Phys101 Lectures 21-22

Fluids I

Key points:

- **Pressure and Pascal's Principle**

- **Buoyancy and Archimedes' Principle**

Ref: 10-1,2,3,4,5,6,7.

10-1 Phases of Matter

The three common phases of matter are **solid, liquid, and gas.**

A solid has a definite **shape and size.**

A liquid has a fixed **volume** but can be any shape.

A gas can be any shape and also can be easily **compressed.**

Liquids and gases both **flow,** and are called **fluids.**

10-2 Density and Specific Gravity

The **density** ρ of a substance is its **mass** per unit **volume**:

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

The SI unit for density is kg/m³. Density is also sometimes given in g/cm³. How do you convert g/cm³ to kg/m³?

Water at 4°C has a density of 1 g/cm³ = 1000 kg/m³.

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

10-3 Pressure in Fluids

Pressure is defined as the force per unit area.

$$\text{pressure} \; = \; P \; = \; \frac{F}{A}.$$

Pressure is a scalar; the units of pressure in the SI system are pascals:

1 Pa = 1 N/m^2.

i-clicker question 21-1:
unit conversion from cm^2 to m^2.

500 cm^2 is equal to

A) 50.0 m^2.
B) 5.00 m^2.
C) 0.500 m^2.
D) 0.0500 m^2.
E) 0.00500 m^2.

Example: Calculating pressure.

The two feet of a 60-kg person cover an area of 500 cm^2.

(a) Determine the pressure exerted by the two feet on the ground.

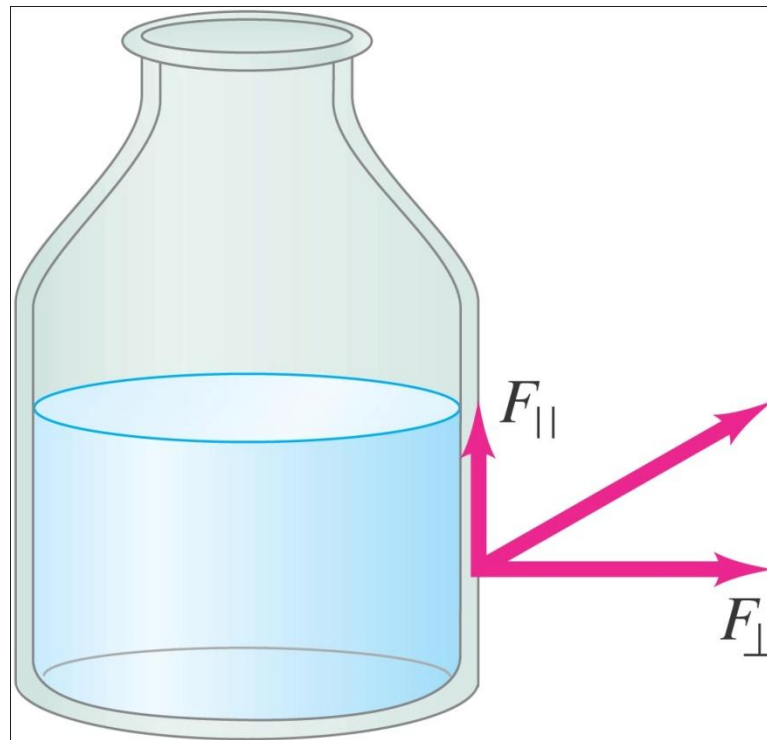(b) If the person stands on one foot, what will the pressure be under that foot?

10-3 Pressure in Fluids

Pressure is the same in every direction in a static fluid at a given depth; if it were not, the fluid would flow.
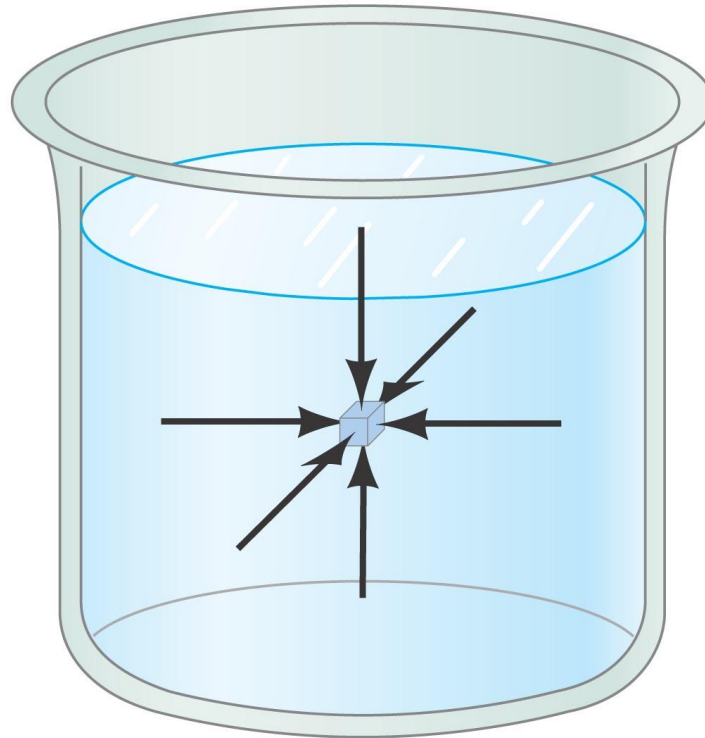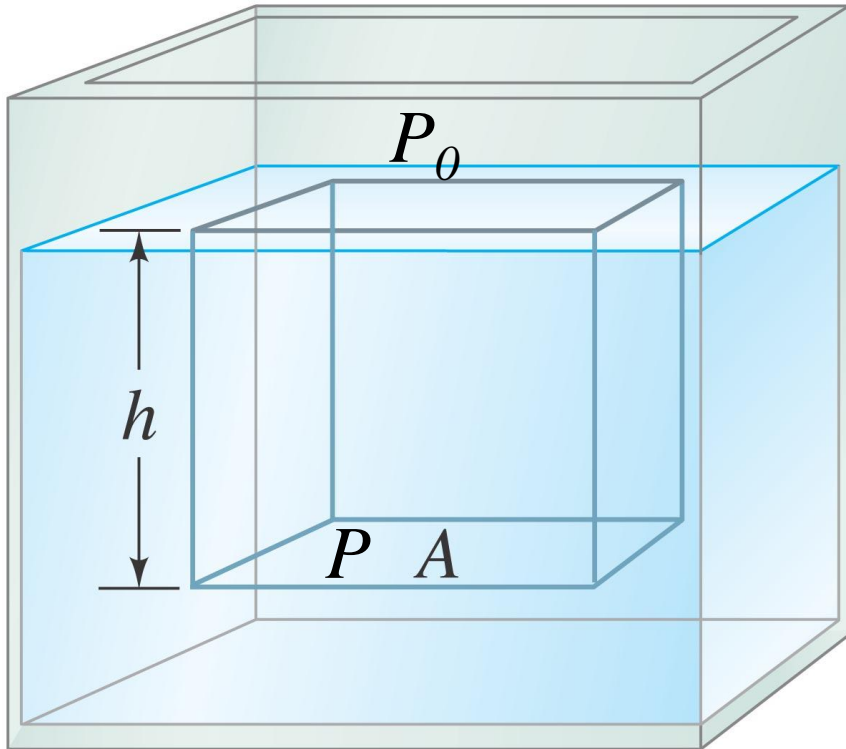
10-3 Pressure in Fluids

For a fluid at rest, there is also no component of force **parallel** to any solid surface—once again, if there were, the fluid would flow.

10-3 Pressure in Fluids

The pressure due to the weight of the liquid at a depth h:

$$P = \frac{F}{A} = \frac{\rho A h g}{A}$$

$$P = \rho g h.$$

This is the pressure due to the liquid. It equals the pressure on A if what above the liquid surface is vacuum.

However, if there is an external pressure on the surface of the liquid such as the atmospheric pressure P_0, then the actual pressure on A should be $P = \rho g h + P_0$.

In general,

$$P - P_0 = \Delta P = \rho g h$$

Example: Pressure at a faucet.

The surface of the water in a storage tank is 30 m above a water faucet in the kitchen of a house. Calculate the difference in water pressure between the faucet and the surface of the water in the tank.

$h = 30\ m$
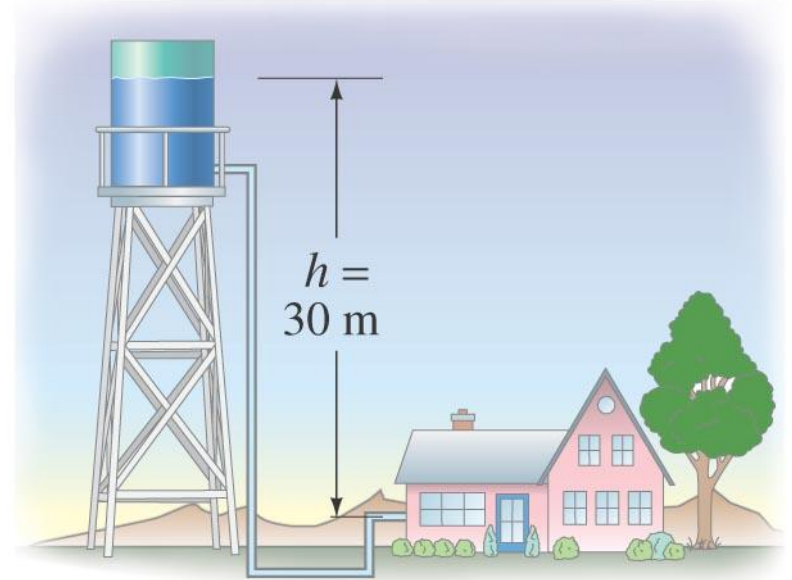
10-4 Atmospheric Pressure and Gauge Pressure

At **sea level** the **atmospheric** pressure is about 1.013 x 10^5 N/m^2; this is called 1 **atmosphere (atm)**.

Another unit of pressure is the bar:

$$1 \text{ bar} = 1.00 \text{ x } 10^5 \text{ N/m}^2.$$

Standard atmospheric pressure is just over 1 bar.

This is 10 times as large as the pressure we apply on our feet ! However, it does not **crush** us, as our body maintains an internal pressure that balances it.

I-clicker question 21-2

Conceptual Example: Finger holds water in a straw.

You insert a straw of length l into a tall glass of water. You place your finger over the top of the straw, capturing some air above the water but preventing any additional air from getting in or out, and then you lift the straw from the water. You find that the straw retains most of the water. Does the air in the space between your finger and the top of the water have a pressure P that is greater than, equal to, or less than the atmospheric pressure P_0 outside the straw?

demo

$P = ?$

l

ρ

h

P_0

PA

$mg = \rho g A h$

$P_0 A$
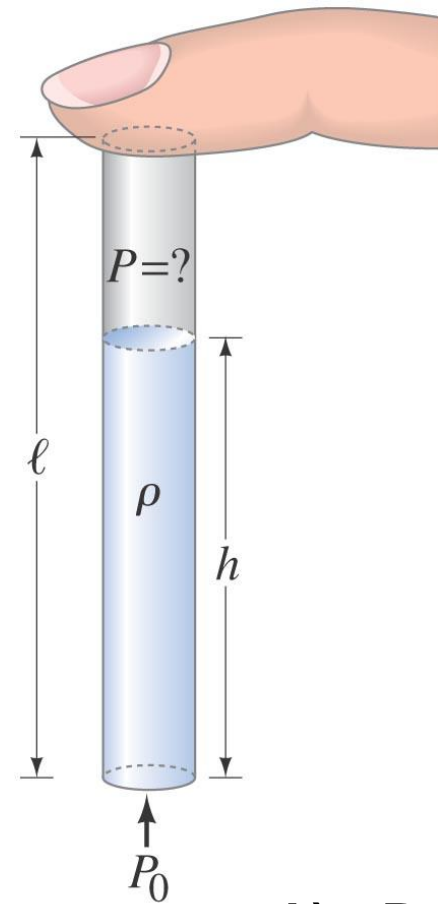
A) $P > P_0$
B) $P = P_0$
C) $P < P_0$
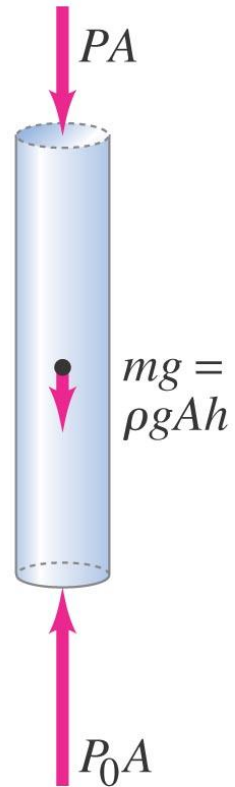
demo

10-4 Atmospheric Pressure and Gauge Pressure

Most pressure gauges measure the pressure above the atmospheric pressure—this is called the gauge pressure.

The absolute pressure is the sum of the atmospheric pressure and the gauge pressure.

$$P = P_0 + P_G.$$

i-clicker question 23-2
**"The pressure in a flat tire is zero". Here "the pressure" refers to:**

A. **The absolute pressure.**
B. **The gauge pressure.**

Note: The normal pressure in a tire is typically 30 psi (pounds per square inches). 1 psi = 6895 pa. The atmospheric pressure is about 15 psi.
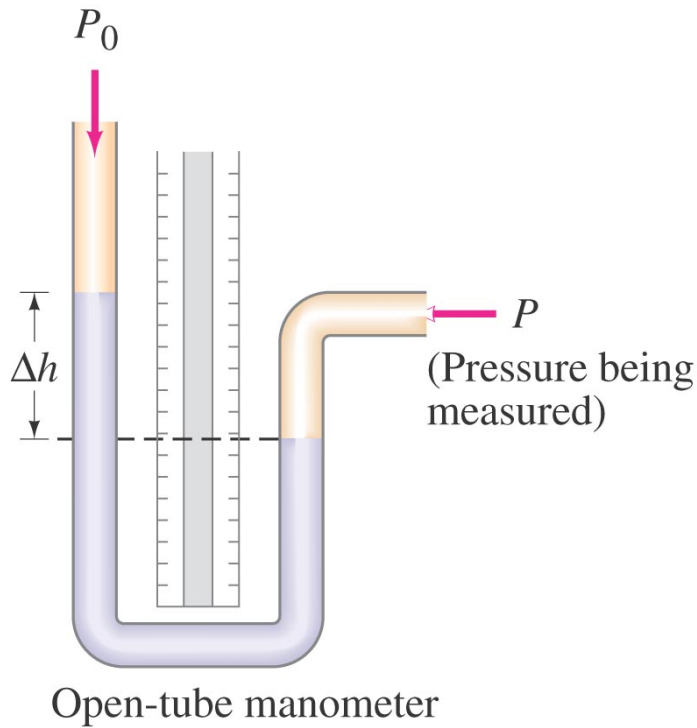
10-5 Pascal's Principle

If an external pressure is applied to a confined fluid, the pressure at every point within the fluid increases by that amount.

This principle is used, for example, in hydraulic lifts.

10-6 Measurement of Pressure; Gauges and the Barometer

P_0

Δh

P
(Pressure being measured)
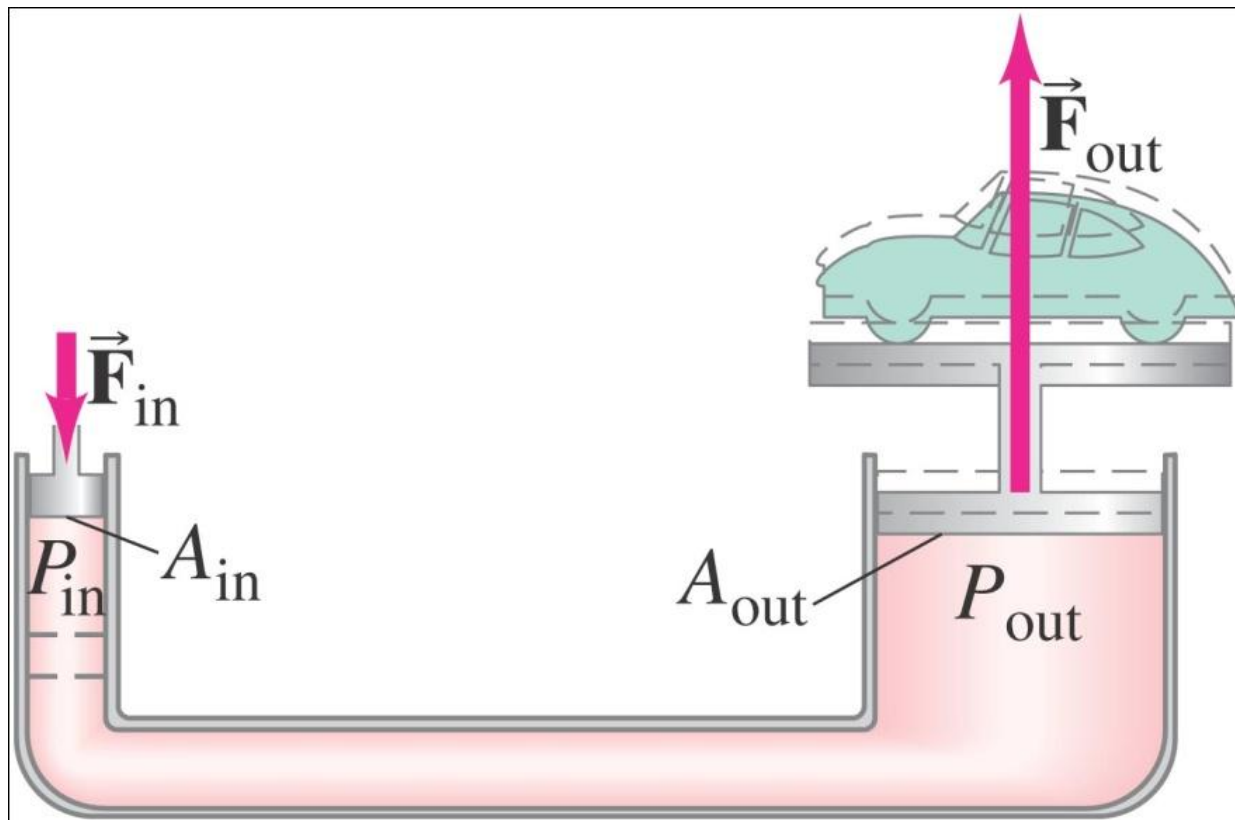
Open-tube manometer

There are a number of different types of **pressure gauges. This** one is an open-tube **manometer.** The pressure in the open end is **atmospheric** pressure; the pressure being measured will cause the fluid to **rise** until the pressures on both sides at the same height are **equal.**

$$P = \rho g \Delta h + P_0$$

# 10-6 Measurement of Pressure; Gauges and the Barometer

Pressure is measured in a variety of different units. This table gives the conversion factors.

TABLE 13–2 Conversion Factors Between Different Units of Pressure

In Terms of $1\,Pa = 1\,N/m^2$	1 atm in Different Units
$1\,atm = 1.013 \times 10^5\,N/m^2$ $= 1.013 \times 10^5\,Pa = 101.3\,kPa$	$1\,atm = 1.013 \times 10^5\,N/m^2$
$1\,bar = 1.000 \times 10^5\,N/m^2$	$1\,atm = 1.013\,bar$
$1\,dyne/cm^2 = 0.1\,N/m^2$	$1\,atm = 1.013 \times 10^6\,dyne/cm^2$
$1\,lb/in.^2 = 6.90 \times 10^3\,N/m^2$	$1\,atm = 14.7\,lb/in.^2$
$1\,lb/ft^2 = 47.9\,N/m^2$	$1\,atm = 2.12 \times 10^3\,lb/ft^2$
$1\,cm\text{-}Hg = 1.33 \times 10^3\,N/m^2$	$1\,atm = 76.0\,cm\text{-}Hg$
$1\,mm\text{-}Hg = 133\,N/m^2$	$1\,atm = 760\,mm\text{-}Hg$
$1\,torr = 133\,N/m^2$	$1\,atm = 760\,torr$
$1\,mm\text{-}H_2O\,(4°C) = 9.80\,N/m^2$	$1\,atm = 1.03 \times 10^4\,mm\text{-}H_2O\,(4°C)$

10-6 Measurement of Pressure; Gauges and the Barometer

$P = 0$

$P = 1$ atm

76.0 cm
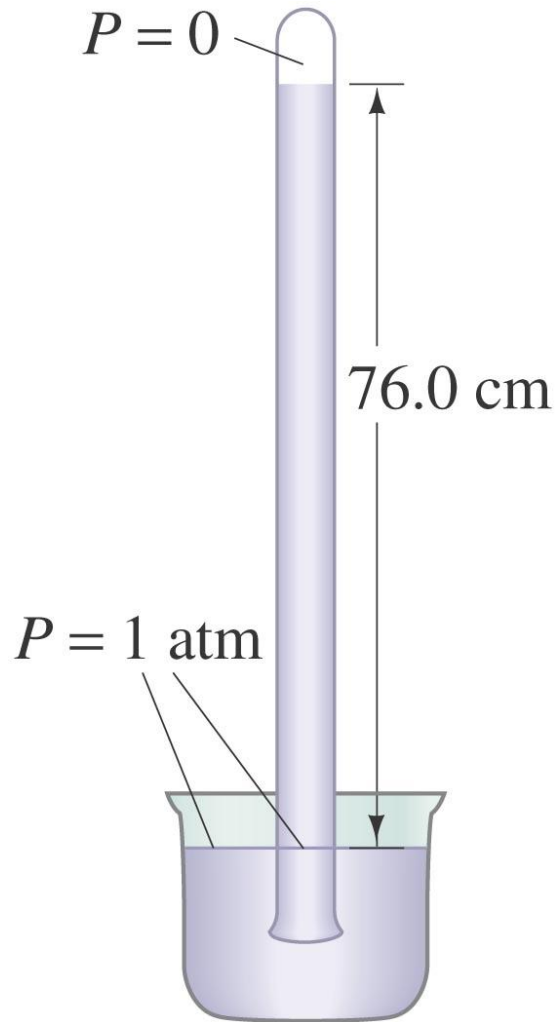
This is a **mercury barometer, developed by Torricelli to measure atmospheric pressure.** The **height** of the column of **mercury** is such that the pressure in the tube at the surface level is 1 atm.

Therefore, pressure is often quoted in **millimeters** (or inches) of mercury.

10-6 Measurement of Pressure; Gauges and the Barometer

Any liquid can serve in a Torricelli-style barometer, but the most **dense** ones are the most convenient. This barometer uses **water**.

Conceptual Example: Suction.

A student suggests suction-cup shoes for Space Shuttle astronauts working on the exterior of a spacecraft. Having just studied this Chapter, you gently remind him of the fallacy of this plan. What is it?
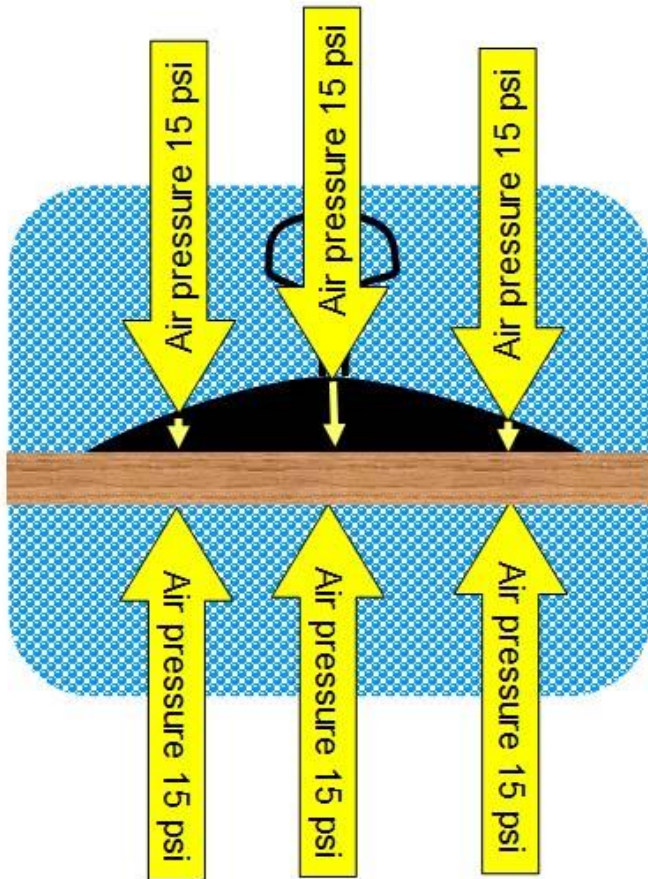
10-7 Buoyancy and Archimedes' Principle

This is an object submerged in a fluid. There is an upward force on the object due to fluid pressure because the pressures at the top and bottom of it are different.
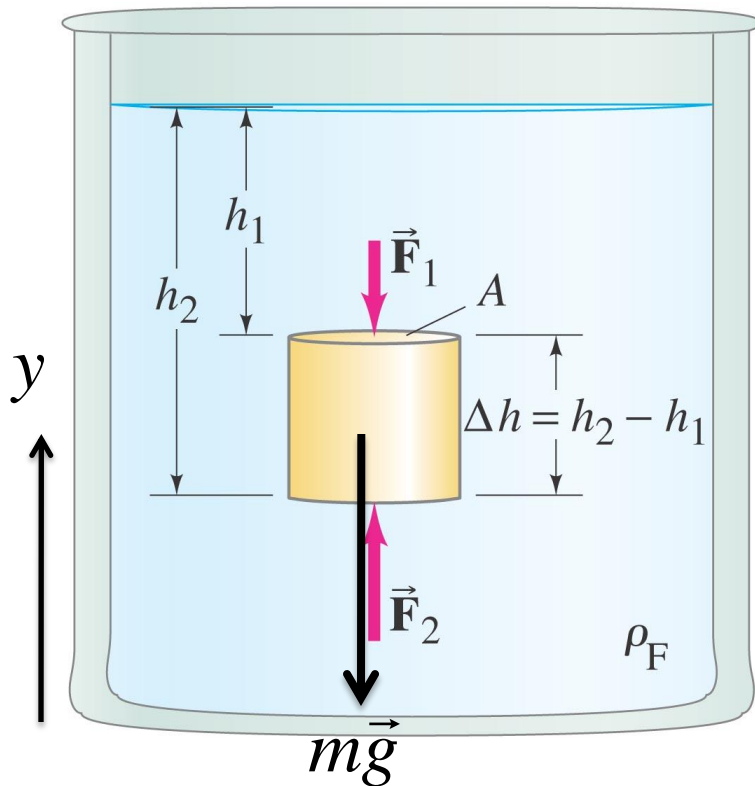
This upward force is called the buoyant force

$$F_B = F_2 - F_1 = \rho_F gA(h_2 - h_1)$$
$$= \rho_F gA \, \Delta h$$
$$= \rho_F V g$$
$$= m_F g.$$

Which is equal to the weight of the fluid that takes up the same volume as the object.
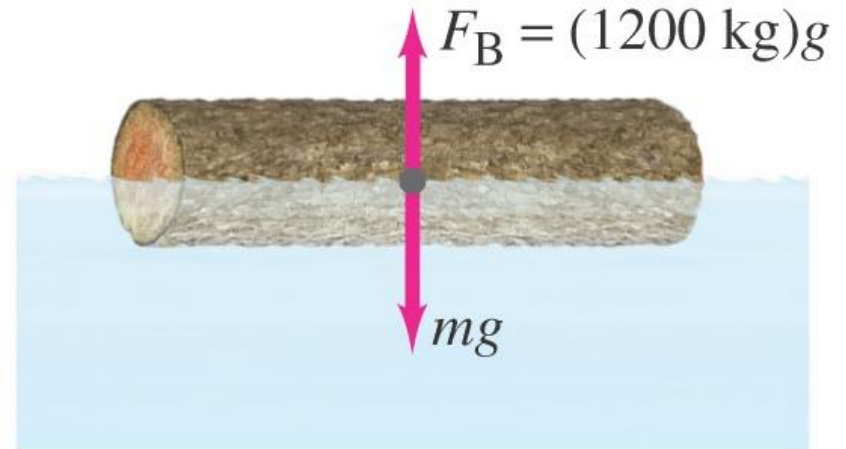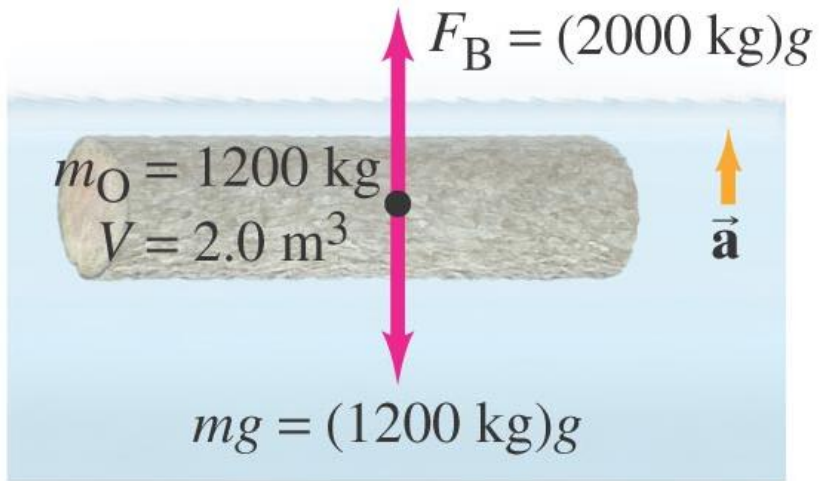
y-comp of net force: $F_2 - F_1 - mg = m_F g - mg = Vg(\rho_F - \rho)$

Therefore, float if $(\rho < \rho_F)$; but sink if $(\rho > \rho_F)$. **demo**

10-7 Buoyancy and Archimedes' Principle

If an object's density is less than that of water, there will be an upward net force on it, and it will rise until it is partially out of the water.

$$F_B = (2000 \text{ kg})g$$

$m_O = 1200 \text{ kg}$
$V = 2.0 \text{ m}^3$

$\vec{a}$

$$mg = (1200 \text{ kg})g$$

$$F_B = (1200 \text{ kg})g$$

$$mg$$
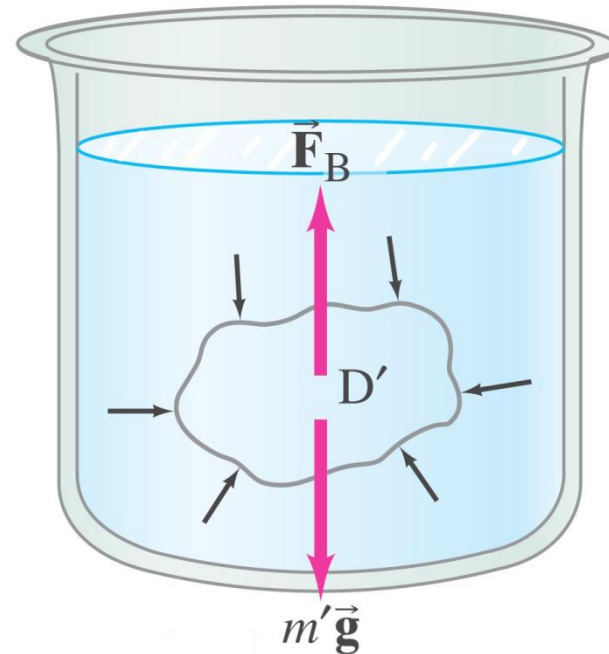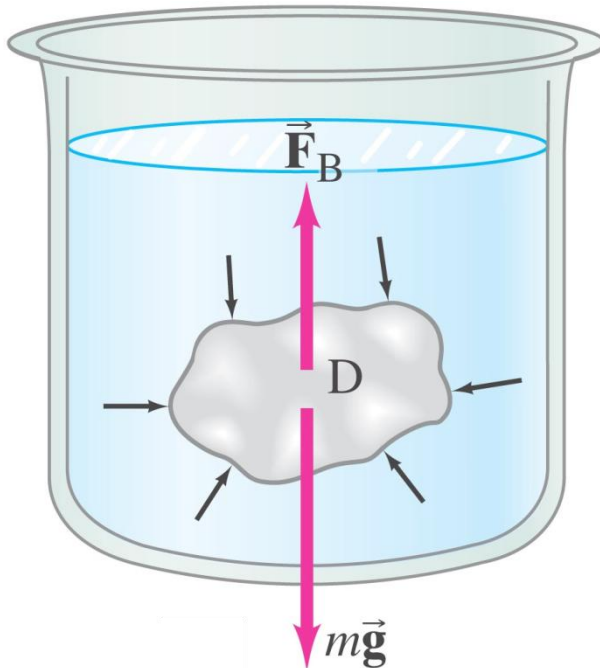
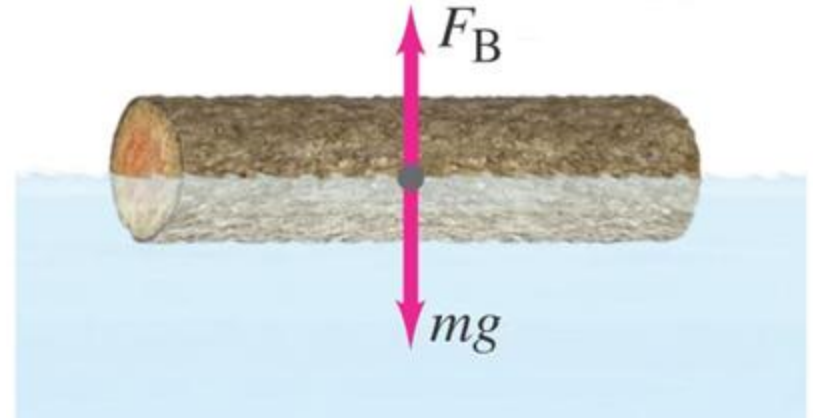# 10-7 Buoyancy and Archimedes' Principle

Archimedes' principle:

The buoyant force on an object immersed in a fluid is equal to the weight of the fluid displaced by that object.

I-clicker question 21-3: Conceptual Example 13-8: Two pails of water.

Consider two identical pails of water filled to the brim. One pail contains only water, the other has a piece of wood floating in it. Which pail has the greater weight?

A. The pail with wood.

B. The pail without wood.

C. The two pails have the same weight.

The buoyant force on the wood object equals the weight of the wood object (static equilibrium).

Also, the buoyant force is equal to the weight of the spilled (i.e., displaced) water (Archimedes' principle).

In other words, the weight of wood is the same as the weight of the spilled water.

Therefore, putting the wood doesn't change the weight of the pail.
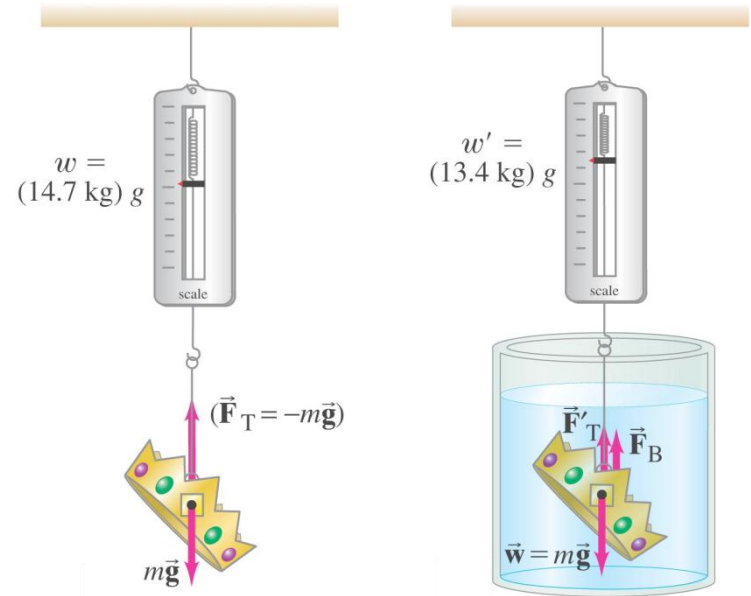
Example: Recovering a submerged statue.

A 70-kg ancient statue lies at the bottom of the sea. Its volume is 3.0 x 10⁴ cm³. How much force is needed to lift it?
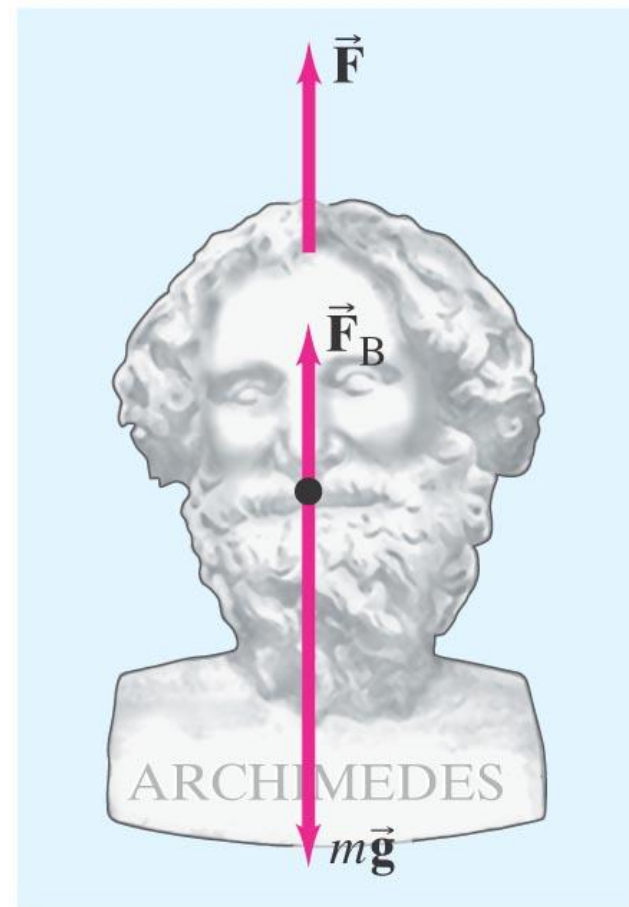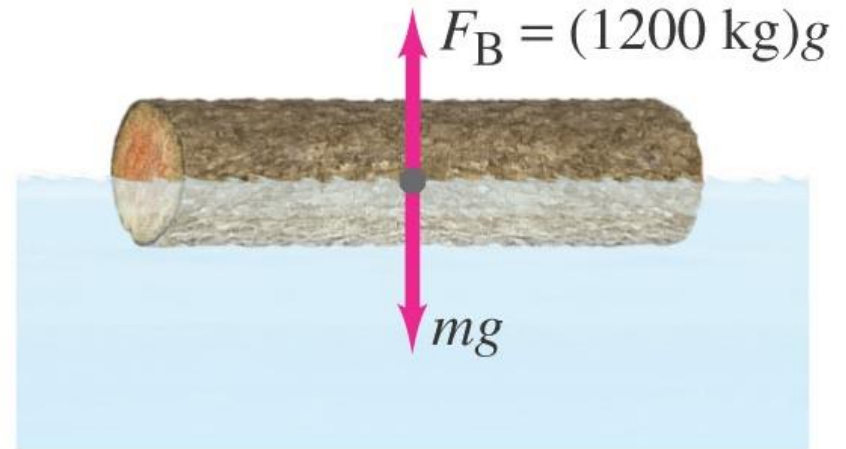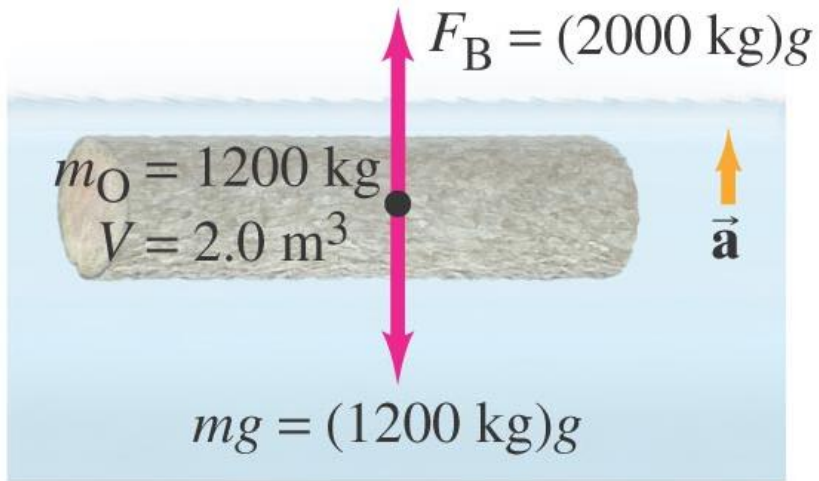
Example: Archimedes: Is the crown gold?

When a crown of mass 14.7 kg is submerged in water, an accurate scale reads only 13.4 kg. Is the crown made of gold?

10-7 Buoyancy and Archimedes' Principle

If an object's **density** is **less** than that of water, there will be an **upward** net force on it, and it will rise until it is partially **out** of the water.

$F_B = (2000 \text{ kg})g$

$m_O = 1200 \text{ kg}$
$V = 2.0 \text{ m}^3$

$\vec{a}$

$mg = (1200 \text{ kg})g$

$F_B = (1200 \text{ kg})g$

mg

10-7 Buoyancy and Archimedes' Principle

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

$$\frac{V_{\mathrm{displ}}}{V_{\mathrm{O}}} = \frac{\rho_{\mathrm{O}}}{\rho_{\mathrm{F}}}.$$
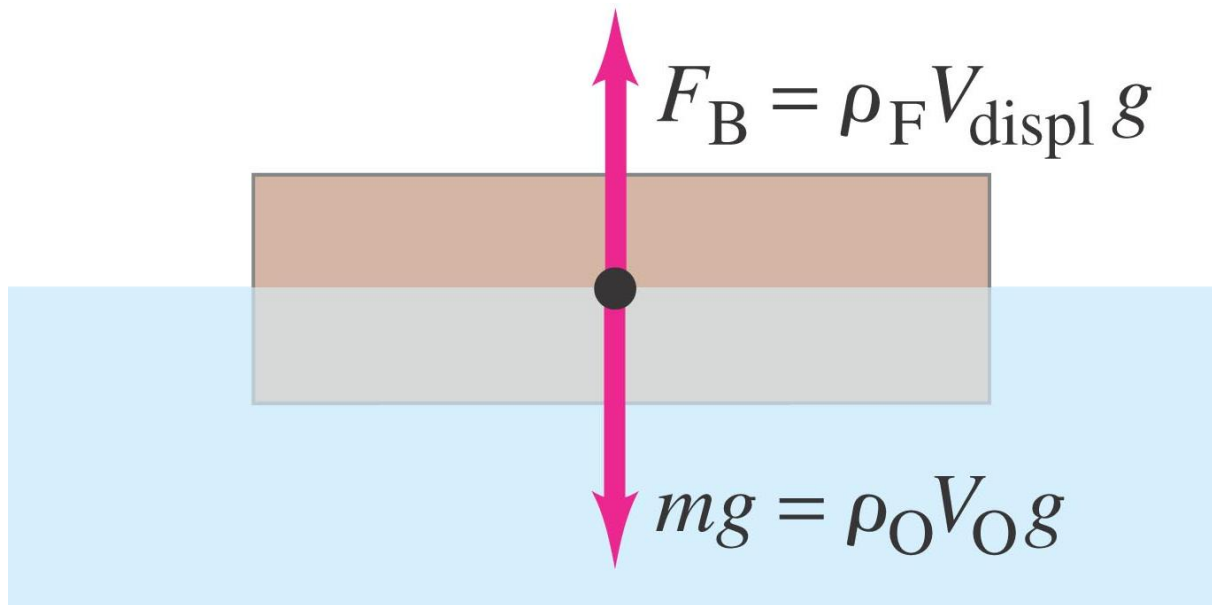
$$F_{\mathrm{B}} = \rho_{\mathrm{F}} V_{\mathrm{displ}}\, g$$

$$mg = \rho_{\mathrm{O}} V_{\mathrm{O}}\, g$$

$$F_{B} = mg$$

$$\rho_{F} V_{displ}\, g = \rho_{O} V_{O}\, g$$

$$\frac{V_{displ}}{V_{O}} = \frac{\rho_{O}}{\rho_{F}}$$

Example: Hydrometer calibration.

A hydrometer is a simple instrument used to measure the specific gravity of a liquid by indicating how deeply the instrument sinks in the liquid. This hydrometer consists of a glass tube, weighted at the bottom, which is 25.0 cm long and 2.00 cm² in cross-sectional area, and has a mass of 45.0 g. How far from the end should the 1.000 mark be placed?
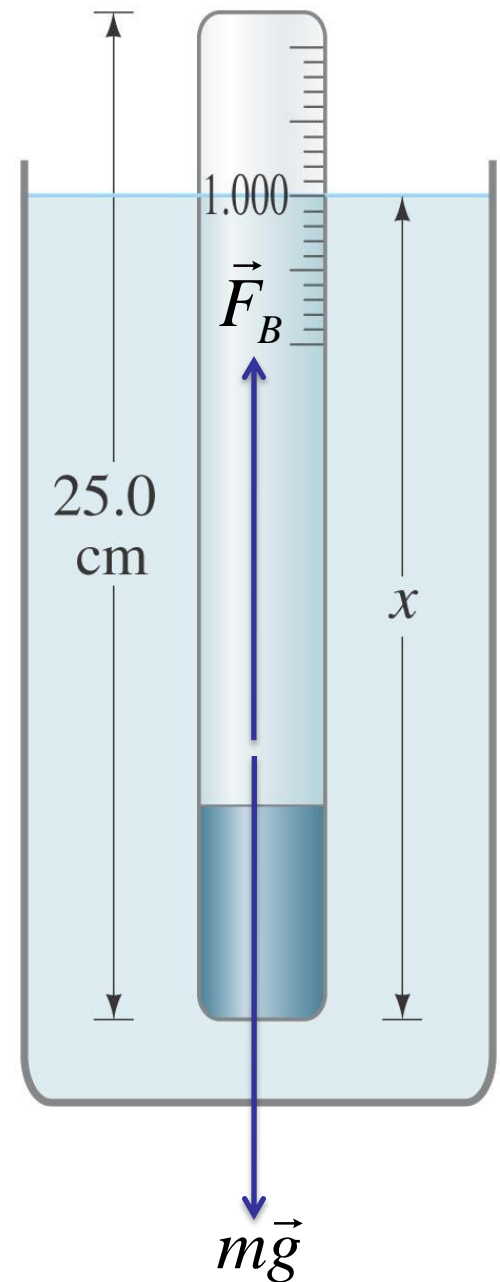
Example: Helium balloon.

What volume V of helium is needed if a balloon is to lift a load of 180 kg (including the weight of the empty balloon)?