New Jersey Center for Teaching and Learning

Progressive Science Initiative

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Fluids

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Density

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Density

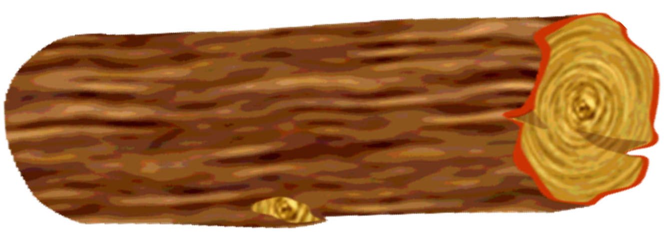
You may recall that the three common phases, or states, of matter are gas, liquid, and solid. Solids maintain a fixed volume and shape, liquids maintain a fixed volume but not shape, and gases can change both. Since gasses and liquids both flow, they are collectively called fluids.

Density

What weights more a pound of feathers or a pound of bricks?

This is a silly questions since they are both a pound. Sometimes people say that iron is "heavier" than wood. But if you have a log of wood it would be heavier than one small iron nail.

What we should really say is that iron is more dense than wood.



http://njc.tl/ua

Density

The density of an object is its mass per unit volume:

$$\rho = \frac{m}{V}$$

ρ (rho) is density.
m is mass.
V is volume.

The SI unit for density is kg/m^3 but sometimes it is measured in g/cm^3. To convert from g/cm^2 to kg/m^3 multiply by 1000.

http://njc.tl/ua

1 The density of a substance is ρ , its mass is m and its volume is V. If the volume is tripled, what is the new mass?

- A m/3
- B 3m
- C m
- D m/6
- E 6m

Answer

1 The density of a substance is ρ , its mass is m and its volume is V. If the volume is tripled, what is the new mass?

- A m/3
- B 3m
- C m
- D m/6
- E 6m

Answer

B

http://njc.tl/ub

2 Liquid A has twice the density of liquid B. A certain experiment needs samples of A and B that have the same mass. What needs to be true about their volumes?

- A $V_A=V_B$
- B $2V_A=V_B$
- C $V_A=2V_B$
- D $V_A/2=V_B$
- E $V_A=4V_B$

Answer

http://njc.tl/uc

2 Liquid A has twice the density of liquid B. A certain experiment needs samples of A and B that have the same mass. What needs to be true about their volumes?

- A $V_A=V_B$
- B $2V_A=V_B$
- C $V_A=2V_B$
- D $V_A/2=V_B$
- E $V_A=4V_B$

Answer

C

3 What is the density (in kg/m^3) of an object that has a mass of 2kg and a volume of 4m^3?

Answer

3 What is the density (in kg/m^3) of an object that has a mass of 2kg and a volume of $4m^3$?

Answer

$$\rho = \frac{m}{V} = \frac{2kg}{4m^3} = 0.5\frac{kg}{m^3}$$

http://njc.tl/ud

4 A container of water has a mass of 5kg. What is the volume of this container (in m^3)? The density of water is 1000 kg/m^3. (Neglect the mass of the container.)

Answer

http://njc.tl/ue

4 A container of water has a mass of 5kg. What is the volume of this container (in m^3)? The density of water is 1000 kg/m^3. (Neglect the mass of the container.)

Answer

$$\rho = \frac{m}{V}$$

$$V = \frac{m}{\rho} = \frac{5kg}{1000\frac{kg}{m^3}}$$

$$V = 0.005m^3$$

http://njc.tl/ue

Specific Gravity

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Specific Gravity

The specific gravity of a substance is the ratio of its density to the density of water.

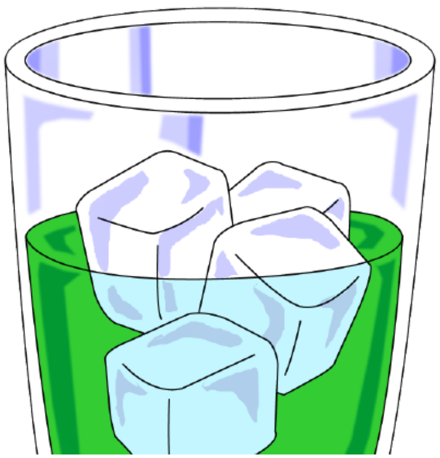
$$SG = \frac{\rho}{\rho_{H_2O}}$$

The density of water at 4 ^{o} C is 1 g/cm^3 or 1000 kg/m^3.

Specific Gravity

Specific gravity is a ratio so it has no units.

A substance with a specific gravity less than one means that it is less dense than water and will float on water and a substance with a specific gravity greater than one means that it is more dense than water and will sink in water.



5 The following are specific gravities of various objects. Which would float on water?

- A Copper - 8.96
- B Gold - 19.3
- C Aluminum - 2.7
- D Oak - 0.78
- E Table Salt - 2.17

Answer

http://njc.tl/ug

5 The following are specific gravities of various objects. Which would float on water?

- A Copper - 8.96
- B Gold - 19.3
- C Aluminum - 2.7
- D Oak - 0.78
- E Table Salt - 2.17

Answer

D

http://njc.tl/ug

6 What is the specific gravity of a substance whose density is 450 kg/m^3?

Answer

http://njc.tl/uh

6 What is the specific gravity of a substance whose density is 450 kg/m^3?

Answer

$$SG = \frac{\rho}{\rho_{H_2O}} = \frac{450\frac{kg}{m^3}}{1000\frac{kg}{m^3}} = 0.45$$

http://njc.tl/uh

7 Mercury's specific gravity is about 13.5. What is itsdensity in kg/m^3?

Answer

http://njc.tl/ui

7 Mercury's specific gravity is about 13.5. What is itsdensity in kg/m^3?

Answer

$$SG = \frac{\rho}{\rho_{H_2O}}$$

$$\rho = \rho_{H_2O} SG$$

$$\rho = (13.5)\left(1000\frac{kg}{m^3}\right)$$

$$\rho = 13500\frac{kg}{m^3}$$

http://njc.tl/ui

Pressure in Fluids

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http://njc.tl/uj

Pressure in Fluids

Pressure is defined at the force per unit area.

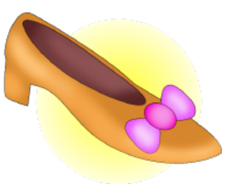
$$P = \frac{F}{A}$$

Pressure is a scalar and its units are in Pascals.

1Pa = N/m^2.

This definition of pressure is true in any situation, not just fluids. You can see from the equation that pressure if related to force and area. Think about what it would mean to get your foot stepped on by a sneaker or a high heal. Which would hurt more? Why?

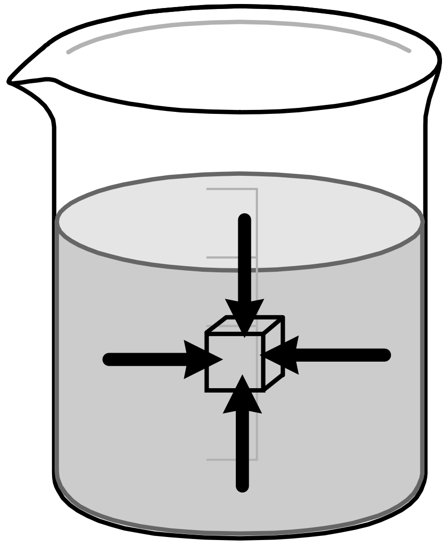
http://njc.tl/uj



Pressure in Fluids

Fluids can exert a pressure normal to any contact surface.

Pressure is the same in every direction in a fluid at a given depth. If it were not, the fluid would flow.



http://njc.tl/uj

8 A perpendicular force is applied to a certain area and produces a pressure P. If the same force is applied to half the area, the new pressure on the surface is:

- A 2P
- B 4P
- C P
- D P/2
- E P/4

Answer

http://njc.tl/uk

8 A perpendicular force is applied to a certain area and produces a pressure P. If the same force is applied to half the area, the new pressure on the surface is:

- A 2P
- B 4P
- C P
- D P/2
- E P/4

Answer

A

9 A 50kg person stands on a square board with sidesof 2m. What is the pressure (in Pa) exerted on theground by the board?

Answer

http://njc.tl/ul

9 A 50kg person stands on a square board with sidesof 2m. What is the pressure (in Pa) exerted on theground by the board?

Answer

$$P = \frac{F}{A}$$

$$P = \frac{F_{normal}}{A} = \frac{mg}{A}$$

$$P = \frac{(50kg)\left(9.8\frac{m}{s^2}\right)}{4m^2} = 122.5Pa$$

http://njc.tl/ul

Pressure in Fluids

$$P = \frac{F}{A}$$

The pressure at a depth of h below the surface of the fluid is due to the weight (mg) of the fluid above it.

$$P = \frac{mg}{A}$$

$$P = \frac{mgh}{Ah}$$

Multiply top and bottom by h.

$$P = \frac{mgh}{V}$$

V = Ah

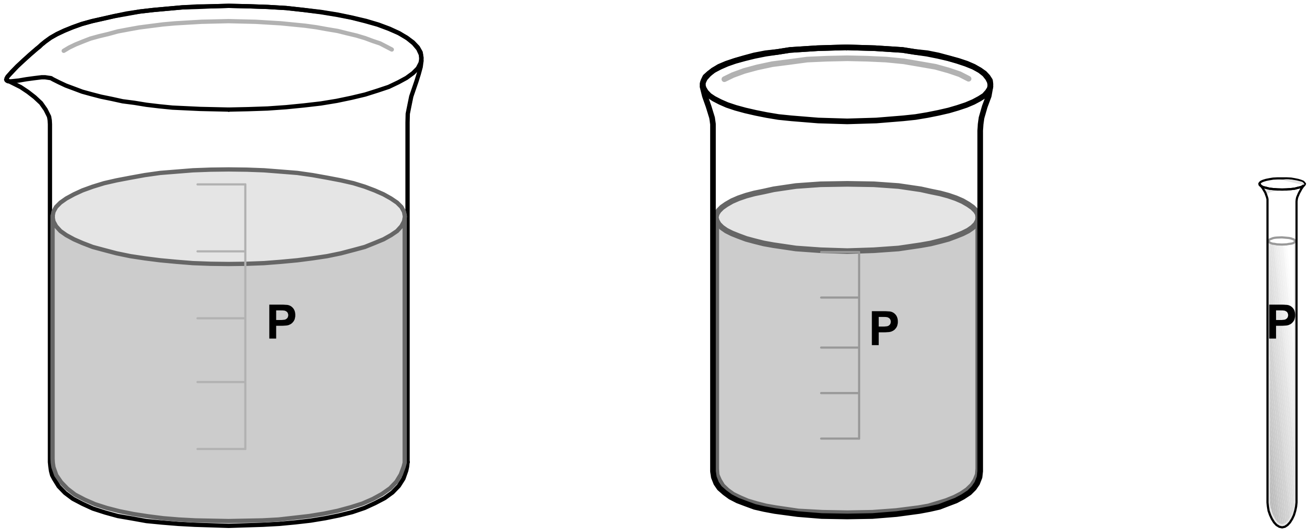
$$P = \rho g h$$

ρ = m/V

http://njc.tl/um

Pressure in Fluids

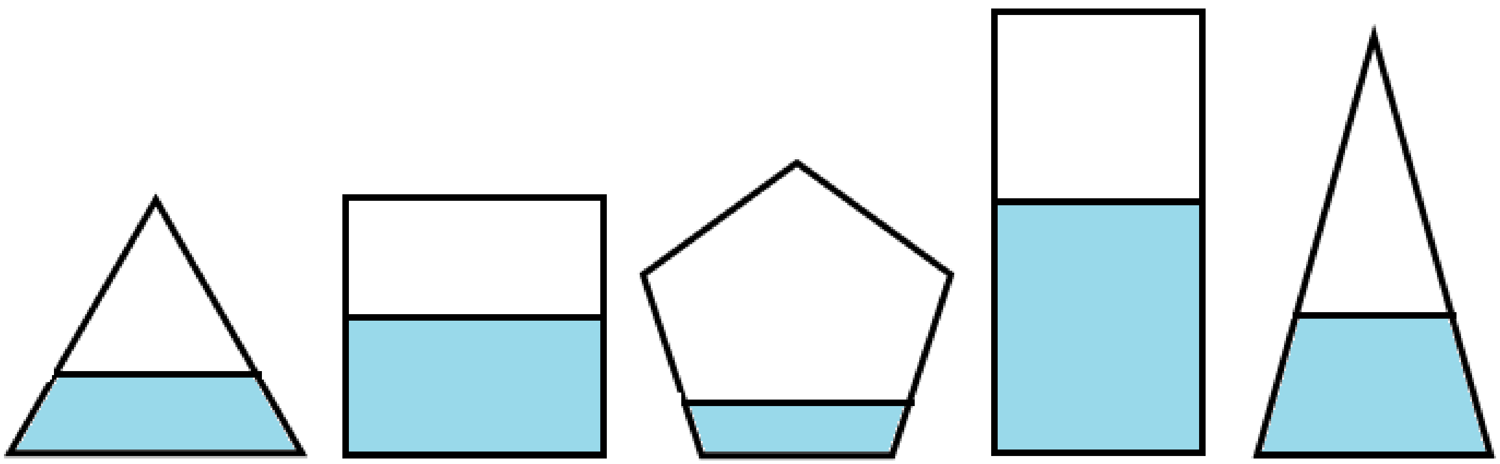
$$P = \rho g h$$



The pressure at a given point depends on only the density of the fluid and the depth. (Not the shape of the container.)

This is valid for liquids whose density does not change with depth.

10 There are five containers of the same fluid in a physics lab. Which has the greatest pressure at the bottom of the container?

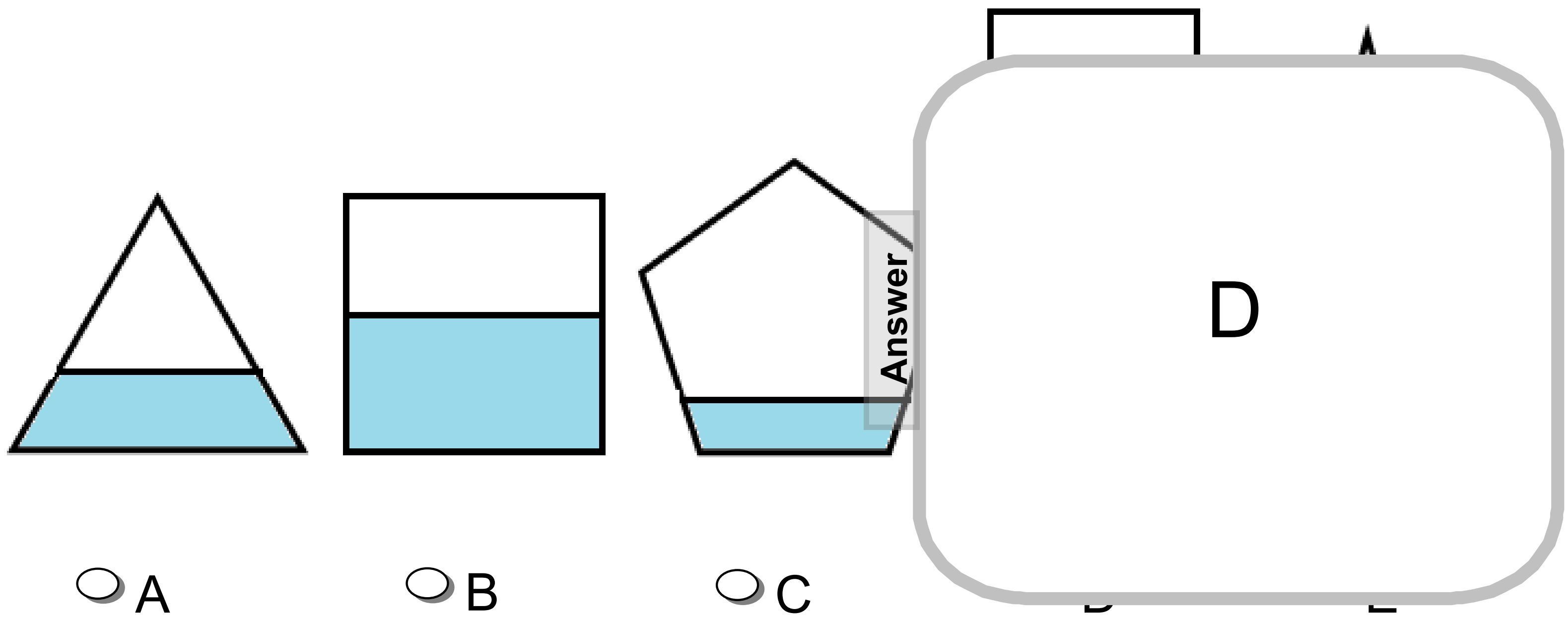


- A
- B
- C
- D
- E

Answer

http://njc.tl/un

10 There are five containers of the same fluid in a physics lab. Which has the greatest pressure at the bottom of the container?



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11 What is the pressure (in Pa) at the bottom of a swimming pool whose depth is 2m?

Answer

11 What is the pressure (in Pa) at the bottom of a swimming pool whose depth is 2m?

Answer

$$P = \rho g h$$

$$P = \left(1000\frac{kg}{m^3}\right)\left(9.8\frac{m}{s^2}\right)(2m)$$

$$P = 19600 Pa$$

Atmospheric Pressure and Gauge Pressure

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Atmospheric Pressure and Gauge Pressure

At sea level, the atmospheric pressure is about **1.013×10^5 Pa**. This is called **1 atm**.

Another unit of pressure is the bar.

1 bar = 1.00×10^5 Pa.

Most pressure gauges measure the pressure above atmospheric pressure. This is called gauge pressure.

Absolute pressure is atmospheric pressure plus gauge pressure.

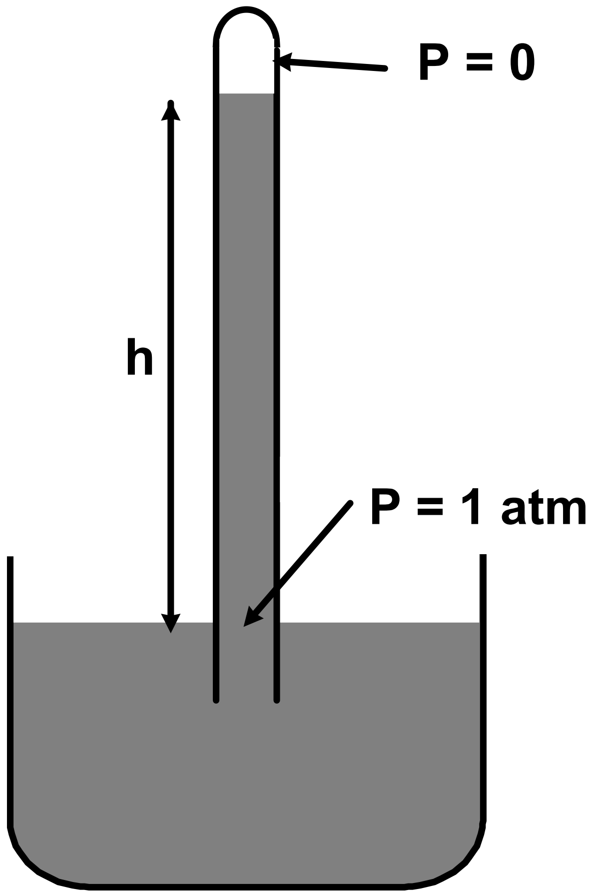
$$P = P_A + P_G$$

http://njc.tl/up

Atmospheric Pressure and Gauge Pressure

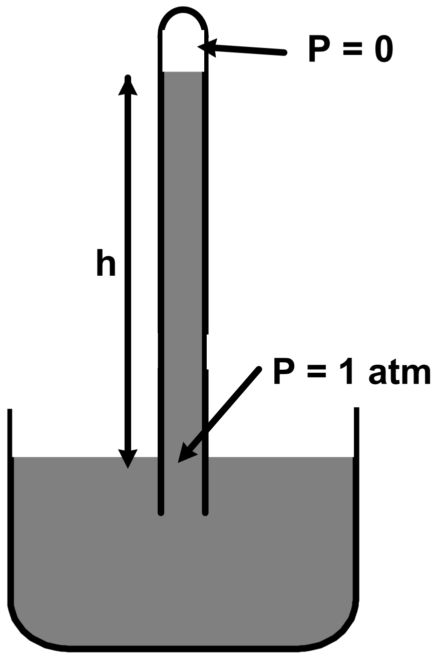
Torricelli invented a mercury barometer to measure atmospheric pressure. Sometimes air pressure is described in millimeters or inches of mercury.

A glass tube is filled with mercury. This glass tube sits upside down in a container, called the reservoir, which also contains mercury. The mercury level in the glass tube falls, creating a vacuum at the top.



Atmospheric Pressure and Gauge Pressure

The barometer works by balancing the weight of mercury in the glass tube against the atmospheric pressure. If the weight of mercury is less than the atmospheric pressure, the mercury level in the glass tube rises. If the weight of mercury is more than the atmospheric pressure, the mercury level falls.



Atmospheric pressure is basically the weight of air in the atmosphere above the reservoir, so the level of mercury continues to change until the weight of mercury in the glass tube is exactly equal to the weight of air above the voir.

http://njc.tl/up

12 A diver in the ocean measures guage pressure to be 515kPa. What is the absolute pressure?

- A 101kPa
- B 313kPa
- C 515kPa
- D 616kPa
- E 5150kPa

Answer

http://njc.tl/uq

12 A diver in the ocean measures guage pressure to be 515kPa. What is the absolute pressure?

- A 101kPa
- B 313kPa
- C 515kPa
- D 616kPa
- E 5150kPa

Answer

D

13 What is the absolute pressure (in Pa) at the bottom of a swimming pool whose depth is 2m?

Answer

http://njc.tl/ur

13 What is the absolute pressure (in Pa) at the bottom of a swimming pool whose depth is 2m?

Answer

$$P_G = \rho g h$$

$$P_G = \left(1000\frac{kg}{m^3}\right)\left(9.8\frac{m}{s^2}\right)(2m)$$

$$P_G = 19600Pa$$

$$P = P_G + P_A$$

$$P = 19600Pa + 101300Pa$$

$$P = 120900Pa$$

or

$$P = 1.209\times 10^5\, Pa$$

Pascal's Principal

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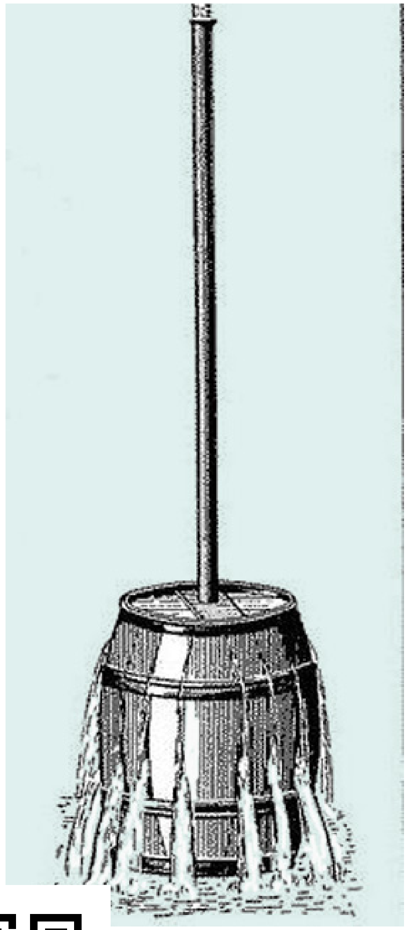
Pascal's Principle



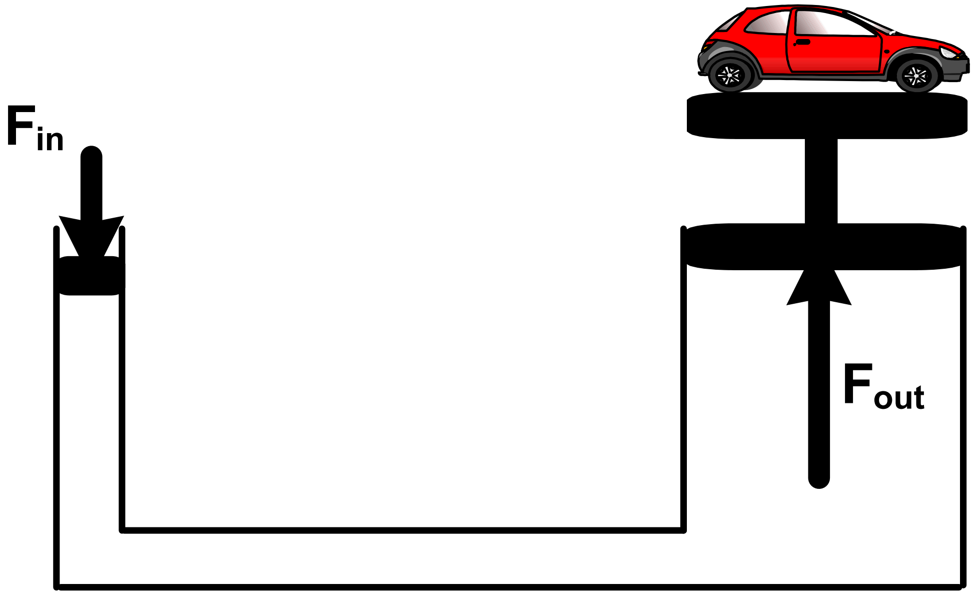
Pascal's principle states that if an external pressure is applied to a confined and incompressible fluid, thepressure everywhere in the fluid increases by that amount.

Pascal's Barrel is an experiment attributed to Pascal but it is unclear if it was ever preformed by him. In this experiment, a 10 meter long tube was inserted into a barrel filled with water. When water was poured into the tube, the increase in pressure caused the barrel to burst.

Pascal's Principle

$$P_{in} = P_{out}$$

$$\frac{F_{in}}{A_{in}} = \frac{F_{out}}{A_{out}}$$



http://njc.tl/ur

14 In a hydraulic lift, the large piston has five times the area as the small piston. How much extra force can the large piston exert?

- A One tenth as much as the small piston
- B One fifth as much as the small piston
- C The same as the small piston
- D Five times as much at the small piston
- E Fifty times as much as the small piston

Answer

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- B One fifth as much as the small pist
- C The same as the small piston
- D Five times as much at the small
- E Fifty times as much as the smal

Answer

D

15 The small piston of a hydraulic lift has an area of 10 cm^2 and its large piston has an area of 100 cm^2. A 40 N force is applied to the small piston. What is the weight of the load can be lifted by the large piston?

Answer

15 The small piston of a hydraulic lift has an area of 10 cm^2 and its large piston has an area of 100 cm^2. A 40 N force is applied to the small piston. What is the weight of the load can be lifted by the large piston?

Answer

$$P_{in} = P_{out}$$

$$\frac{F_{in}}{A_{in}} = \frac{F_{out}}{A_{out}}$$

$$F_{out} = \frac{F_{in}A_{out}}{A_{in}} = \frac{(40N)(10cm^2)}{100cm^2}$$

$$F_{out} = 400N$$

Buoyancy and Archimedes' Principle

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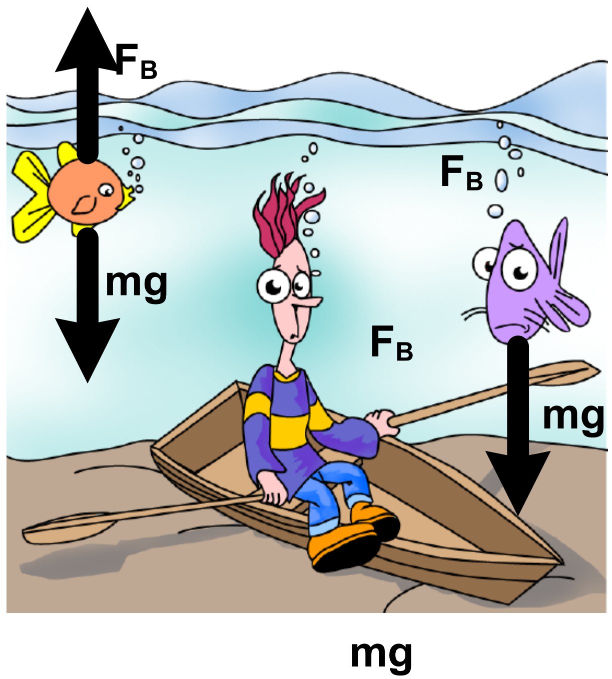
Buoyancy and Archimedes' Principle

The upward buoyant force on an object immersed in a fluid, partially or completely, is equal to the weight of the displaced fluid.



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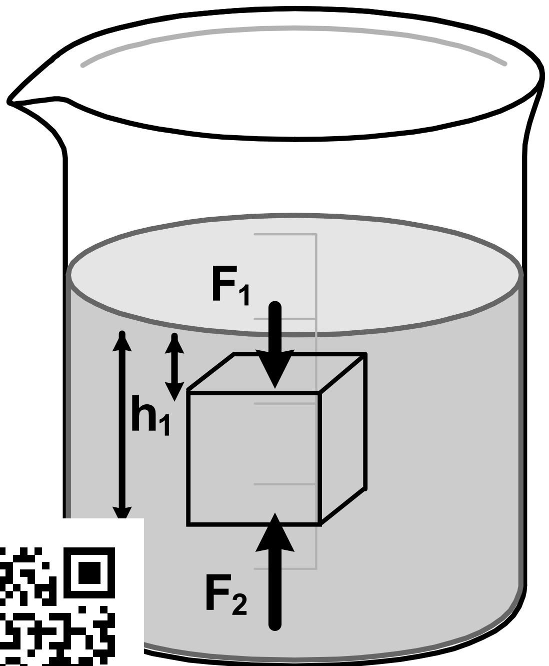
Buoyancy and Archimedes' Principle

If an object is submerged in a fluid, there is a net force on the object because the pressure is greater at the bottom than at the top of the object. The buoyant force is upward because the force is greater at bottom than at the top of the object.



$$F_B = F_2 - F_1$$

$$F_B = P_2A - P_1A$$

$$F_B = \rho_F g h_2 A - \rho_F g h_1 A$$

$$F_B = \rho_F g A(h_2 - h_1)$$

$$F_B = \rho_F g V$$

$$F_B = m_F g$$

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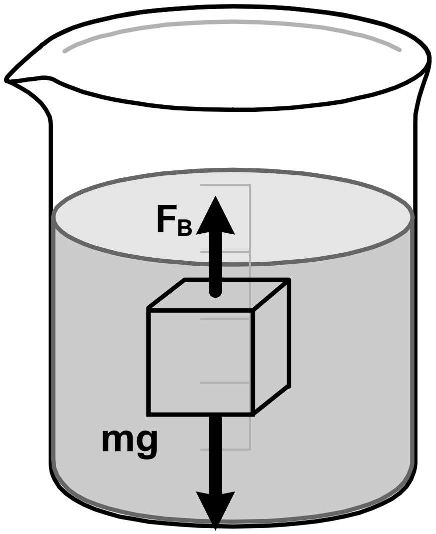
Buoyancy and Archimedes' Principle



$$F_B = \rho_F g V$$

$$F_B = m_F g$$

Where:

ρ_F is the density of the fluid.

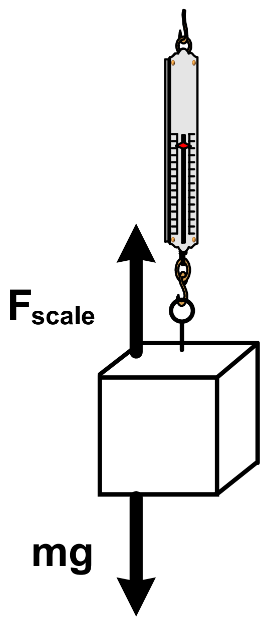
m_F is the mass of the displaced fluid.

V is the volume of the displaced fluid.

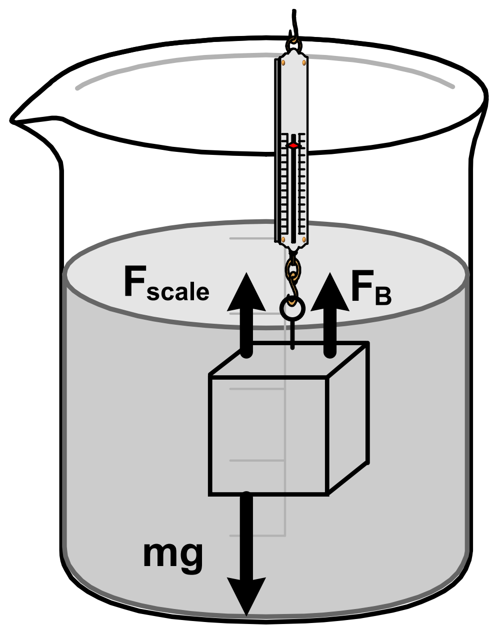
http://njc.tl/uu

Buoyancy and Archimedes' Principle

The net force on a object is the difference between the buoyant force and the gravitational force.



$$F_{scale} = mg$$



$$F_{scale} + F_B = mg$$

http://njc.tl/uu

16 Three objects of the same volume but different materials are completly submerged in water. They are zinc with a density of 7000 kg/m^3, nickel with a density of 8900 kg/m^3, and silver with a density of 10500 kg/m^3. Which has the greatest buoyant force exerted on it?

- A Zinc
- B Nickel
- C Silver
- D They all have the same buoyant force.
- E It is impossible to tell without knowing the volume.

Answer

http://njc.tl/uv

16 Three objects of the same volume but different materials are completly submerged in water. They are zinc with a density of 7000 kg/m^3, nickel with a density of 8900 kg/m^3, and silver with a density of 10500 kg/m^3. Which has the greatest buoyant force exerted on it?

- A Zinc
- B Nickel
- C Silver
- D They all have the same buoyant
- E It is impossible to tell without kno

Answer

D

17 A metal sphere weights 5N in air and 3N when it is submerged in water. What is the buoyant force on the sphere when it is submerged in water?

- A 0.2N
- B 2N
- C 3N
- D 5N
- E 8N

Answer

http://njc.tl/uw

17 A metal sphere weights 5N in air and 3N when it is submerged in water. What is the buoyant force on the sphere when it is submerged in water?

- A 0.2N
- B 2N
- C 3N
- D 5N
- E 8N

Answer

B

http://njc.tl/uw

18 An object has a volume of 2.0 m^3. What is the buoyant force on the object when it is completely submerged into water (density 1000 kg/m^3)?

Answer

http://njc.tl/ux

18 An object has a volume of 2.0 m^3. What is the buoyant force on the object when it is completely submerged into water (density 1000 kg/m^3)?

Answer

$$F_B = \rho_{fluid} g V_{displaced}$$

$$F_B = \left(1000\frac{kg}{m^3}\right)\left(9.8\frac{m}{s^2}\right)\left(2m^3\right)$$

$$F_B = 19600N$$

http://njc.tl/ux

Buoyancy and Archimedes' Principle

$F_B = m_{fluid}g$

Any floating object displaces its own weight of fluid.

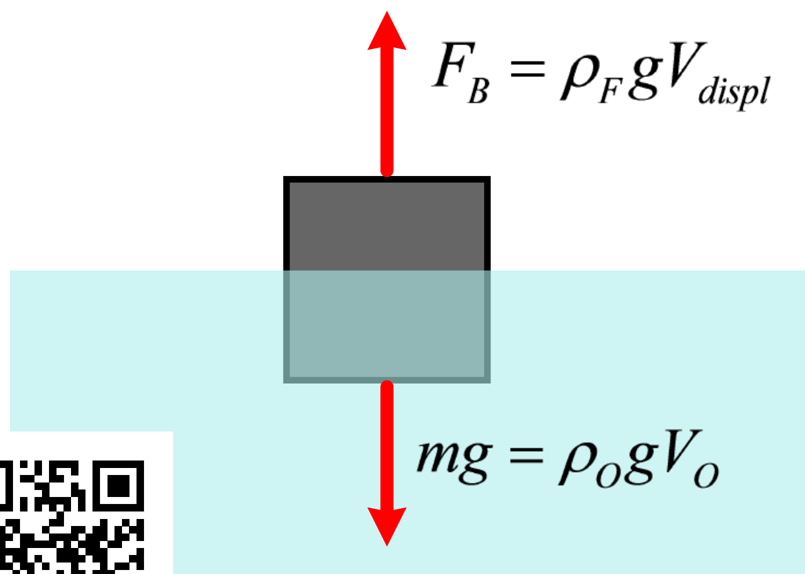
$m_{boat}g$

http://njc.tl/uy

Buoyancy and Archimedes' Principle

For an object whose density is less than that of the fluid, there will an net force upward and it will rise until it is partial out of the fluid.

For a floating object, the fraction that is submerged is given by the ratio of the objects density to that of the fluid.



$$F_B = mg$$

$$\rho_F g V_{displ} = \rho_O g V_O$$

$$\rho_F V_{displ} = \rho_O V_O$$

$$\frac{V_{displ}}{V_O} = \frac{\rho_O}{\rho_F}$$

http://njc.tl/uy

19 A 1500 N object floats in water. What is the weight of displaced water?

Answer

http://njc.tl/uz

19 A 1500 N object floats in water. What is the weight of displaced water?

http://njc.tl/uz

20 A small empty row boat with a mass of 48kg floats on water. What is the volume of the water it displaces?

Answer

http://njc.tl/v0

20 A small empty row boat with a mass of 48kg floats on water.
What is the volume of the water it displaces?

Fluids in Motion & Bernoulli's Principle

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Fluids in Motion & Bernoulli's Principle

If the flow of a fluid is smooth, it is called streamline or laminar flow. This is what we will deal with.

The mass flow rate is the mass that passes a given point per unit time. The flow rates of a fluid must be equal, as long as no fluid is added or taken away.

This gives us the equation of continuity:

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

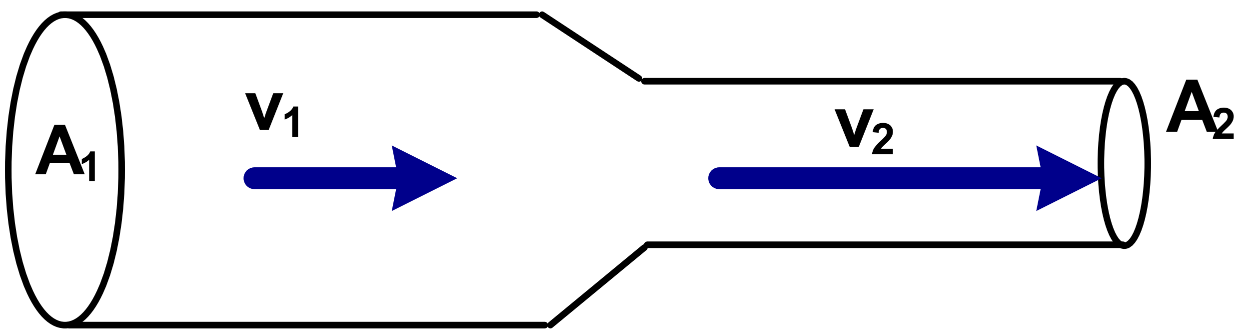
If the density of the fluid doesn't change, it can be simplified to:

$$A_1 v_1 = A_2 v_2$$

Fluids in Motion & Bernoulli's Principle

$$A_1 v_1 = A_2 v_2$$

Density does not typically change in liquids. This means that where a pipe is wider the flow is slower.



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Fluids in Motion & Bernoulli's Principle

You can see this happening in a river when the water flow is slow when it is wide and fast when it is narrow.

21 Water flows at a constant speed though one section of a pipe, when it enters another section that is half the cross sectional area what happens to the speed of the water?

- A The speed is reduced to one fourth the original.
- B The speed is reduced to one half the original.
- C The speed says the same.
- D The speed is doubled.
- E The speed is quadrupled.

Answer

21 Water flows at a constant speed though one section of a pipe, when it enters another section that is half the cross sectional area what happens to the speed of the water?

- A The speed is reduced to one fourth the original.
- B The speed is reduced to one half the original.
- C The speed says the same.
- D The speed is doubled.
- E The speed is quadrupled.

Answer

D

22 Water flows through a pipe of cross-sectional area 10 cm^2 at a rate of 15 m/s. The cross-sectional area of the pipe is decreased to 5 cm^2. What is the water rate in the narrow section of the pipe?

Answer

http://njc.tl/v3

22 Water flows through a pipe of cross-sectional area10 cm^2 at a rate of 15 m/s. The cross-sectional areaof the pipe is decreased to 5 cm^2. What is the waterrate in the narrow section of the pipe?

Answer

$$A_1v_1 = A_2v_2$$

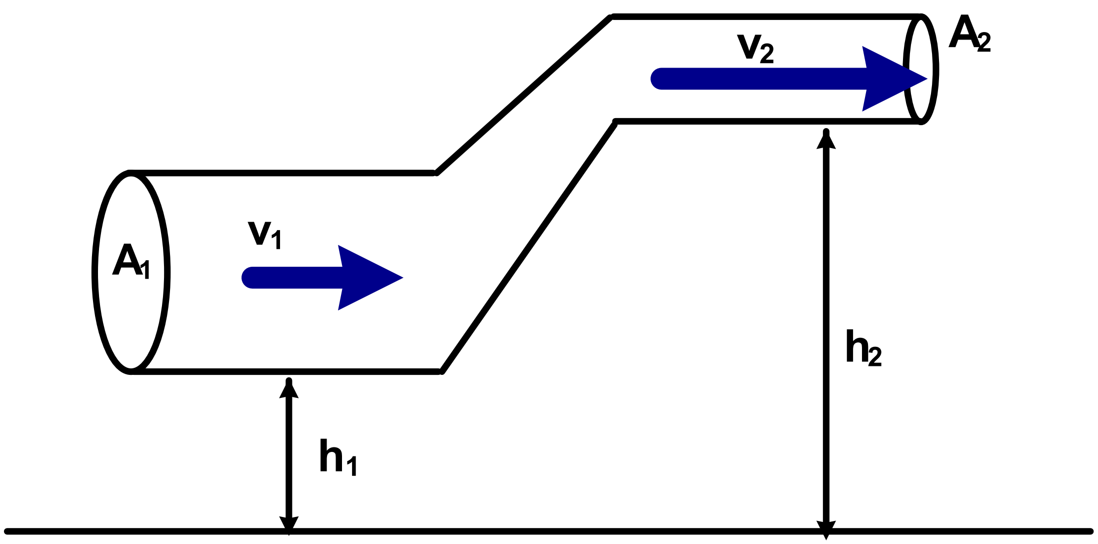
$$v_2 = \frac{A_1v_1}{A_2}$$

$$v_2 = \frac{(10cm^2)\left(15\frac{m}{s}\right)}{5cm^2} = 30\frac{m}{s}$$

Fluids in Motion & Bernoulli's Principle

A fluid can also change height. If we look at the work done...

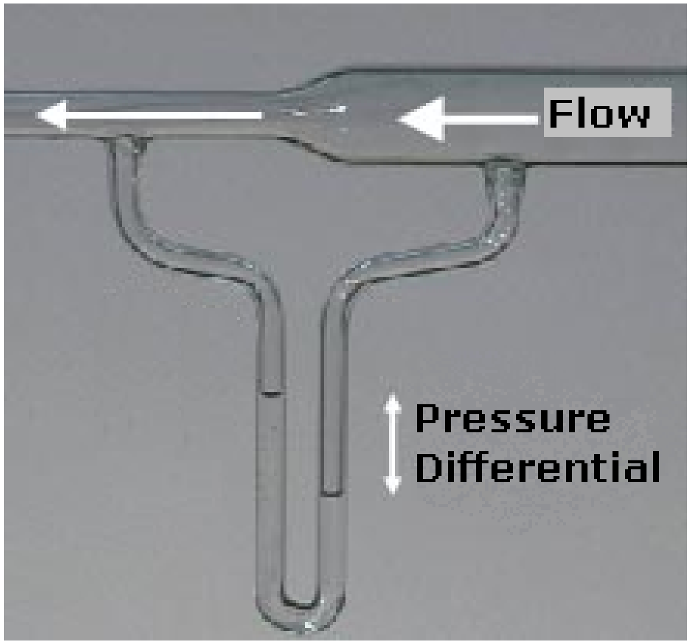
$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$$



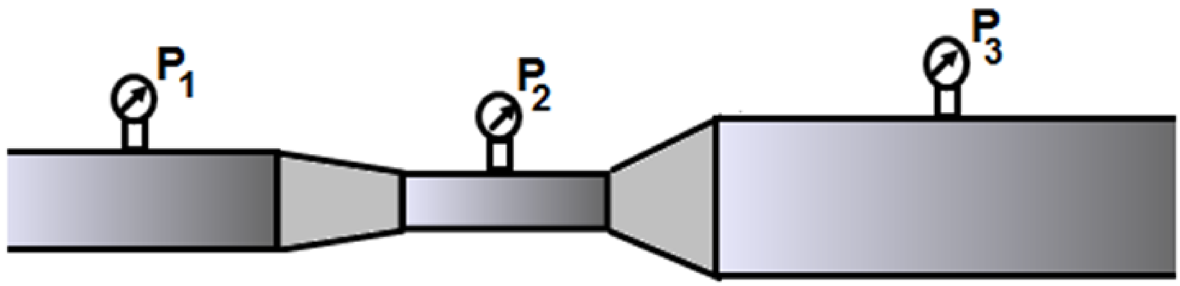
Fluids in Motion & Bernoulli's Principle

One thing this tells us is that as the speed of the water flow goes up, the pressure goes down.

$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$$



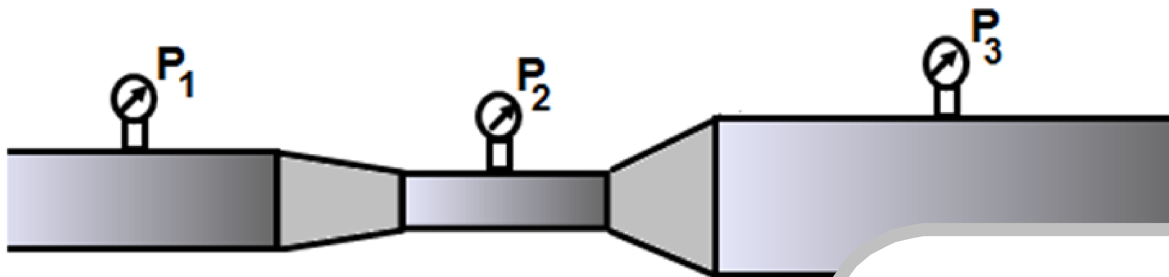
23 A pipe has three different sections with three different cross-sectional area. Where is the pressure the least?



- A P_1
- B P_2
- C P_3
- D The pressure is the same in all three sections.
- E The pressures cannot be determined.

Answer

23 A pipe has three different sections with three different cross-sectional area. Where is the pressure the least?



- A P_1
- B P_2
- C P_3
- D The pressure is the same in all t
- E The pressures cannot be determined.

Answer

B

24 Water flows through a horizontal pipe at a speed of 10 m/s and pressure 2.5×10^5 Pa. The pipe narrows and the water speed goes up to a 20 m/s. What is the pressure in the narrow section of the pipe?

Answer

24 Water flows through a horizontal pipe at a speed of 10 m/s and pressure 2.5 x 10^5 Pa. The pipe narrows and the water speed goes up to a 20 m/s. What is the pressure in the narrow section of the pipe?

Answer

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

$$h_1 = h_2$$

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

$$P_2 = P_1 + \frac{1}{2}\rho v_1^2 - \frac{1}{2}\rho v_2^2 = P_1 + \frac{1}{2}\rho\left(v_1^2 - v_2^2\right)$$

$$P_2 = 2.5\times 10^5\,Pa + \frac{1}{2}\left(1000\frac{kg}{m^3}\right)\left(\left(10\frac{m}{s}\right)^2 - \left(20\frac{m}{s}\right)^2\right)$$

$$P_2 = 1\times 10^5\,Pa$$

http://njc.tl/v6

Torricelli's Theorem

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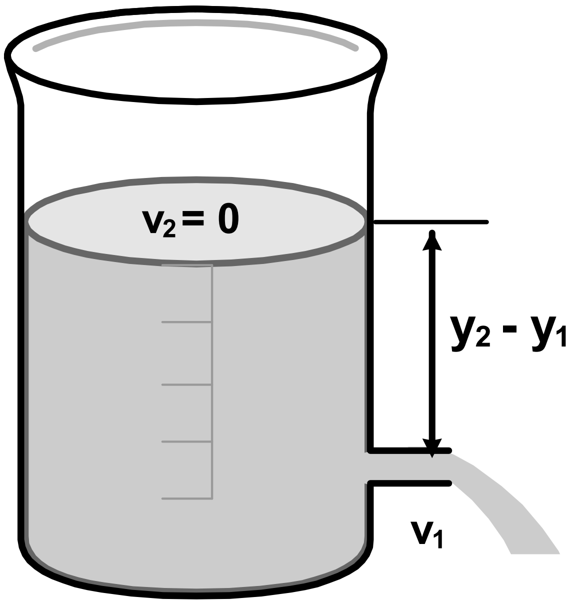
Torricelli's Theorem



We can use Bernoulli's Principle, to find the speed of a fluid coming out to spigot of an open tank. This is called Torricelli's Theorem.

$$v_1 = \sqrt{2g\left(y_2 - y_1\right)}$$

25 A container of water has spigot at its bottom. What happenes to the water speed out of the spigot as the container empties?

- A The water speed decreases.
- B The water speed increases.
- C The water speed stays the same.

Answer

http://njc.tl/v8

25 A container of water has spigot at its bottom. What happenes to the water speed out of the spigot as the container empties?

- A The water speed decreases.
- B The water speed increases.
- C The water speed stays the same

Answer

A

26 A container holds water at a depth of 5 m. There is a hole in the bottom of the container. At what speed will water flow out of the hole?

Answer

http://njc.tl/v9

26 A container holds water at a depth of 5 m. There is a hole in the bottom of the container. At what speed will water flow out of the hole?

Answer

$$v_1 = \sqrt{2g(y_2 - y_1)}$$

$$v_1 = \sqrt{2\left(9.8\frac{m}{s^2}\right)(5m)}$$

$$v_1 = 9.9\frac{m}{s}$$

http://njc.tl/v9

Summary

Density

$$\rho = \frac{m}{V}$$

Specific Gravity

$$SG = \frac{\rho}{\rho_{H_2O}}$$

Pressure

$$P = \frac{F}{A}$$

Pressure in Fluids

$$P = \rho g h$$

Buoyant Force

$$F_B = \rho_F g V$$

$$F_B = m_F g$$

Equation of Continuity

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

Bernoulli's Principle

$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$$