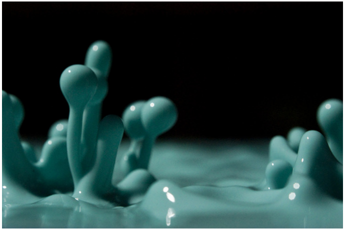
Chapter 14 - Fluids



"Any solid lighter than a fluid will, if placed in the fluid, be so far immersed that the weight of the solid will be equal to the weight of the fluid displaced."

-Archimedes, *On Floating Bodies*

David J. Starling
Penn State Hazleton
PHYS 213

Objectives (Ch 14)

Objectives for Chapter 14

(a) Identify and apply concepts related to pressure, force, mass and density as they relate to fluids.

(b) Identify the difference between absolute and gauge pressure and relate these concepts.

(c) Describe the use of both a barometer and an open-tube manometer in measuring pressure.

(d) Apply Pascal's principle to solve problems involving hydraulic lift.

(e) Apply Archimedes's principle to connect the buoyant force to gravity, mass and volume of an object.

(f) Describe and apply the concepts related to fluid flow using the equation of continuity.

(g) Describe and apply Bernoulli's equation to problems involving fluid flowing in a gravitational field.

Objectives (Ch 14)

A penny is laying flat on a desk. When a student blows over the penny, it is observed to be lifted upward and then carried away. Which of the following statements best describes why the penny was lifted up from the desk?

(a) The penny was attracted by the force of the wind.

(b) The pressure of the moving air above the penny was greater than that of the air between the penny and the desk top.

(c) The pressure of the moving air above the penny was less than that of the air between the paper and the desk top.

(d) The weight of the penny was reduced by the wind blowing over it.

(e) The wind pushed the side of the penny and lifted it upward.

Density and Pressure

A fluid can flow freely and conforms to its container.

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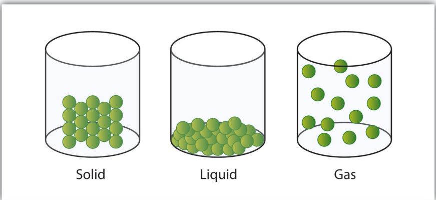
Although a fluid resists compression/expansion, shearing forces cause motion.

Density and Pressure

Fluids include both gases and liquid, excluding solids.



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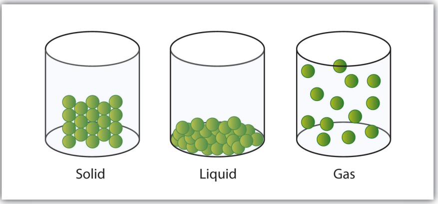

Differnt fluids have different properties, such as viscocity, density, compressibility.

Density and Pressure

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$$\rho = \frac{\Delta m}{\Delta V} \rightarrow \rho = \frac{m}{V} \tag{1}$$

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- If the fluid is incompressible (e.g., water), this density does not change much.
- For compressible fluids (e.g., air), the density can vary.

Density and Pressure

The pressure experienced by a fluid is defined as the ratio of force to area:

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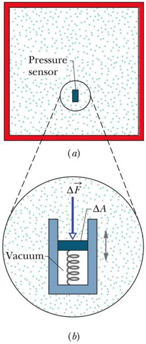

Pressure is a scalar (i.e., the sensor doesn't care about direction).

Density and Pressure

Pressure has a variety of common units in addition the S.I. standard N/m^2:

- pascal (1 Pa = 1 N/m^2)
- astmosphere (atm)
- torr (equivalent to mm Hg)
- pound/in^2 (psi)

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$$1 \text{ atm} = 1.01 \times 10^5 \text{ Pa} = 760 \text{ torr} = 14.7 \text{ lb/in}^2.$$

Density and Pressure

A swimming pool with a width of 15.0 m and a length of 20.0 m is filled with water. If the total force, which is directed downward, on the bottom of the pool is 54.0×10^7 N, what is the pressure on the bottom of the bottom of the pool?

(a) 0.79×10^5 Pa

(b) 1.01×10^5 Pa

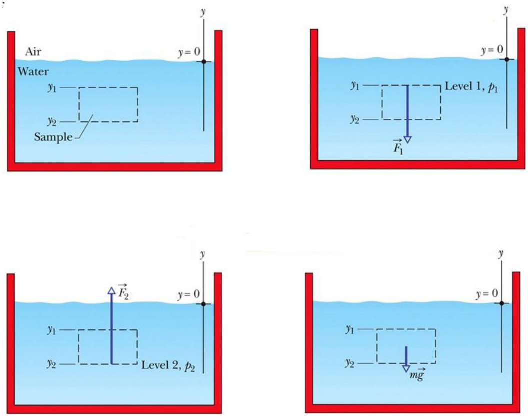
(c) 1.80×10^5 Pa

(d) 1.97×10^5 Pa

(e) 2.09×10^5 Pa

Hydrostatic Fluids

When a fluid is at rest, we can easily describe its properties using forces and density.



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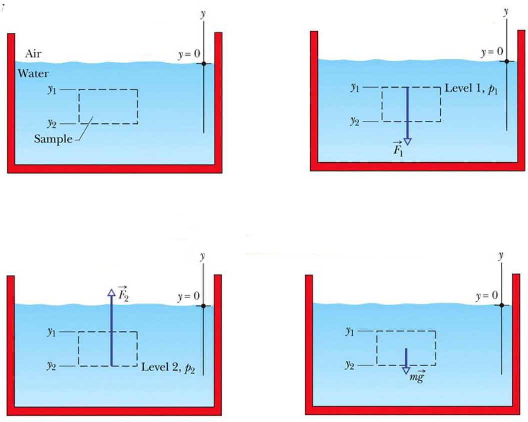

These three forces sum together to give us the net force.

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$$\begin{aligned} \sum F_i &= 0 \\ F_2 - F_1 - mg &= 0 \end{aligned}$$

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If we use the surface of the water as the reference, we get:

$$p = p_0 + \rho g h.$$

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- p is known as the absolute pressure
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- Pressure only depends on depth and density, not on shape at all!

Hydrostatic Fluids

An above ground water pump is used to extract water from an open well. A pipe extends from the pump to the bottom of the well. What is the maximum depth from which water can be pumped?

(a) 19.6 m

(b) 39.2 m

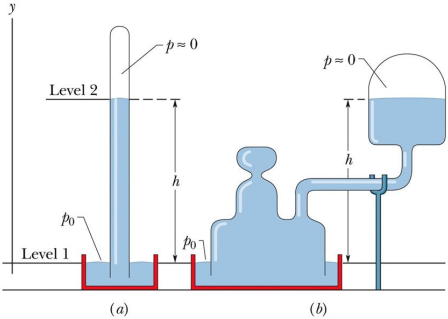
(c) 10.3 m

(d) 101 m

(e) With a big enough pump, you can extract water from any depth.

Measuring Pressure

To measure pressure, we will use $p = p_0 - \rho g h$ *along with a dense fluid (mercury, for instance).*



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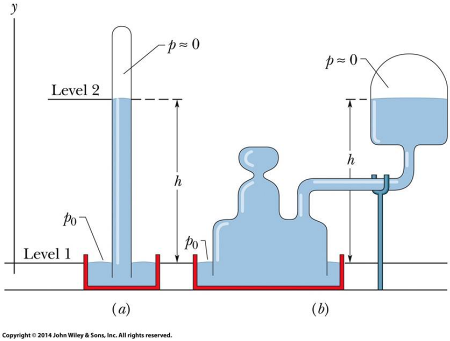
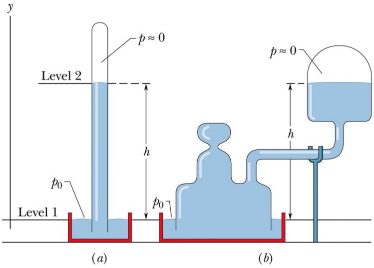


In this case, $p \approx 0$ and so $p_0 = \rho g h$. By measuring h, we measure pressure.

Measuring Pressure

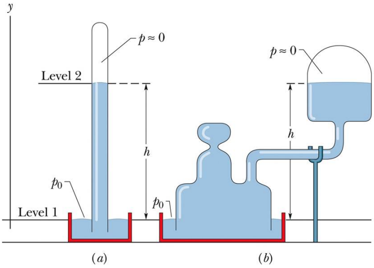
For mercury barometers, the height difference (mm-Hg) is equal to torr if:



Measuring Pressure

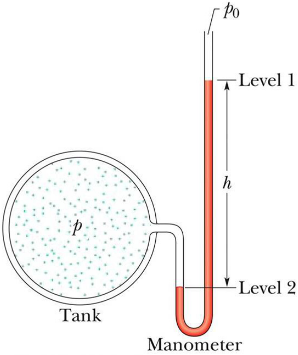
For mercury barometers, the height difference (mm-Hg) is equal to torr if:

- Gravity g has its standard value (9.8 m/s^2)
- The mercury is held at 0°.



Measuring Pressure

Alternatively, we can use an open-tube manometer with a gas on both sides.



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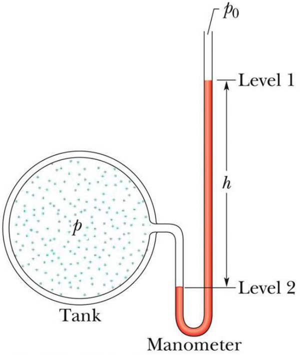


Here, we measure the gauge pressure: $p_g = p - p_0 = \rho g h$.

Measuring Pressure

Consider the mercury U-shaped tube manometer shown. Which one of the following choices is equal to the gauge pressure of the gas enclosed in the spherical container? The acceleration due to gravity is g and the density of mercury is ρ.

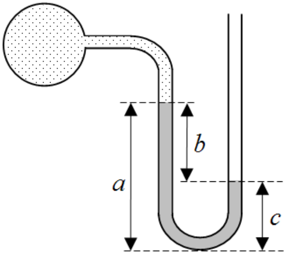
(a) $\rho g c$

(b) $-\rho g b$

(c) $\rho g a$

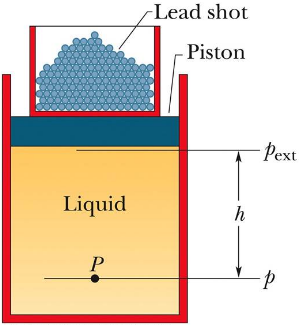
(d) $p_{atm} + \rho g b$

(e) $p_{atm} - \rho g c$



Pascal and Archimedes

For enclosed, incompressible fluids, a change in pressure at one point in the fluid is transmitted undiminished to every other point of the fluid.



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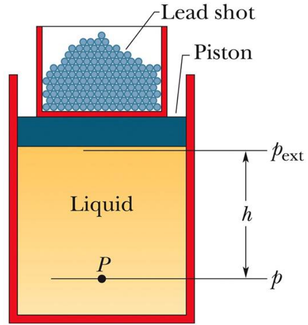
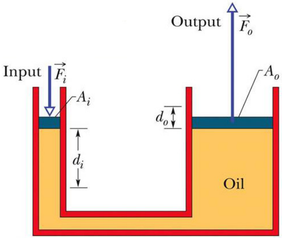


This effect is independent of height: $\Delta p = \Delta p_{ext}$

Pascal and Archimedes

This affect is known as Pascal's Principle and is the explanation for hydraulic lever:



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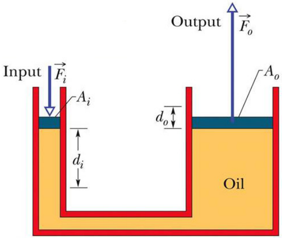

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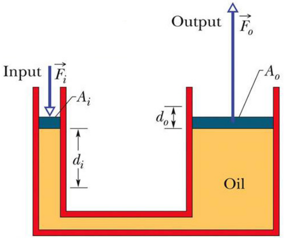
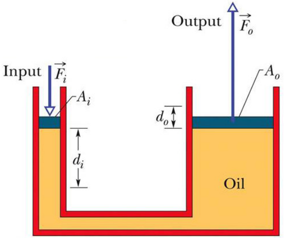


- If a small force F_i is applied, this increases the pressure within the fluid by $\Delta p = F_i/A_i$.
- This increase in pressure propagates through the material to the other side: $\Delta p = F_o/A_0$.

Pascal and Archimedes



Together:

$$\frac{F_i}{A_i} = \frac{F_o}{A_o} \rightarrow F_o = F_i \frac{A_o}{A_i} \qquad (3)$$

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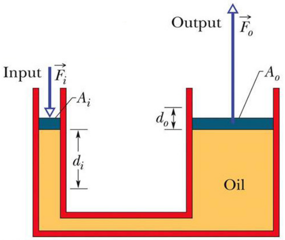

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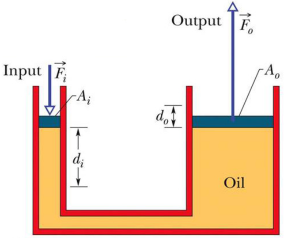
- The bigger the ratio A_o/A_i, the bigger the output force!

Pascal and Archimedes



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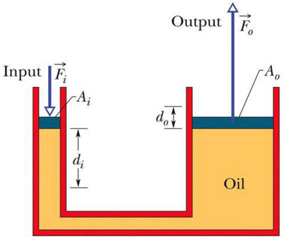
- The bigger the ratio A_o/A_i, the bigger the output force!
- How does this affect distance?

Pascal and Archimedes

The fluid is conserved and uncompressed, so

$V_i = V_o$,

$$d_i A_i = d_o A_o \rightarrow d_o = d_i \frac{A_i}{A_o}. \tag{4}$$



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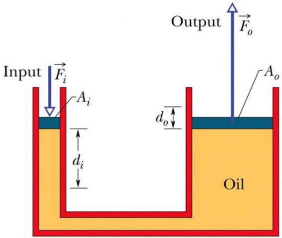
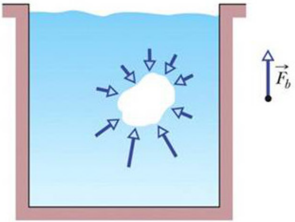


- The smaller the ratio A_i/A_o, the smaller the output motion!

Pascal and Archimedes

When an object is submerged in a fluid, the pressure on the object varies along its surface according to its depth: $p = p_0 + \rho g h$.



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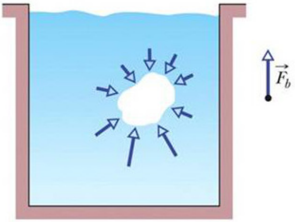

The force on the bottom is greater than the force at the top, resulting in a **buoyant force**.

Pascal and Archimedes

How big is the buoyant force on an object in a fluid? Archimedes's principle states:

$$F_b = m_f g \tag{5}$$

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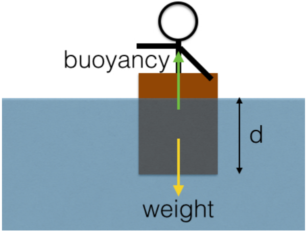
The buoyant force on a (partially) submerged object is upward and equal to the *weight* of the fluid that has been displaced, $m_f g$.

Pascal and Archimedes

When an object floats (in or on top of the fluid), it is in static equillibrium and $F_b = F_g = m_f g$.



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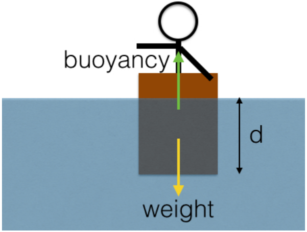


Buoyant forces also make things appear less heavy. This is known as apparent weight: $W_{app} = W - F_b$.

Pascal and Archimedes

A solid block of mass m is suspended in a liquid by a thread. The density of the block is greater than that of the liquid. Initially, the fluid level is such that the block is at a depth d and the tension in the thread is T. Then, the fluid level is decreased such that the depth is $0.5d$. What is the tension in the thread when the block is at the new depth?

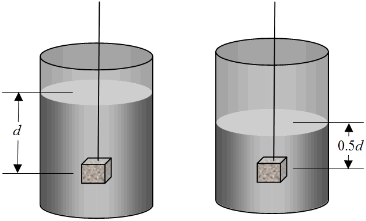
(a) $0.25T$

(b) $0.50T$

(c) T

(d) $2T$

(e) $4T$



Bernoulli's Equation

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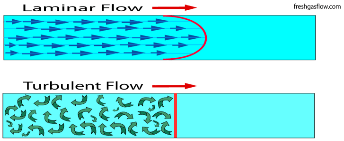

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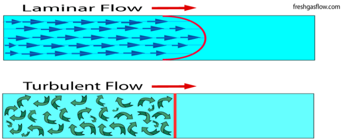

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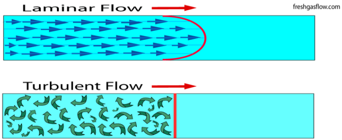

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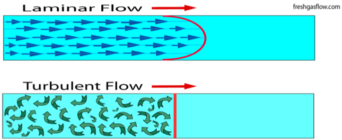
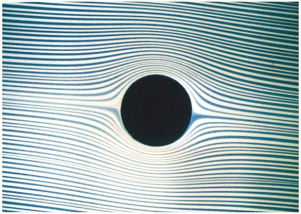
(c) **nonviscous flow**: there is no resistance to motion;

(d) **irrotational flow**: particles placed in fluid can only translate, not rotate.

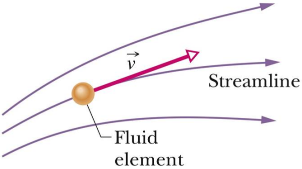


Bernoulli's Equation

We can visualize the flow of a fluid using streamlines made of the motion of tracers.



Courtesy D. H. Peregrine, University of Bristol



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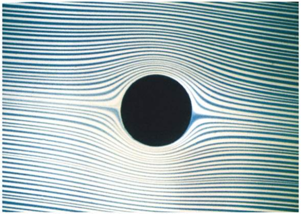

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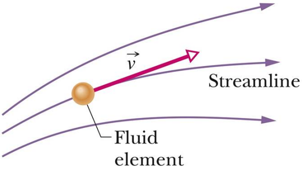
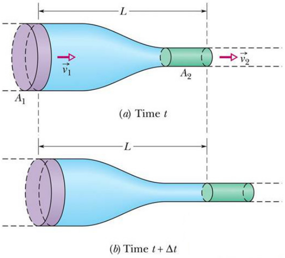


Velocity is tangent to the streamlines; no two streamlines intersect, and streamlines are stationary for laminar flow.

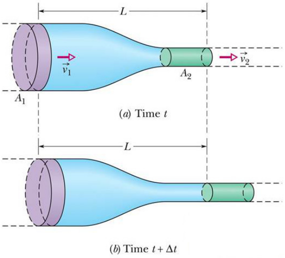
Bernoulli's Equation

Since the fluid is incompressible, a fixed volume of fluid will experience different speeds based upon cross-sectional area.



Bernoulli's Equation

Since the fluid is incompressible, a fixed volume of fluid will experience different speeds based upon cross-sectional area.



$$A_1 v_1 = A_2 v_2 \tag{6}$$

Can apply to any "tube" of flow that follows the streamlines.

Bernoulli's Equation

We can define two flow rates for an ideal fluid:

- Volume flow rate: $R_V = Av$ (m^3/s)
- Mass flow rate: $R_m = \rho Av$ (kg/s)

Bernoulli's Equation

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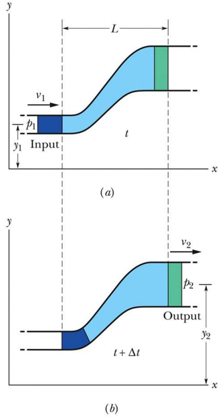
Both R_V and R_m are constants for ideal fluids.

Bernoulli's Equation

Let's apply conservation of energy to the motion of a volume of ideal fluid, using the work done by the pressure at each side.



$$W = \Delta E$$

Bernoulli's Equation

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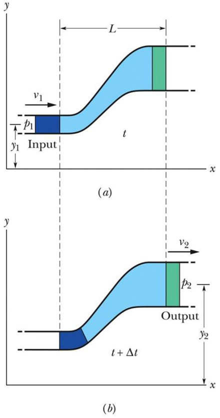
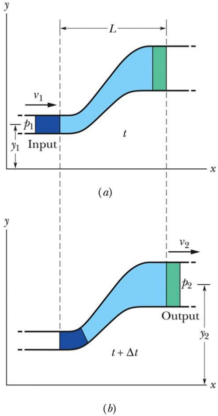


$$W = \Delta E$$
$$W_1 - W_2 = E_2 - E_1$$

Bernoulli's Equation

Let's apply conservation of energy to the motion of a volume of ideal fluid, using the work done by the pressure at each side.



$$\begin{aligned} W &= \Delta E \\ W_1 - W_2 &= E_2 - E_1 \\ W_1 + E_1 &= W_2 + E_2 \end{aligned}$$

Bernoulli's Equation

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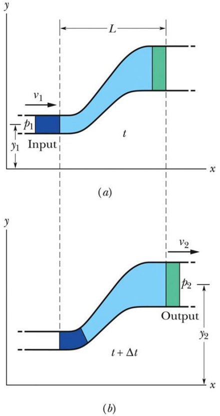
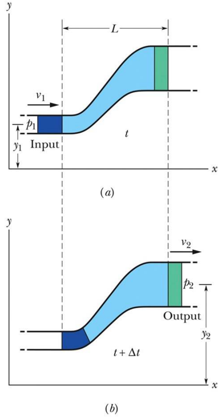


$$
\begin{aligned}
W &= \Delta E \\
W_1 - W_2 &= E_2 - E_1 \\
W_1 + E_1 &= W_2 + E_2 \\
F_1 d_1 + \frac{1}{2} m v_1^2 + m g y_1 &= (\text{same})_2
\end{aligned}
$$

Bernoulli's Equation

Let's apply conservation of energy to the motion of a volume of ideal fluid, using the work done by the pressure at each side.



$$
\begin{aligned}
W &= \Delta E \\
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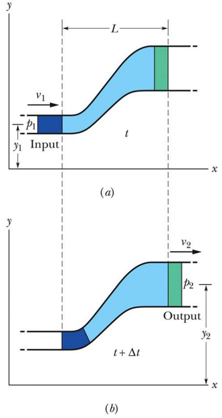
W_1 + E_1 &= W_2 + E_2 \\
F_1 d_1 + \frac{1}{2} m v_1^2 + m g y_1 &= (\text{same})_2 \\
p_1 V + \frac{1}{2} (\rho V) v_1^2 + (\rho V) g y_1 &= (\text{same})_2
\end{aligned}
$$

Bernoulli's Equation

Let's apply conservation of energy to the motion of a volume of ideal fluid, using the work done by the pressure at each side.



$$
\begin{aligned}
W &= \Delta E \\
W_1 - W_2 &= E_2 - E_1 \\
W_1 + E_1 &= W_2 + E_2 \\
F_1 d_1 + \frac{1}{2} m v_1^2 + m g y_1 &= (\text{same})_2 \\
p_1 V + \frac{1}{2}(\rho V) v_1^2 + (\rho V) g y_1 &= (\text{same})_2 \\
p_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 &= (\text{same})_2
\end{aligned}
$$

Bernoulli's Equation

Bernoulli's equation states that fluid flow has this particular quantity conserved:

$$p + \frac{1}{2}\rho v^2 + \rho g y = \text{constant} \tag{7}$$

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$$p + \frac{1}{2}\rho v^2 + \rho g y = \text{constant} \quad (7)$$

- For stationary fluid: $p + \rho g y = \text{constant}$

Bernoulli's Equation

Bernoulli's equation states that fluid flow has this particular quantity conserved:

$$p + \frac{1}{2}\rho v^2 + \rho g y = \text{constant} \tag{7}$$

- For stationary fluid: $p + \rho g y = \text{constant}$
- For horizontal fluid flow: $p_1 + \frac{1}{2}\rho v_1^2 = p_2 + \frac{1}{2}\rho v_2^2$

Bernoulli's Equation

Fluid is flowing from left to right through the pipe shown in the drawing. Rank the pressures at the three locations in order from lowest to highest?

(a) $p_A > p_B > p_C$

(b) $p_B > p_A = p_C$

(c) $p_C > p_B > p_A$

(d) $p_B > p_A$ and

$p_B > p_C$

(e) $p_C > p_A$ and

$p_C > p_B$