# AP2 Fluids

A cart full of water travels horizontally on a frictionless track with initial velocity **v**. As shown in the diagram, in the back wall of the cart there is a small opening near the bottom of the wall that allows water to stream out. Considering just the cart itself (and not the water inside it), which of the following most accurately describes the characteristics of the cart?
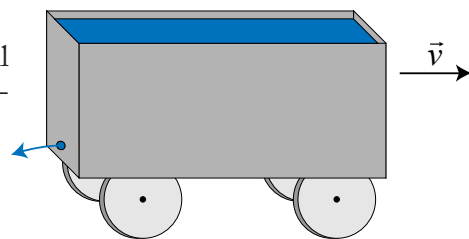
|     | **Speed** | **Kinetic Energy** |
| --- | --- | --- |
| (A) | stays the same | stays the same |
| (B) | increases | increases |
| (C) | stays the same | increases |
| (D) | increases | stays the same |

**Answer:** B

As the water streams out of the cart, the water is pushed out of the cart by pressure from above, exerting a reactionary force pushing the cart and its contents forward, increasing the speed of the cart. As the speed of the cart is increasing, and its mass remains the same, the kinetic energy of the cart must also increase.

**EK:** 3.A.4 If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction. 3.E.1 The change in the kinetic energy of an object depends on the force exerted on the object and on the displacement of the object during the interval that the force is exerted. 5.A.2 For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings.

**SP:** 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

**LO:** 3.A.4.1 The student is able to construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. 3.E.1.1 The student is able to make predictions about the changes in kinetic energy of an object based on considerations of the direction of the net force on the object as the object moves. 5.A.2.1 The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations.

*Special thanks to Dan Burns, Gardner Friedlander, and Zaid Khalil for assistance with problem development.*

# AP2 Fluids

A 20-kg uniform solid cylinder, A, is suspended underwater by a light rope. A second cylinder, B, with the same external dimensions but made of a higher density material is hollowed out and filled with pressurized helium gas such that, once sealed, it has the same total mass as the first cylinder. Cylinder B is then suspended underwater at the same depth by an identical rope. Compare the tension in the two ropes.

(A) $T_A < T_B$
(B) $T_A = T_B$
(C) $T_A > T_B$
(D) Not enough information given
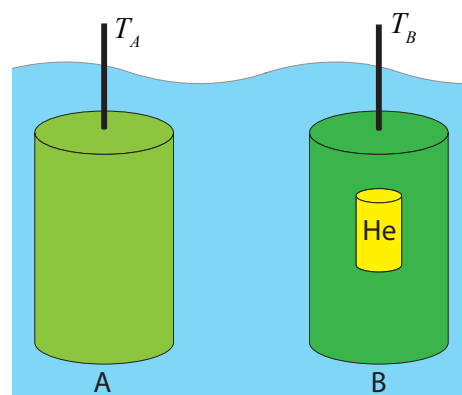


**Answer:** B

Because the two cylinders have the same total mass encased in the same total volume, they have the same average density, and therefore, the same upward buoyant force acting upon them. The force of gravity on each cylinder is also the same as they have the same mass. Therefore, the same net force acts on each cylinder, and each rope must maintain the same tension.

**EK:** 1.E.1 Matter has a property called density. 3.B.2 Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation. 3.C.4 Contact forces such as the buoyant force result from the interaction of one object touching another object and they arise from interatomic electric forces.

**SP:** 1.1 The student can create representations and models of natural or man–made phenomena and systems in the domain. 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena.

**LO:** 1.E.1.1 The student is able to predict the densities, differences in densities, or changes in densities under different conditions for natural phenomena and design an investigation to verify the prediction. 3.B.2.1 The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. 3.C.4.1 The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces.

# AP2 Fluids

A reservoir of incompressible fluid is topped by two pistons of non-equal areas, as shown in the diagram at right (not drawn to scale). The larger piston has four times the surface area of the smaller piston. If a force $F$ pushes the smaller piston down by some distance $d$, which of the following best describes the upward force and distance traveled for the larger piston?
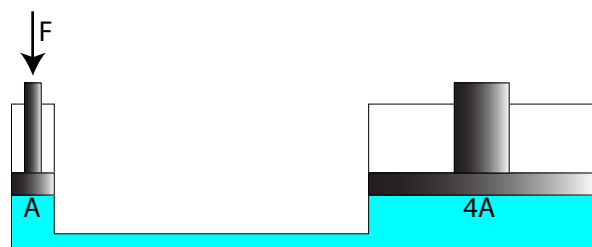
|     | Force | Distance Traveled |
|-----|-------|-------------------|
| (A) | 4F    | d/4               |
| (B) | F/4   | 4d                |
| (C) | F     | 4d                |
| (D) | 4F    | d                 |

**Answer:** A

When a force is applied to a contained, incompressible fluid, the pressure increases equally in all directions throughout the fluid. Since the pressure at all points must be equal, the force per area must be equal, therefore the larger piston must have a four times larger force. Conservation of energy, however, dictates that the work done in pushing the small piston down must equal the work done in raising the larger piston, therefore the larger piston only moves one fourth the distance of the smaller piston.

**EK:** 3.C.4 Contact forces such as the buoyant force result from the interaction of one object touching another object and they arise from interatomic electric forces. 5.B.10 Bernoulli's equation describes the conservation of energy in fluid flow.

**SP:** 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

**LO:** 3.C.4.1 The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces. 5.B.10.2 The student is able to use Bernoulli's equation and/or the relationship between force and pressure to make calculations related to a moving fluid.

# AP2 Fluids

Two rain barrels, A and B, each contain the same volume of water at the same temperature, as shown at right. A pressure gauge is placed at the bottom of each barrel. Which statement best describes the pressures at the bottom of the barrels?
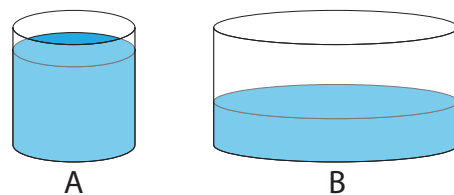
(A) $P_A > P_B$ since the pressure of the water depends upon the water's depth.
(B) $P_A < P_B$ since the pressure of the water depends upon the amount of atmosphere above the water.
(C) $P_A = P_B$ since the pressure of the water depends upon the volume of water.
(D) Not enough information given.

A        B

**Answer:** A

The pressure at the bottom of the barrels depends primarily upon the depth of the water.

**EK:** 5.B.10 Bernoulli's equation describes the conservation of energy in fluid flow. 7.A.1 The pressure of a system determines the force that the system exerts on the walls of its container and is a measure of the average change in the momentum or impulse of the molecules colliding with the walls of the container. The pressure also exists inside the system itself, not just at the walls of the container.

**SP:** 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.

**LO:** 5.B.10.2 The student is able to use Bernoulli's equation and/or the relationship between force and pressure to make calculations related to a moving fluid.

# AP2 Fluids

A student places several ice cubes in a glass and fills the glass with water. After the ice cubes melt, will the water level in the glass

(A) rise a small amount
(B) fall a small amount
(C) remain at the same level
(D) not enough information given



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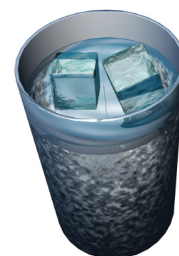
**Answer:** C

The weight of the water displaced is equal to the weight of the ice cubes. Put another way, the volume of ice floating above the surface of the water matches the amount by which the water expanded when it turned to ice. Therefore, as the ice melts and returns to a liquid state, the water level remains constant.

**EK:** 1.E.1 Matter has a property called density. 3.C.4 Contact forces such as the buoyant force result from the interaction of one object touching another object and they arise from interatomic electric forces.

**SP:** 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

**LO:** 1.E.1.1 The student is able to predict the densities, differences in densities, or changes in densities under different conditions for natural phenomena and design an investigation to verify the prediction. 3.C.4.1 The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces.

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# AP2 Fluids

Water flows in a section of pipe of diameter $d_1$ with a constant volumetric flow rate $Q_1$ and linear velocity $v_1$. What happens to the volumetric flow rate $Q_2$ and linear velocity $v_2$ as the water transitions to a section of pipe with diameter $d_2$, which is one third the original pipe's diameter, as shown in the diagram?
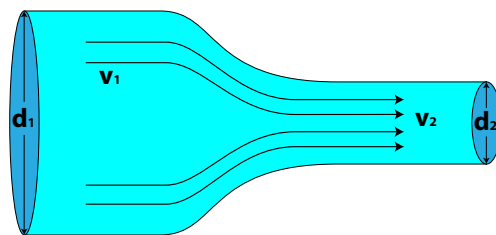


|  | **Volumetric Flow Rate** | **Linear Velocity** |
|---|---|---|
| (A) | $Q/9$ | $v$ |
| (B) | $Q/3$ | $9v$ |
| (C) | $Q$ | $9v$ |
| (D) | $3Q$ | $v/9$ |

**Answer:** C

When fluids move through a full pipe, the volume of fluid that enters the pipe must equal the volume of fluid that leaves the pipe, even if the diameter of the pipe changes. This is a restatement of the law of conservation of mass for fluids. The volume flow rate, then, is equal to the area of the pipe multiplied by the velocity of the fluid. This must remain constant. Since the thin section of pipe has one-ninth the area of the thick section of pipe, the velocity of the fluid in the thin section must be nine times greater than in the thick section of pipe.

**EK:** 5.F.1 The continuity equation describes conservation of mass flow rate in fluids. Examples should include volume rate of flow, mass flow rate.
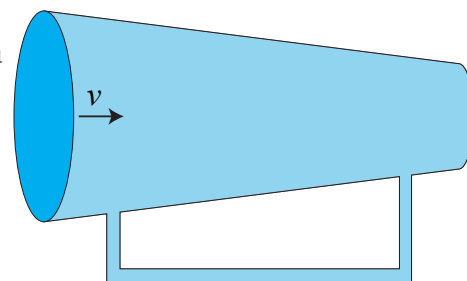
**SP:** 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena.

**LO:** 5.F.1.1 The student is able to make calculations of quantities related to flow of a fluid, using mass conservation principles (the continuity equation).

# AP2 Fluids

Water flows through a section of thick piping with some velocity $v$ as shown in the diagram at right. Based on the diagram, in which direction would you expect water to flow through the narrow section?

(A) to the right
(B) to the left
(C) remain stagnant
(D) not enough information given



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**Answer:** A

Bernoulli's Principle states that fluids moving at higher velocities lead to lower pressures, and fluids moving at lower velocities result in higher pressures. Since there is a higher pressure at the left of the pipe, and a lower pressure at the right of the pipe, the water in the narrow section must flow from high to low pressure, or left to right.



**EK:** 5.B.10 Bernoulli's equation describes the conservation of energy in fluid flow.

**SP:** 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.

**LO:** 5.B.10.1 The student is able to use Bernoulli's equation to make calculations related to a moving fluid.

Difficulty: 1
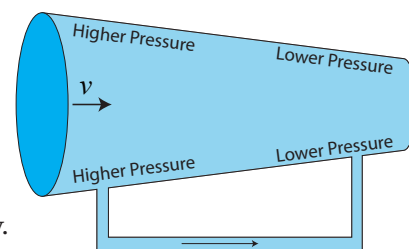
# AP2 Fluids

A vertical cylinder attached to the ground is partially evacuated to a pressure of 10,000 Pa by a vacuum pump. An airtight lid of radius 5 cm and mass 400 g is placed on its top. A rope is tied to the lid and a force of 800N vertically upward is applied. Which of the following best describes the result of the force applied to the rope?

(A) The lid pops off the container and then accelerates upward at roughly 2000 m/s².
(B) The lid pops off the container and then accelerates upward at roughly 220 m/s².
(C) The lid pops off the container and then accelerates upward at roughly 0.23 m/s².
(D) The entire container, with sealed lid, remains stationary.
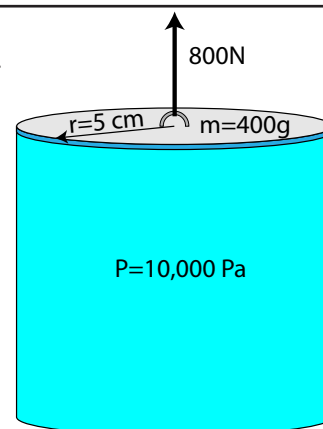
**Answer:** (A) The lid pops off the container and then accelerates upward at 2000 m/s². As the lid is pulled upward with a force of 800N, the force of gravity on the lid is roughly 4N down, and the force holding the lid of the cylinder to the body of the cylinder, determined from the difference in pressure on the inside and outside of the cylinder (90,000 pascals) multiplied by the area of the lid, is roughly 707N. This net imbalance in the force pops the lid off the cylinder, at which point it accelerates upward with a net force of 800N-4N = 796N upward. Applying Newton's 2nd Law, the acceleration of the lid is F/m or 796N/0.4kg = 2000 m/s².

**EK:** 7.A.1 The pressure of a system determines the force that the system exerts on the walls of its container and is a measure of the average change in the momentum or impulse of the molecules colliding with the walls of the container. The pressure also exists inside the system itself, not just at the walls of the container.

**SP:** 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.

**LO:** 7.A.1.2 Treating a gas molecule as an object (i.e., ignoring its internal structure), the student is able to analyze qualitatively the collisions with a container wall and determine the cause of pressure, and at thermal equilibrium, to quantitatively calculate the pressure, force, or area for a thermodynamic problem given two of the variables.

Difficulty: 2

# AP2 Fluids

I.  A square bedroom on the second floor of a house at sea level has a length of 4 meters.  What is the total downward force on the surface of the bedroom floor due to air pressure?
(A) 16 N
(B) $4 \times 10^5$ N
(C) $8 \times 10^5$ N
(D) $1.6 \times 10^6$ N

II.  Three students examine the situation and make the following statements regarding why the force of the air pushing down on the floor does not collapse the floor:

**Student A**: Despite the large force due to air pressure on the surface of the floor, the floor is a high density solid and is attached to the much more massive Earth.  The combined stability of the Earth and the flooring structure is more than enough to withstand the force of air pressure on the surface of the floor.

**Student B**: The force of the air underneath the floor pushing up very nearly balances the force of the air pushing down on the floor, creating a net force on the surface of the floor that is very nearly zero.

**Student C**: The force of the air pressure pushing down on the surface of the floor causes the floor to deform slightly, compressing the molecules of the floor, resulting in an elastic force pushing the air molecules back up.  The elastic force of the floor balances the force of air pressure pushing down, resulting in a net force on the surface of the floor that is very nearly zero.

Which, if any, of these three students do you agree with and think is correct?

Student A_____        Student B_____        Student C_____        None of them_____

Explain your reasoning.

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**Answers:**
I: (D) $1.6 \times 10^6$ N        F=PA=(100,000 Pa)(4 m)$^2$ = $1.6 \times 10^6$ N
II: Student B - Pascal's Principle states that the force exerted by an enclosed fluid is applied to all surfaces of the container, therefore the force of air pressure in the room underneath the bedroom is exerting nearly the same force upward due to air pressure as the force of the air pushing down on the bedroom floor (neglecting the width of the floor itself, which makes a negligible difference in this problem.)

**EK:** 7.A.1 The pressure of a system determines the force that the system exerts on the walls of its container and is a measure of the average change in the momentum or impulse of the molecules colliding with the walls of the container. The pressure also exists inside the system itself, not just at the walls of the container.

**SP:** 2.2 The student can apply mathematical routines to quantities that describe natural phenomena.  6.5 The student can evaluate alternative scientific explanations.

**LO:** 7.A.1.1 The student is able to make claims about how the pressure of an ideal gas is connected to the force exerted by molecules on the walls of the container, and how changes in pressure affect the thermal equilibrium of the system.

# AP2 Fluids

A closed-tube mercury barometer has a height of 760 mm when placed in a room at one atmosphere (101,300 Pa) of pressure. If mercury has a density of 13,600 kg/m³, how tall would the barometer need to be if the liquid used inside it were honey (density 1400 kg/m³)?

(A) 78 mm
(B) 7.4 m
(C) 78 m
(D) 7400 m
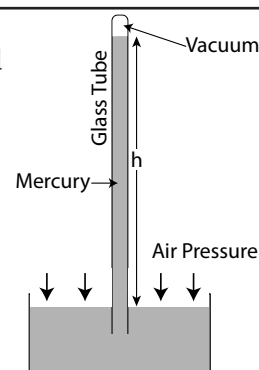


**Answer:** (B) 7.4 m. Utilizing Bernoulli's Equation you can solve for the height of the honey in the glass tube. Set side 1 as the air side, and side 2 as the inside of the tube.

$$P_1 + \tfrac{1}{2}\rho_1 v_1^2 + \rho_1 g h_1 = P_2 + \tfrac{1}{2}\rho_2 v_2^2 + \rho_2 g h_2 \xrightarrow[h_1=0,P_2=0]{v_1=v_2=0}$$

$$P_{air} = \rho_2 g h_2 \rightarrow h_2 = \frac{P_{air}}{\rho_2 g} = \frac{101,300\,Pa}{(1400\,^{kg}/_{m^3})(9.8\,^{m}/_{s^2})} = 7.4m$$

**EK:** 5.B.10 Bernoulli's equation describes the conservation of energy in fluid flow. 7.A.1 The pressure of a system determines the force that the system exerts on the walls of its container and is a measure of the average change in the momentum or impulse of the molecules colliding with the walls of the container. The pressure also exists inside the system itself, not just at the walls of the container.
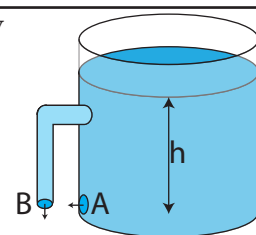
**SP:** 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

**LO:** 5.B.10.2 The student is able to use Bernoulli's equation and/or the relationship between force and pressure to make calculations related to a moving fluid. 7.A.1.1 The student is able to make claims about how the pressure of an ideal gas is connected to the force exerted by molecules on the walls of the container, and how changes in pressure affect the thermal equilibrium of the system.

# AP2 Fluids

A cylinder filled with water to a height h has two outlets. Water exits the barrel simultaneously through both outlet A and outlet B. Use this information and the diagram at right to answer the following question. Neglect friction.

Where is the water velocity fastest?
(A) Fastest at A.
(B) Fastest at B.
(C) Fastest at whichever point has the smallest opening.
(D) They have the same velocity at A and B.

**Answer:** (D) They have the same velocity at A and B. Utilizing Bernoulli's Equation, both outlets are at the same depth from the surface, therefore they should have the same velocity.

**EK:** 5.B.10 Bernoulli's equation describes the conservation of energy in fluid flow.

**SP:** 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.

**LO:** 5.B.10.1 The student is able to use Bernoulli's equation to make calculations related to a moving fluid.