Chapter 15 Homework

Due: 9:00am on Tuesday, November 24, 2009

Note: To understand how points are awarded, read your instructor's Grading Policy.

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Problem 15.9

A research submarine has a 10.0 cm-diameter window 8.90 cm thick. The manufacturer says the window can withstand forces up to 1.20×10^6 N. What is the submarine's maximum safe depth?

Part A

The pressure inside the submarine is maintained at 1.0 atm.

ANSWER: 1.51×10^4 m

Correct

Problem 15.12

Part A

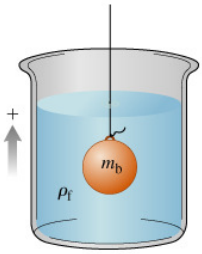
How far must a 2.0-cm-diameter piston be pushed down into one cylinder of a hydraulic lift to raise an 8.0-cm-diameter piston by 20 cm?

ANSWER: 3.20 m

Correct

A Submerged Ball

A ball of mass m_b and volume V is lowered on a string into a fluid of density ρ_f. Assume that the object would sink to the bottom if it were not supported by the string.



Part A

What is the tension T in the string when the ball is fully submerged but not touching the bottom, as shown in the figure?

Hint A.1 **Equilibrium condition**

Although the fact may be obscured by the presence of a liquid, the basic condition for equilibrium still holds: The net force on the ball must be zero. Draw a free-body diagram and proceed from there.

Hint A.2 **Find the magnitude of the buoyant force**

Find F_{buoyant}, the magnitude of the buoyant force.

Hint A.2.1 **Archimedes' principle**

Hint not displayed

Hint A.2.2 **Find the mass of the displaced fluid**

Hint not displayed

Express your answer in terms of any or all of the variables ρ_f, V, m_b, and g.

ANSWER: $F_{\mathrm{buoyant}} = \rho_f V g$

Correct

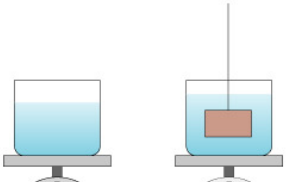
Express your answer in terms of any or all of the given quantities and g, the magnitude of the acceleration due to gravity.

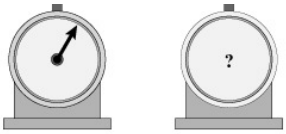
ANSWER: $T = m_b g - \rho_f V g$

Correct

Block Suspended in Water Conceptual Question

A flask of water rests on a scale that reads 100 N. Then, a small block of unknown material is held completely submerged in the water. The block does not touch any part of the flask, and the person holding the block will not tell you whether the block is being pulled up (keeping it from falling further) or pushed down (keeping it from bobbing back up).





Part A

What is the new reading on the scale?

Hint A.1 **Archimedes' principle**

Hint not displayed

Hint A.2 **Newton's 3rd law applied to the buoyant force**

Hint not displayed

ANSWER:

- (•) greater than 100 N
- ( ) 100 N
- ( ) less than 100 N
- ( ) It is impossible to determine.

Correct

The experiment is repeated with the six different blocks listed below. In each case, the blocks are held completely submerged in the water.

	Mass (g)	Volume (cm^3)
A	100	50
B	100	200
C	200	50
D	50	100
E	200	100
F	400	50

Part B

Rank these blocks on the basis of the scale reading when the blocks are completely submerged.

Hint B.1 **Buoyant force on a submerged block**

Hint not displayed

Rank from largest to smallest. To rank items as equivalent, overlap them.

ANSWER:

View

Correct

Part C

If the blocks were released while submerged, which, if any, would sink to the bottom of the flask?

Hint C.1 **Density of water**

The density of water is 1.0 $\mathrm{g/cm^3}$. Only objects of lesser or equal density can float in water.

Enter the correct letters from the table in alphabetical order without commas or spaces (e.g., ABC).

ANSWER: ACEF

Correct

Flow Velocity of Blood Conceptual Question

Arteriosclerotic plaques forming on the inner walls of arteries can decrease the effective cross-sectional area of an artery. Even small changes in the effective area of an artery can lead to very large changes in the blood pressure in the artery and possibly to the collapse of the blood vessel.

Imagine a healthy artery, with blood flow velocity of $v_0 = 0.14\ \mathrm{m/s}$ and mass per unit volume of $\rho = 1050\ \mathrm{kg/m^3}$. This leads to a value for the kinetic energy per unit volume of blood of

$$\frac{1}{2}\rho v_0^2 = \frac{1}{2}(1050\ \mathrm{kg/m^3})(0.14\ \mathrm{m/s})^2 \approx 10\ \mathrm{Pa}.$$

Imagine that plaque has narrowed an artery to one-fifth of its normal cross-sectional area (an 80% blockage).

Part A

Compared to normal blood flow velocity, v_0, what is the velocity of blood as it passes through this blockage?

Hint A.1 **Continuitity equation and reduced cross-sectional area**

By the equation of continuity, as the cross-sectional area of an artery decreases because of plaque formation, the velocity of blood through that region of the artery will increase. The new flow speed can be calculated by rearranging the equation of continuity,

$$A_1 v_1 = A_2 v_2;$$

so

$$v_2 = \frac{A_1}{A_2} v_1$$

where A_1 and A_2 are the initial and final cross-sectional areas, and v_1 and v_2 are the initial and final velocities of the blood, respectively.

ANSWER:

- $80v_0$
- $20v_0$
- $5v_0$
- $v_0/5$

Correct

Part B

By what factor does the kinetic energy per unit of blood volume change as the blood passes through this blockage?

ANSWER:

- 25
- 5
- 1

Correct

Part C

As the blood passes through this blockage, what happens to the blood pressure?

Hint C.1 Blood pressure and blood velocity

Bernoulli's equation states that the sum of the pressure, the kinetic energy per volume, and the gravitational energy per volume of a fluid is constant. For initial and final pressures p_1 and p_2, initial and final velocities v_1 and v_2, and mass per unit volume of blood, ρ, ignoring the effects of changes in gravitational energy leads to

$$p_1 + \frac{1}{2}\rho v_1^2 = p_2 + \frac{1}{2}\rho v_2^2.$$

Basically, the sum of kinetic energy and pressure must remain constant in an artery. This leads to a very serious health risk. As blood velocity increases, blood pressure in a section of artery can drop to a dangerously low level, and the blood vessel can collapse, completely cutting off blood flow, owing to lack of sufficient internal pressure.

Hint C.2 Calculating the change in blood pressure

From Bernoulli's equation, the change in pressure is the negative of the change in kinetic energy per unit volume. For initial and final kinetic energies of the blood, K_1 and K_2, respectively,

$$p_1 + \frac{1}{2}\rho v_1^2 = p_2 + \frac{1}{2}\rho v_2^2,$$

or

$$p_1 + K_1 = p_2 + K_2,$$

where $K = (1/2)\rho v^2$. Rearranging this equation yields

$$p_2 - p_1 = -(K_2 - K_1)$$

or

$$\Delta p = -\Delta K.$$

ANSWER:

- It increases by about 240 Pa.
- It increases by about 40 Pa.
- It stays the same.
- It decreases by about 40 Pa.
- It decreases by about 240 Pa.

Correct

Since the kinetic energy increases by a factor of 25,

$$\Delta K = 25 \times 10\ \mathrm{Pa} - 10\ \mathrm{Pa} = 24 \times 10\ \mathrm{Pa} = 240\ \mathrm{Pa}.$$

Bernoulli's equation tells you that $\Delta K = -\Delta p$.

As the blood velocity increases through a blockage, the blood pressure in that section of the artery can drop to a dangerously low level. In extreme cases, the blood vessel can collapse, completely cutting off blood flow, owing to lack of sufficient internal pressure. In the next three parts, you will see how a small increase in blockage can cause a much larger pressure change.

For parts D - F imagine that plaque has grown to a 90% blockage.

Part D

Relative to its initial, healthy state, by what factor does the velocity of blood increase as the blood passes through this blockage?

Express your answer numerically.

ANSWER: **10**
Correct

Part E

By what factor does the kinetic energy per unit of blood volume increase as the blood passes through this blockage?

Express your answer numerically.

ANSWER: **100**
Correct

Part F

What is the magnitude of the drop in blood pressure, Δp, as the blood passes through this blockage? Use 10 Pa as the normal (i.e., unblocked) kinetic energy per unit volume of the blood.

Express your answer in pascals.

ANSWER: Δp = **990** Pa
Correct

Problem 15.23

Water flowing through a 2.00 cm-diameter pipe can fill a 200 L bathtub in 6.60 min.

Part A

What is the speed of the water in the pipe?

ANSWER: **1.61** m/s
Correct

Understanding Bernoulli's Equation

Bernoulli's equation is a simple relation that can give useful insight into the balance among fluid pressure, flow speed, and elevation. It applies exclusively to ideal fluids with steady flow, that is, fluids with a constant density and no internal friction forces, whose flow patterns do not change with time. Despite its limitations, however, Bernoulli's equation is an essential tool in understanding the behavior of fluids in many practical applications, from plumbing systems to the flight of airplanes.

For a fluid element of density ρ that flows along a streamline, Bernoulli's equation states that

$$p_1 + \rho g h_1 + \frac{1}{2}\rho v_1^2 = p_2 + \rho g h_2 + \frac{1}{2}\rho v_2^2,$$

where p is the pressure, v is the flow speed, h is the height, g is the acceleration due to gravity, and subscripts 1 and 2 refer to any two points along the streamline. The physical interpretation of Bernoulli's equation becomes clearer if we rearrange the terms of the equation as follows:

$$p_1 - p_2 = \rho g(h_2 - h_1) + \frac{1}{2}\rho(v_2^2 - v_1^2).$$

The term $p_1 - p_2$ on the left-hand side represents the total work done on a unit volume of fluid by the pressure forces of the surrounding fluid to move that volume of fluid from point 1 to point 2. The two terms on the right-hand side represent, respectively, the change in potential energy, $\rho g(h_2 - h_1)$, and the change in kinetic energy, $\frac{1}{2}\rho(v_2^2 - v_1^2)$, of the unit volume during its flow from point 1 to point 2. In other words, Bernoulli's equation states that the work done on a unit volume of fluid by the surrounding fluid is equal to the sum of the change in potential and kinetic energy per unit volume that occurs during the flow. This is nothing more than the statement of conservation of mechanical energy for an ideal fluid flowing along a streamline.

Part A

Consider the portion of a flow tube shown in the figure. Point 1 and point 2 are at the same height. An ideal fluid enters the flow tube at point 1 and moves steadily toward point 2. If the cross section of the flow tube at point 1 is greater than that at point 2, what can you say about the pressure at point 2?

Hint A.1 **How to approach the problem**
Hint not displayed

Hint A.2 **Apply Bernoulli's equation**
Hint not displayed

Hint A.3 **Determine v_2 with respect to v_1**
Hint not displayed

ANSWER: The pressure at point 2 is
- (●) lower than the pressure at point 1.
- ( ) equal to the pressure at point 1.
- ( ) higher than the pressure at point 1.

Correct

Thus, by combining the continuity equation and Bernoulli's equation, one can characterize the flow of an ideal fluid.When the cross section of the flow tube decreases, the flow speed increases, and therefore the pressure decreases. In other words, if $A_2 < A_1$, then $v_2 > v_1$ and $p_2 < p_1$.

Part B

As you found out in the previous part, Bernoulli's equation tells us that a fluid element that flows through a flow tube with decreasing cross section moves toward a region of lower pressure. Physically, the pressure drop experienced by the fluid element between points 1 and 2 acts on the fluid element as a net force that causes the fluid to _____.

Hint B.1 **Effects from conservation of mass**

Hint not displayed

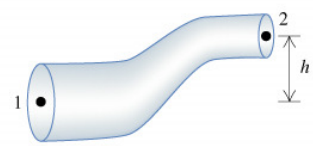
ANSWER:

- decrease in speed
- (•) increase in speed
- remain in equilibrium

Correct

Part C

Now assume that point 2 is at height h with respect to point 1, as shown in the figure. The ends of the flow tube have the same areas as the ends of the horizontal flow tube shown in Part A. Since the cross section of the flow tube is decreasing, Bernoulli's equation tells us that a fluid element flowing toward point 2 from point 1 moves toward a region of lower pressure. In this case, what is the pressure drop experienced by the fluid element?



Hint C.1 **How to approach the problem**

Hint not displayed

ANSWER:

The pressure drop is

- smaller than the pressure drop occurring in a purely horizontal flow.
- equal to the pressure drop occurring in a purely horizontal flow.
- (•) larger than the pressure drop occurring in a purely horizontal flow.

Correct

Part D

From a physical point of view, how do you explain the fact that the pressure drop at the ends of the elevated flow tube from Part C is *larger* than the pressure drop occurring in the similar but purely horizontal flow from Part A?

Hint D.1 **Physical meaning of the pressure drop in a tube**

Hint not displayed

ANSWER:

A greater amount of work is needed to balance the

- (•) increase in potential energy from the elevation change.
- decrease in potential energy from the elevation change.
- larger increase in kinetic energy.
- larger decrease in kinetic energy.

Correct

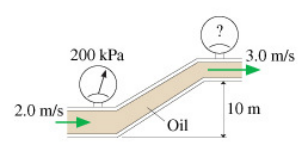
In the case of purely horizontal flow, the difference in pressure between the two ends of the flow tube had to balance only the increase in kinetic energy resulting from the acceleration of the fluid. In an elevated flow tube, the difference in pressure must also balance the increase in potential energy of the fluid; therefore a higher pressure is needed for the flow to occur.

Problem 15.26

Part A

What does the top pressure gauge read?

Express your answer using two significant figures.



ANSWER: P = **110** *Correct* kPa

A Wire under Stress

A steel wire of length 2.06 m with circular cross section must stretch no more than 0.300 cm when a tensile force of 370 N is applied to each end of the wire.

Part A

What minimum diameter d_{min} is required for the wire?

Hint A.1 **How to approach the problem**

Hint not displayed

Hint A.2 **Calculate the tensile strain**

Hint not displayed

Hint A.3 **Definition of tensile stress**

Hint not displayed

Hint A.4 **Relation between the area and the diameter**

Hint not displayed

Express your answer in millimeters. Take Young's modulus for steel to be Y = 2.00×10^{11} Pa.

ANSWER: d_{min} = **1.27** *Correct* mm

Note that you were asked for the *minimum* diameter. Where does this figure?

The extension is directly proportional to the stress, i.e., the force per unit area. One way to decrease the stress is to increase the surface area over which the stretching force is applied. So any diameter (and so area) greater than the one you calculated would serve to keep the extension within the tolerance specified (i.e., the maximum allowable extension).

Problem 15.69

Part A

At what ocean depth would the volume of an aluminum sphere be reduced by 0.10%?

ANSWER: **6.92** *Correct* km

Score Summary:

Your score on this assignment is 98.8%.
You received 69.15 out of a possible total of 70 points.