a tube.

Each cylinder is a tightly fitting piston.

Pressing down on the lever moves the small piston down, increasing the pressure in the oil. The increased pressure acts on the larger surface area of the second piston, pushing it up with a force that is larger than the downward force on the small piston.

Equipment

1. Hydraulic press, complete with large readable pressure gauge.
2. Supply of wooden blocks.
3. Supply of metal bars.

Demo 12-08 Hydrostatic Paradox

A glass plate can be held against a truncated glass cone submerged in water by the hydrostatic pressure of the water, as shown in *Figure 1*.[†] If the tube does not have a large enough area, the net force provided by the water is insufficient to hold the plate up, as shown in the video.

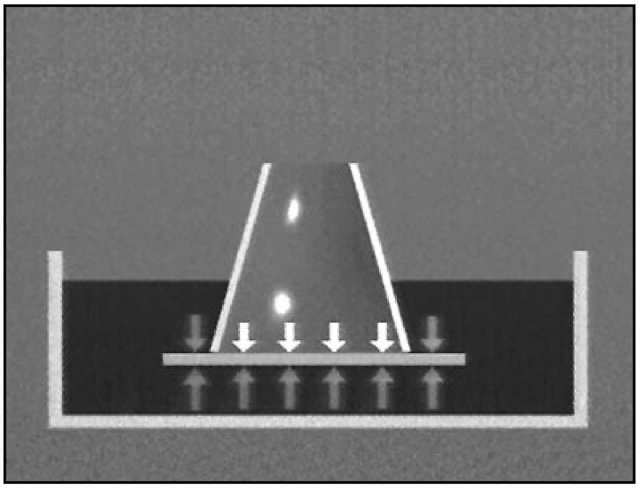

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-276.
Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Fc-1, Water Pressure.

When an object is submerged in water, the water pressure on it increases with depth.

We can use that pressure to hold a glass plate onto the bottom of this truncated glass cone which is filled with air. The air pressure on top of the plate is less than the water pressure on the bottom of the plate.

The difference in pressures results in an upward force that holds the glass plate onto the bottom of the cone.

If we turn the cone over so that the small end is down, the plate will no longer be held against the cone. What causes the difference?

As this graphic shows, the area of the pressure differential is smaller for the small end of the cone. That results in a smaller total upward force on the plate.

Equipment

1. Truncated glass cone with ground glass ends.
2. Flat piece of glass.
3. Clear container of water large enough to hold the glassware and hands.

CHAPTER 28

BUOYANCY

Demo 12-09 Hydrometer

A hydrometer, seen in *Figure 1*, is a calibrated device that uses buoyancy to determine the density of liquids.† In the video the hydrometer is placed first in water, with a density of 1, and then in alcohol, in which it floats more deeply and thus gives a smaller density, as shown in the Figure.

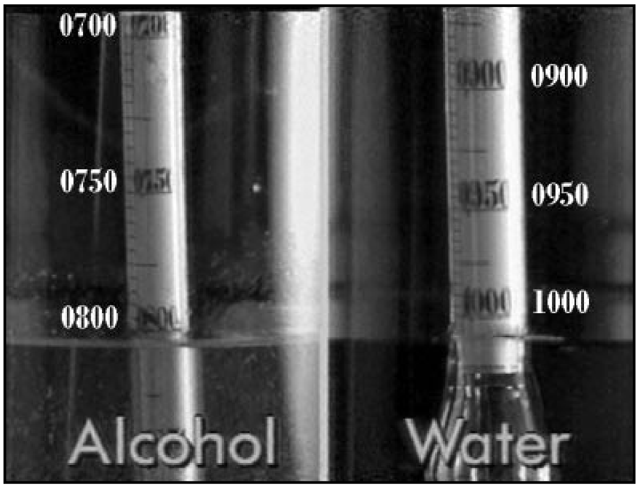

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-286, Hydrometers.

This hydrometer is used to measure the density of liquids. When placed in water, it floats with this much of its volume submerged.

When the same hydrometer is placed in a lower density liquid such as alcohol, it floats with more of its volume submerged.

In each case the density of the liquid can be calculated using the depth at which the hydrometer floats.

Equipment

1. Hydrometer.
2. Tall clear cylinder of water.
3. Tall clear cylinder of alcohol.

Demo 12-10 Weight of Air

A hollow sphere is weighed on a pan balance, as in *Figure 1*. The air is then pumped out of the sphere and it is again weighed on the balance.† An additional mass must be added to the side of the balance with the evacuated hollow ball to compensate for the weight of the missing air, as shown in the video.

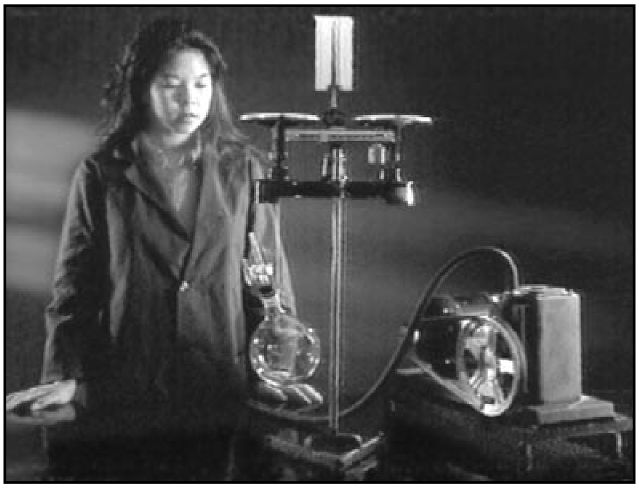

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-315, Gases Have Mass.

Weight of Air / Script

Does the air that we breathe have weight?

It’s not apparent in everyday life, but we will demonstrate that air does indeed have a small amount of weight.

This glass flask is first weighed by hanging it from a balance scale. Then we see that the scale is in balance.

We’ll evacuate the air from the flask using a vacuum pump.

The weight of the evacuated flask is less than that of the flask when filled with air, and the balance tips.

One gram must be added to the balance to replace the weight of the air.

Equipment

1. Platform balance mounted on a ring stand.
2. Round bottom flask fitted with a rubber stopper and stopcock and having a piece of string tied around its neck with a loop tied on the opposite end.
3. Vacuum tubing.
4. Vacuum pump.
5. One-gram weight.

Demo 12-11 Buoyant Force

When a heavy object is submerged in water the water exerts an upward buoyant force on the object. This video shows that the loss of weight of the submerged object is equal to the buoyant force.† A weight hanging on a spring balance is lowered into a container of water which is hanging from a second spring balance. The loss of weight of the upper balance is equal to the gain of weight on the lower balance, as indicated in *Figure 1* and in the video.

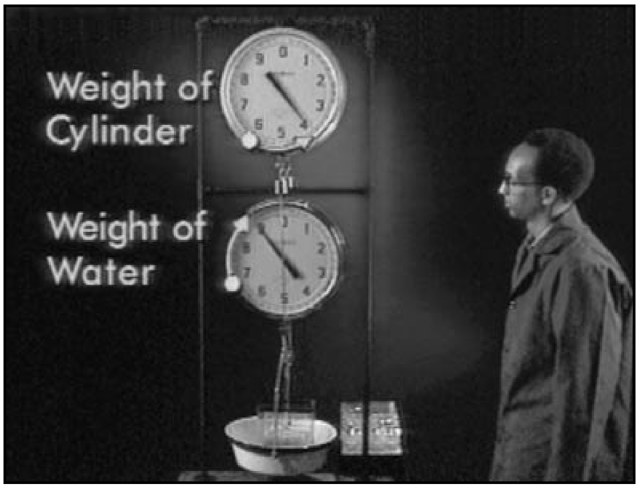

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-283, Archimede's Principle. Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Fg-4, Loss of Weight in Water.

Why do objects seem lighter when they are put under water?

We'll use this pair of kitchen scales in a frame to find out.

The upper scale shows the weight of this aluminum cylinder.

The lower scale shows the weight of this container of water.

If we lower the cylinder into the water, how will those readings change?

The weight of the cylinder appears to have decreased by two pounds, while the weight of the water appears to have increased by the same amount.

The water is pushing up on the aluminum, and the aluminum pushes down on the water by an equal amount.

Equipment

1. Two large spring scales mounted on a vertical framework. Each scale supports frameworks below it so it can give comparative reads when the actions in the script are followed.
2. Weight.
3. Clear container of water.
4. Weight hanger.

Demo 12-12 Archimedes' Principle

Archimedes' principle states that the buoyant force is equal to the weight of the water displaced. As a large weight, hanging from a spring scale, is lowered into a water bath, the displaced water is collected in a glass beaker. When the displaced water is poured into a pail, also hanging from the spring scale, as shown in *Figure 1*, the original reading of the spring scale is restored.†

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-284.
Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Fg-1, Archimedes' Principle.

This demonstration will show how the buoyant force on a submerged object is related to the amount of water displaced by the object.

This aluminum cylinder and pail hang from a scale, which shows the total weight to be 29 newtons. We'll lower the cylinder into this water container, which has an overflow spout.

When the cylinder is submerged, the reading on the scale decreases to 20 newtons. All water displaced by the cylinder will flow into a beaker.

If we pour the water that was displaced by the cylinder into the small bucket hanging from the scale, how will the reading change?

The scale now reads the same as before the cylinder was lowered into the water. The buoyant force on the cylinder is equal to the weight of the water displaced.

Equipment

1. Tall ring stand.
2. Clamp, short bar, and hook.
3. Spring scale.
4. Small bucket with string running below the bucket from handle to handle.
5. Weight with hook (can be irregularly shaped).
6. Large clear container of water with spillover spout and an appropriate sized rubber stopper.
7. Catch basin.

Demo 12-13 Board and Weights Float

A long balsa board is inserted into a tall cylinder of water. A series of weights is then added to the lower end of the board and the board inserted into the water tube after the addition of each weight. The length of wood that is submerged increases by a constant amount after the addition of each equal weight, as shown in graphics on the video.

Figure 1

This thin board is made of balsa wood and weighs very little. When the board is placed in a column of water, about one-seventh of the board is submerged.

We'll attach three equal weights to the board, one at a time, to show how deep the board sinks in each case.

This is how far the board sinks with one weight.

This is how far the board sinks with two weights.

This is how far the board sinks with three weights.

Equipment

1. Long thin board—balsa wood.
2. Tall clear cylinder of water.
3. Three weights (we used pairs of cylinders with a threaded rod axle that can be inserted into one of three appropriate sized holes at one end of the board).

Demo 12-14 Different Density Wood

Three types of wood, of increasing density, are floated in a water tank. The fraction of the wood block that is submerged is equal to its specific gravity, as shown in the video and in *Figure 1*. The woods and their specific gravities are:

balsa 0.14
pine 0.5
ironwood 0.9

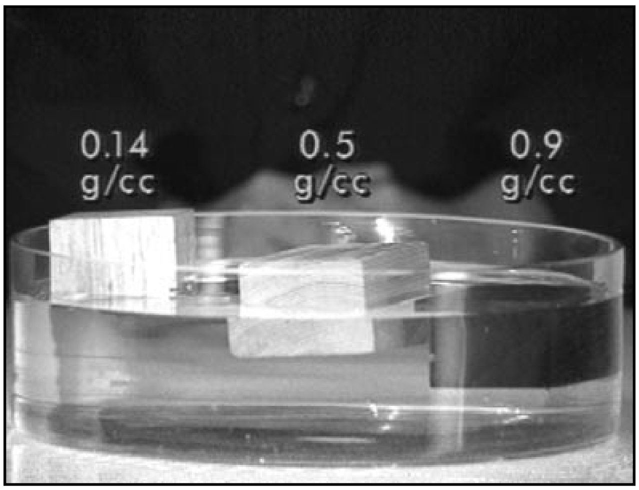

Figure 1

We'll use these three blocks of wood to demonstrate how density affects the depth at which objects float.

This block is cut from balsa wood, with a density of about .14 grams per cubic centimeter. When placed in water, it floats with only about one-seventh of its volume submerged.

This is a block of pine, with a density of about 0.5 grams per cubic centimeter. It floats with about half of its volume submerged.

This is a block of ironwood, with a density of about 0.9 grams per cubic centimeter. When placed in water, it floats with about nine-tenths of its volume submerged.

Equipment

1. Three blocks of wood with identical dimensions:
   a) Balsa wood
   b) Pine wood
   c) Iron wood
2. Transparent container of water large enough to float all three blocks at once.

Demo 12-15 Density Ball

A density ball is a hollow metal sphere whose density is very nearly equal to the density of water near 30° Celsius. In cold water, 15° Celsius, the density ball floats with only a very small piece of the ball above the surface of the water, as shown in *Figure 1*. As the water is heated, it expands, so its density becomes less and the density ball sinks.

Figure 1

Density Ball / Script

The density of water changes with temperature. We'll demonstrate this change in density using this hollow metal ball.

When the ball is placed in cold water, it floats just below the surface because the density of the water is slightly greater than that of the ball.

When the water is warmed over a burner, the decrease in density of the water as it warms causes the ball to sink.

Equipment

1. Ring stand.
2. Ring clamp.
3. Pyrex beaker.
4. Density ball (can be made from toilet tank float with just enough lead shot in to just float below the surface). The seal needs to be watertight.
5. Water.
6. Meker-type burner.
7. Supply of natural gas.
8. Source of flame.

Demo 12-16 Density Balls in Beans

A beaker of dry beans provides a "liquid" in which balls can be "floated."† If a steel ball is placed on the surface of the beans and the bowl of beans is gently shaken, the heavy ball will sink to the bottom. A light Ping-Pong ball previously placed in the middle of the bean bath comes to the surface, as shown in *Figure 1*!

Figure 1

† Robert B. Prigo, Liquid Beans, *The Physics Teacher 26*, 101 (1988).

These dry beans act a bit like a fluid, running from one container to another. And like a fluid, they show effects similar to buoyancy. We'll demonstrate that, using this heavy steel ball.

When the ball is placed on top of the beans and the beaker swirled gently, the steel ball sinks out of sight in the lighter beans.

A light Ping-Pong ball which was below the surface of the beans pops to the top.

Equipment

1. Two large beakers of dry beans.
2. Ping-Pong ball.
3. Heavy steel sphere of similar size to Ping-Pong.

Demo 12-17 Battleship in Bathtub

An object can float in a very small amount of water. Theoretically, if a bathtub were of exactly the right size and shape, a battleship could float in the bathtub in only a few cups of water, hence the demonstration name, "Battleship in Bathtub." † In this video, a rectangular block of wood with a square cross section is floated in a square plastic container in a very small amount of water, as shown in *Figure 1*.

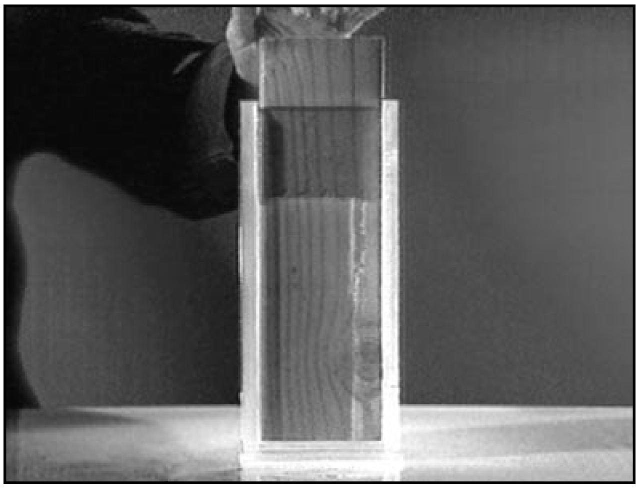

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Fg-5, Battleship in a Cup of Water.

We're used to seeing objects floating in large amounts of water. But how much water is actually required to float an object?

We'll use this wooden block to find out.

This container is just barely larger than the block, and has a small amount of water in the bottom.

When the block is placed inside, the small amount of water is enough to float the block. The amount of water required to float an object is just enough to actually surround the object in its container.

In a container of the right size a large object, such as this ocean liner, could also float in a small amount of water.

Equipment

1. Clear container whose geometry closely matches that of available dimensional wood.
2. Water.
3. Block of wood (we used a 4 x 4 about a foot long since we have a tall square "cylinder").

Demo 12-18 Buoyancy in Various Liquids

Three liquids of different density are poured into a cylindrical tube and form layers, from the bottom: mercury, carbon tetrachloride, and water. In the video, samples of three materials of different density are dropped into the liquids. Iron floats on the mercury, bakelite floats on the carbon tetrachloride, and wood floats on the water, as shown in *Figure 1*.†

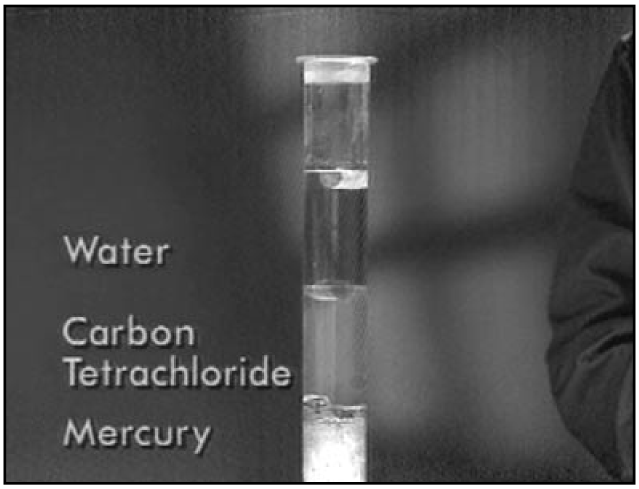

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-285, Floating and Density.

This column contains three liquids with different densities. In order from the bottom, they are: mercury, carbon tetrachloride, and water.

We'll drop three objects made of different materials into the liquids to see where each object floats.

Here is a piece of iron. It sinks through the first two layers and floats on the mercury.

Here is a piece of bakelite. It sinks through the first column and comes to rest atop the carbon tetrachloride.

This piece of wood floats atop the water.

Equipment

1. Tall clear cylinder.
2. Mercury.
3. Carbon tetrachloride.
4. Water (use roughly equal volumes of each liquid).
5. Cylinder of iron.
6. Cylinder of bakelite.
7. Wooden dowel rod (use essentially equal sizes of numbers 5, 6, and 7).

Demo 12-19 Floating Square Bar

A symmetric long square bar floats in water with its sides at angles that depend on the specific gravity of the bar.† Because the density of the bar cannot easily be changed, the density of the liquid in which it floats is varied in this video. The original bath is alcohol, in which the specific gravity of the bar is greater than 0.78, so it floats with its sides horizontal and vertical. When water is poured into the bath, the mixture of alcohol and water has a greater density, so the specific gravity of the bar in that bath becomes less than 0.72. The orientation of the bar in the bath changes, with the sides at ±45°, as shown in *Figure 1*.

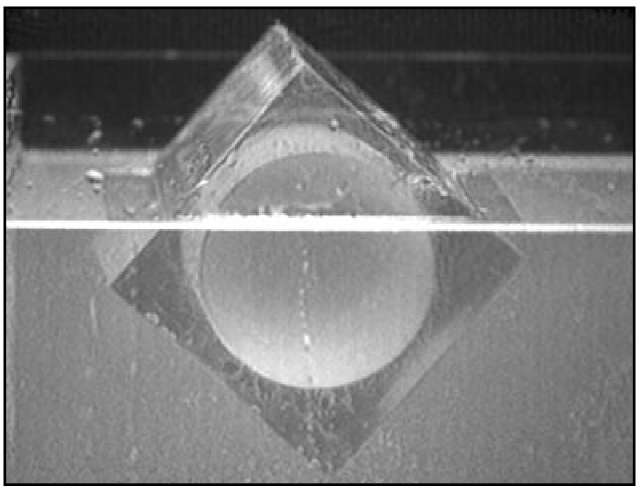

Figure 1

† Walter P. Reid, Floating Long Square Bar, *Am. J. Phys.* 31, 565-568 (1963).

Floating Square Bar / Script

A floating long square bar will be used to illustrate a feature of buoyancy.

This long square symmetric bar of carefully machined Plexiglass floats with its sides horizontal and vertical.

As water is added to the bath the stable horizontal orientation of the floating bar becomes diagonal.

How can this happen?

The initial bath was alcohol, which has a low density. As the water, which has a higher density, was added, the density of the bath increased, changing the conditions for the bar to float, and causing the bar to rotate to a diagonal orientation.

Equipment

1. Transparent float can be fabricated from a piece of Plexiglass that has a square cross section with a hole machined through the major axis of the bar, thereby removing the majority of the bar's mass. Each end is squarely machined to enable airtight end plates to seal both ends of the bar.
2. Clear tank.
3. Alcohol.
4. Water.

Demo 12-20 Helium Balloon in Glass Jar

A helium balloon floats at the top of an inverted glass jar.† When the jar is also filled with helium, the balloon floats near the mouth of the jar. When the helium is allowed to escape from the jar, the balloon again floats at the top of the jar, as shown in *Figure 1*.

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-328, Gas-filled Balloons.

If we place this helium balloon inside a glass jar filled with air, it floats to the top.

If we replace the air in the jar with helium, what will happen to the balloon?

The balloon sinks to the bottom.

If the jar is now lifted off the table, what will the balloon do?

It floats at the bottom of the jar. If we tip the jar to let the helium escape, the balloon floats back to the top.

Equipment

1. Large clear container.
2. Balloons.
3. Helium gas.
4. Three blocks to elevate the inverted container.

Demo 12-21 Helium Balloon in Liquid Nitrogen

A helium balloon, originally tethered by a light string to the table, is drenched with liquid nitrogen. The gas becomes cooler and, according to the ideal gas law, PV = nkT, the volume of the gas becomes smaller and the balloon shrinks. Because the balloon now displaces less air, the buoyant force is reduced and the balloon sinks to the table. When the helium balloon is allowed to warm up to room temperature, it becomes larger, regains its buoyancy, and again rises.[†]

† Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Hk-2, Change in Volume with Change of Temperature.

This helium balloon floats in air because it weighs less than the amount of air it displaces.

If we drench the balloon with liquid nitrogen, it cools the helium and the balloon shrinks to less than half its original size; the balloon no longer floats.

As the helium warms, the balloon expands and its displacement increases; the balloon floats once again.

Equipment

1. Balloons.
2. Helium gas.
3. Liquid nitrogen.
4. String.
5. Hooked weight.

Demo 12-22 Cartesian Diver

The cartesian diver used in this video is a small buoyant plastic bottle in an enclosed water bath.† The cartesian diver, which contains some air within its volume, normally floats at the top of the water. When the pressure is increased inside the water tube using a hypodermic syringe, the air in the diver is compressed, allowing additional water to flow into the bottom of the diver container. This added weight causes the average density of the diver to become greater than the density of water, so it sinks, as shown in *Figure 1*. When the pressure is released the diver returns to the surface of the water. If the pressure in the tank is continually adjusted, as shown in the video, the diver will remain in the vertical center of the water column.

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-320, Cartesian Diver.
Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Fg-6, Cartesian Diver.

In this tank of water we have a small plastic bottle full of air, with an opening at the bottom.

A weight at the bottom of the bottle makes the overall density of the bottle slightly less than that of the water.

A syringe is connected to the side of the water column; as the syringe is compressed, the increased pressure compresses the air inside the bottle and increases its overall density.

When the density of the bottle is greater than the density of the water, the bottle sinks to the bottom of the tank.

Reducing the air pressure in the tank expands the air inside the bottle and returns it to the surface.

If the pressure is continually adjusted, the bottle can be kept in the center of the water column.

Equipment

Cartesian diver.