Chapter 6

Solids and Fluids

Unlike Chapter 5, which was a unified, comprehensive treatment of rotational motion, Chapter 6 is a collection of topics that don't really have a common theme. The sections are fairly short, containing the bare essence of the subject matter; your textbook and teacher can fill in the interesting details and practical applications.

There is one exception — Section 6.4's treatment of Archimedes' Principle will teach you valuable strategies that you probably won't learn from other sources.

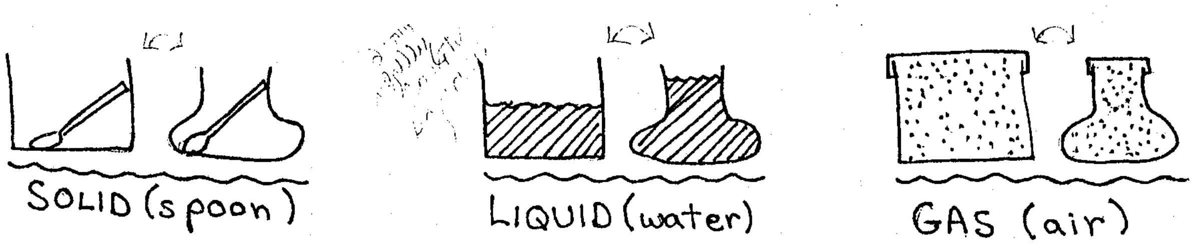
Read Section 6.1 first, then use the other sections when your class studies the corresponding topics: 6.2 (density and pressure), 6.3 (solids and elasticity), 6.4 (fluids at rest, Pascal's principle, Archimedes' principle), and 6.5 (fluids in motion, flow rate and Bernoulli's equation, fluid resistance and viscosity).

==this chapter doesn't discuss surface tension or ==[?]

6.1 Solid, Liquid and Gas

The three common *phases* [states of matter] are solid, liquid and gas. As shown below, a solid (like a metal spoon) tends to maintain its shape, while a liquid (like water) or gas (like air) changes shape to match the shape of its container.

Because they can change shape easily and have the ability to "flow", liquids and gases are called *fluids.*



{ A solid's shape is difficult to change, but it can be done. For example, a spoon's handle will be bent if enough force is applied to it. Or the spoon could be heated until it turns into a liquid that can be reformed into a metal fork or knife or ... }

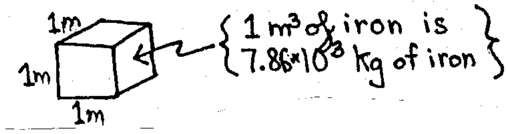
Look at the pictures above, and notice that liquid fills only the bottom part of its container but there is gas in every part of its container. A liquid has a characteristic volume that can be changed (by a very small amount) only by applying a huge force, but it is relatively easy to change the volume of a gas.

The properties of solids, liquids & gases are discussed in more detail later: **solids** in Section 6.3, **fluids (liquid or gas)** in Sections 6.4-6.5, and **gases** in Sections 7.3-7.4.

Your textbook may describe a "fourth phase", *plasma,* that won't be discussed in this book.

6.2 Density and Pressure

One cubic meter of iron has a mass of 7860 kg:



Section 1.7 shows that "12 inches/1 foot" can be used as a *conversion factor* because 12 inches **equals** 1 foot. 7860 kg and 1 m^3 measure different quantities (mass and volume) so they cannot be "equal". But 7860 kg and 1 m^3 describe the same amount of iron in different ways, so we say they are **equivalent**. We can use the ratio of 7860 kg/1 m^3, which is called *density,* as a conversion factor.

PROBLEM 6-A: Using Density as a Conversion Factor.
The density of aluminum is 2700 kg/m^3. a) What is the mass of a .710 m^3 block of aluminum? b) What is the volume of 125 kg of aluminum? c) Calculate the density of aluminum from this data: 2.90 m^3 of aluminum has a mass of 7830 kg.

SOLUTION 6-A: Use the standard conversion-factor method of Section 1.7.

a) $$.710 \text{ m}^3 \text{ of Al} \bullet \frac{2700 \text{ kg of Al}}{1 \text{ m}^3 \text{ of Al}} = 1920 \text{ kg of Al}$$

b) $$125 \text{ kg of Al} \bullet \frac{1 \text{ m}^3 \text{ of Al}}{2700 \text{ kg of Al}} = .0463 \text{ m}^3 \text{ of Al}$$

c) $$\frac{7830 \text{ kg of Al}}{2.90 \text{ m}^3 \text{ of Al}} \Rightarrow \frac{2.70 \times 10^3 \text{ kg of Al}}{1 \text{ m}^3 \text{ of Al}}$$ so the density of Al is 2.70×10^3 kg/m^3.

This conversion-factor relationship is summarized by $(\mathbf{m} \text{ kg}) = (\rho \text{ kg/m}^3)(\mathbf{V} \text{ m}^3)$ or simply $\mathbf{m} = \rho \mathbf{V}$, where m, ρ and V are an object's mass, density and volume.
Problem 6-# will help you understand the meaning of "per" ratios like "2700 g per m^3", so you can improve your intuitive logic about ratios, instead of mechanically plugging numbers into equations or using conversion-factors.

A common non-SI unit for density is g/cm^3. It can be shown (as in Problem 6-#, which shows why 1 m = 10^2 cm and 1 m^3 = 10^6 cm^3) that numerical values of density in kg/m^3 and g/cm^3 differ by a factor of 1/1000. For example, aluminum density is 2.70×10^3 kg/m^3, which is 2.70 g/cm^3. Similarly, iron density is 7860 kg/m^3 = 7.86 g/cm^3, and water density is 1000 kg/m^3 = 1.00 g/cm^3.
1 ml ($\equiv 10^{-3}$ liter) equals 1 cm^3, so water density is also 1.00 g/ml.

Another way to describe density is *specific gravity,* which is defined as a ratio:

$$\text{the } \textit{specific gravity} \text{ of a substance} \equiv \frac{\text{density of that substance}}{\text{density of water}}$$

The specific gravity of aluminum is 2.70, because aluminum is 2.70 times denser than water, as shown by the ratios of 2700/1000 [using kg/m^3 densities] or 2.70/1.00

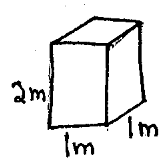
[with g/cm^3 values]. Similarly, the specific gravities of iron & water are 7.86 & 1.00. Specific gravity has no units, because the density-units cancel during division.

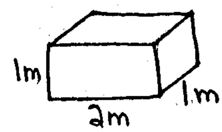
Pressure is defined as a ratio: Pressure $\equiv \frac{\text{Force}}{\text{Area}}$, or $P \equiv \frac{F}{A}$.

Only the component of F that is exerted perpendicular to the area (like pushing straight sideways against a wall) causes pressure, so the P-definition should be "$P \equiv F_\perp / A$". Instead, it is usually simplified to "$P \equiv F/A$" and it is understood, without saying so, that F really means $F_\perp$.

"P" is used for both power and pressure. Use "context" to decide which meaning is intended.

The two iron blocks below have the same mass, (2.0 m^3)(7860 kg/m^3) = 15720 kg, so they exert the same force against the ground: mg = (15720 kg)(9.80 m/s^2) = 154000 N. But the left block exerts this force on a smaller area [it has (1 m)(1 m) = 1 m^2, instead of (1 m)(2 m) = 2 m^2)] so it exerts a larger pressure against the ground.





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

$$P = \frac{154000 \text{ Newtons}}{1 \text{ m}^2} \qquad\qquad P = \frac{15400 \text{ N}}{2 \text{ m}^2}$$

$$P = 154000 \text{ N/m}^2 \qquad\qquad P = 77000 \text{ N/m}^2$$

As discussed in Section 3.5, the block and ground exert *mutual interaction forces* against each other: block pushes ground downward, ground pushes block upward. The left block exerts more pressure against the ground and, by mutual interaction, also has more pressure exerted against itself.

The SI unit for pressure is N/m^2, which is called a *Pascal,* "Pa". Some common non-SI units for pressure are the bar [1 bar $\equiv 10^5$ Pa], *atmosphere* (atm), mm of mercury (mm of Hg), torr, and pounds/in^2 (lbs/in^2). Some useful relationships are:

$$101{,}300 \text{ Pa} = 1.013 \text{ bar} = 1 \text{ atm} = 760 \text{ mm Hg} = 760 \text{ torr} = 14.7 \text{ lbs/in}^2$$

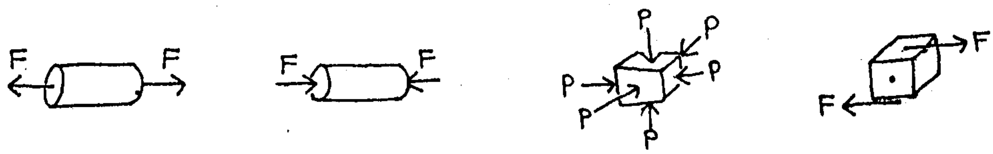
6.3 Solids and Elasticity

If an aluminum wire is stretched a small amount by pulling on its ends, it will return to its original size and shape. This restoring property is called *elasticity.*

{If you want to know "why", a logical reason for elasticity is explored in Problem 6-#.}

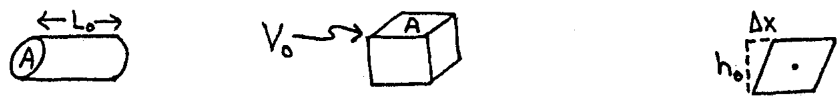
The pictures below show four ways to "stress" an object and cause it to deform. You can pull on its ends (this is called *tensile stress),* push on its ends *(compressive stress),* immerse it in a fluid so pressure is applied to every part of the surface *(volume stress),* or apply force parallel to the opposite faces *(shear stress).*

tensile stress | compressive stress | volume stress | shear stress



The pictures below show geometric characteristics of an unstressed object (its cross-section area **A**, length $\mathbf{L_o}$, volume $\mathbf{V_o}$, height $\mathbf{h_o}$, sideways distortion $\Delta\mathbf{x}$) that will be used in formulas.

To understand shear, look at the third picture and imagine that the object-bottom is glued to the ground and the object-top is glued to a flat plate. When the plate is pushed straight sideways, the object's shape is distorted as its top moves sideways a distance "Δx".



The equations below, describing the four kinds of stress-distortion, all have the same format: Stress = Modulus x Strain. The *stress,* which is F/A or P ($\equiv$ F/A), is what you do to the object. The *strain* is what happens to the object. If you study the strain-formats and think about what the Δ's and o-subscripts mean, you'll see that each strain is a "fractional change": in length, volume or shape. The *modulus* is a property of the material (aluminum, iron,...) that forms the object.

type of stress	Stress	=	Modulus	x	Strain
tensile (or compressional)	$\frac{F}{A}$	=	Y		$\frac{\Delta L}{L_o}$
volume	P	=	B		$\frac{\Delta V}{V_o}$
shear	$\frac{F}{A}$	=	G		$\frac{\Delta x}{h_o}$

Different names and symbols can be used for moduli. *Young's modulus* "Y" is sometimes called the *elastic modulus* (symbolized "E") or *stretch modulus.* The *bulk modulus* is usually "B". The *shear modulus* "G" can also be "S" or "γ".

Memory tricks: Stress causes strain; stress and cause both have an s-sound at the end.
Also, cause-effect & stress-strain have e-e & s-s in the middle.

To understand the ratio logic of tensile stress, rearrange the equation to get

$$\frac{F\ L_o}{A\ Y} = \Delta L .$$

Wire stretch (ΔL) increases if there is a large force (F), a wire that is long (L_o) and thin (A), and if the wire-material is easily distorted (as shown by a small value of Y).

A similar ratio logic analysis can be done for volume stress and shear stress.

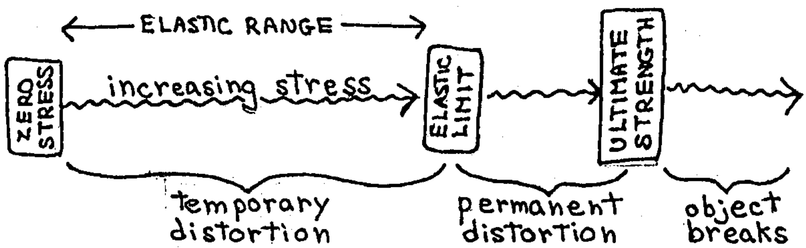
Let's compare two objects made of steel: a thin wire and a coiled spring. It will be easier to stretch (or compress) the spring a given amount, but for either object the amount of stretch is proportional to applied force. In Section 3.8 this proportionality was expressed as "$F_{spring} = -k\ \Delta x$" and we focused our attention on the force exerted

by the ends of the spring. In this section, however, we are interested in the third-law partner of F_{spring}, which is the force exerted **on** the ends of the spring.

The diagram below shows what happens to an object as the tensile stress (F/A) that acts on it steadily increases. The *elastic range* of a material extends from zero stress to the *elastic limit;* within this range the object is temporarily deformed by a stress but returns to its original size and shape when the stress is removed. {In the upper end of the elastic range, near the elastic limit, stress & strain aren't proportional and the "Stress = Modulus x Strain" equation isn't reliable.}

Above the *elastic limit,* an object doesn't recover its original size and shape after the stress is removed. The object is no longer elastic (so it is permanently deformed) even though it doesn't break.

If F/A exceeds the material's *ultimate strength,* the object will *fracture* (break).



Each material has a characteristic elastic limit & ultimate strength. For tensile, compressive and shear stress, a material's ultimate strength (its breaking point) is called its *tensile strength, compressive strength* and *shear strength,* respectively.

PROBLEM 6-B

A 1.5 m long cylindrical steel wire, diameter = 1.8 mm = .071 inch, is connected to the ceiling and a 7 kg block hangs from it. How much does the wire stretch?

Will the wire break if a 100 kg block hangs from it? If the 100 kg block is removed, will the wire return to its original unstretched size?

For the kind of steel in this wire, elastic modulus is 2000 x 10^8 N/m^2, elastic limit is 3 x 10^8 N/m^2, and ultimate tensile strength is 5 x 10^8 N/m^2.

SOLUTION 6-B

While it supports a 7.0 kg block, the wire has a tension-force of 7.0(9.8) pulling on each of its ends. The cross-section of a cylindrical wire is a circle with an area of πr^2. The wire's radius is half its diameter: r = .9 mm = .9 x 10^{-3} m = .0009 m.

$$\frac{F}{A} = E \frac{\Delta L}{L_o}$$

$$\frac{7.0\,(9.8)}{\pi\,(.0009)^2} = (2000 \times 10^8)\,\frac{\Delta L}{1.5}$$

$$.00020 \text{ meter} = \Delta L$$

With a 100 kg block, the tensile stress on the wire is F/A = 100(9.8) / [π (.0009)^2] = 3.9 x 10^8 N/m^2. This is less than the tensile strength of the steel so the wire doesn't break, but it exceeds the elastic limit so the wire won't return to its original size.

Section 6.91 contains all four kinds of stress/strain problems.

6.4 Fluids at Rest: Pressure Fundamentals, Pascal's Principle, Archimedes' Principle

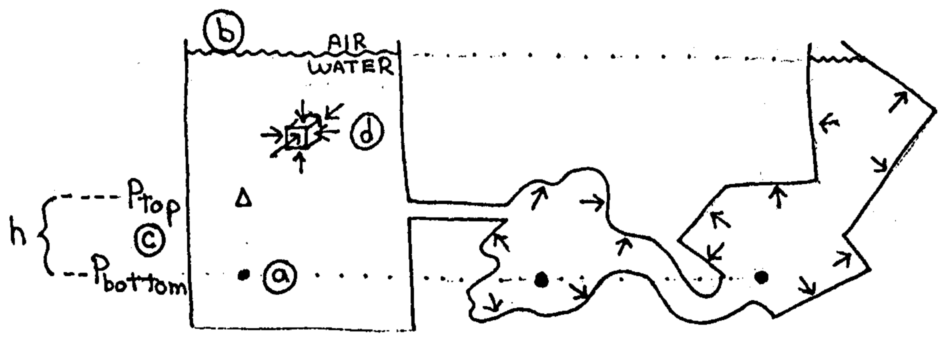
Fluids and *pressure* were defined in Sections 6.1 and 6.2. The picture below shows four fundamentals of pressure for a fluid (either liquid or gas) at rest:

a) The •-points are at the same height in the same body of fluid, so fluid pressure is the same at all three points.

b) At the boundary between two fluids (in this case, air and water), the two fluid pressures are equal: $P_{air\text{-}at\text{-}surface} = P_{water\text{-}at\text{-}surface}$.

c) When two points (like • and Δ) are at different heights, they can be called the "bottom" and "top" points. Fluid pressure at the bottom-point is larger than fluid pressure at the top-point. If the fluid density is assumed to be constant between the bottom and top points, $P_{bottom} = P_{top} + \rho g h$, where "ρ" is the fluid density, "g" is the acceleration of gravity, and "h" is the height difference between the points.
{Problem 6-# discusses the change in air pressure that is caused by a change in height.}

d) A fluid exerts pressure in all directions. Fluid pressure is exerted on every surface that is in contact with the fluid, whether it is a submerged object (the six arrows at the left show fluid pressure pushing against the sides of a square object) or a wall of the container (this is shown by fourteen arrows at the right). Notice that the fluid pressure is exerted on each solid surface at a 90° angle.



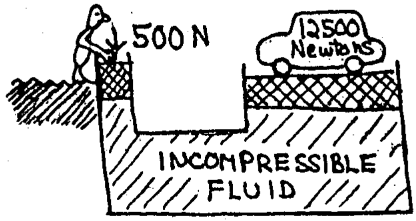
Problems 6-# to 6-# show how these principles are used to solve problems.

Gauge pressure is defined as $P_{gauge} \equiv P_{fluid} - P_{atmosphere}$. P_{gauge} is the "excess pressure" above atmospheric pressure. If a car-tire gauge, which measures P_{gauge}, says the pressure of a tire is 32.0 lbs/in^2, and atmospheric pressure is 14.7 lbs/in^2, the gas pressure inside the tire is $(32.0 + 14.7)$ lbs/in^2 = 46.7 lbs/in^2.

Pascal's Principle and Hydraulics

The 17th century philosopher-scientist Blaise Pascal discovered that *a change in pressure at any point in a confined fluid is transmitted undiminished to all points in the fluid and acts in all directions.* For example, if a change in weather causes air pressure in the above picture to increase by 1000 Pa, the pressure at all •-points will increase by 1000 Pa (compared with what it was at the original air pressure), and the pressure against each side of the square object increases by 1000 Pa.

A *hydraulic lift* is a common practical use of Pascal's Principle. In the picture below, a force of 500 Newtons (= 112 pounds) is exerted downward at the left. The right-side piston has 25 times the surface area of the left-side piston, both pistons are at the same height, and there are no fluid leaks. Do you see why Pascal's Principle lets us say that $P_{left} = P_{right}$? By substituting $P = F/A$ and the given information, we calculate that the 500 N force can support a car that weighs 12500 N (= 2810 pounds). A force of 501 Newtons would push the car upward.



Because both pistons are at the same height,

$$P_{left} = P_{right}$$

$$\frac{F_{left}}{A_{left}} = \frac{F_{right}}{A_{right}}$$

$$\frac{500\text{ N}}{A_{left}} = \frac{F_{right}}{25\ A_{left}}$$

$$12500\text{ N} = F_{right}$$

PROBLEM 6-C: A 500 N force is multiplied by 25 so it can support a 12500 N car. Have we "gotten something for nothing"? (Hint: If you push your piston downward 1.00 m, how much work have you done? How far does the car move, and what is its potential energy change?)

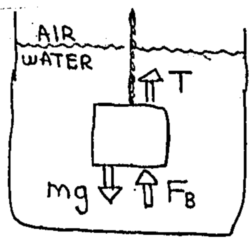
SOLUTION: Your work is $W = F\,\Delta y = (500)(1.00) = 500$ J. The volume changes at the left & right sides are equal, and Volume = (piston Area)(Δy moved). Since the right-side piston has 25 times as much area, it only moves 1/25 as far: $\Delta y_{car} = (1.00\text{ m})(1/25) = .04$ m. The car has $\Delta PE = (mg)\Delta h = (12500)(.04) = 500$ J. The work you do equals the work done on the car: $(500)(1.00) = (12500)(.04)$. Like the pulley and levers discussed in Problems 3-9 and 5-#, this hydraulic lift gives you a benefit (F is increased) but you must tolerate a disadvantage (Δx is decreased).

Archimedes' Principle and Buoyant Force

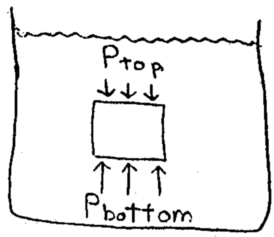
In the first picture below, a cube of aluminum that is .50 meter on each side is submerged in water and supported by a rope. Three forces act on the block: the rope tension **T**, the block's weight **mg**, and a *buoyant force* $\mathbf{F_B}$. (An alternative to "T": in some problems an object is supported with an upward normal force "N".)

The second picture shows the reason for $\mathbf{F_B}$. The bottom and top of the cube have the same surface area "A". Fluid pressure that pushes on the bottom of the block produces an upward force of $P_{bottom}A$, and fluid pressure pushing on the top of the block produces a downward force of $P_{top}A$. P_{bottom} is larger than P_{top}, so there is a net upward force that is called the buoyant force.

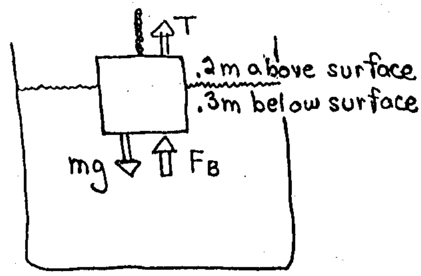
The third picture shows the block when it is partly submerged. If "X" represents the fraction of the block that is submerged, a totally submerged block has X = 1.00. Because the partly submerged block has .3 m of its total .5 m height under water, it has X = .3 m / .5 m = .60. (**Be careful, because the "visual cues" in the picture & fraction-format are reversed: .2 m of the block-height is on top of the water, but .3 m goes on top of the X-fraction.**)



TOTAL SUBMERSION, X = 1.00



P_{top} is smaller than P_{bottom}, so there is a net upward "buoyant" force.



PARTIAL SUBMERSION, X = .60

The block's volume is $(.5\text{ m})^3 = .125\text{ m}^3$. Imagine that a tub of water is full to the rim, and the block is then lowered into the water. Two objects (block & water) cannot occupy the same location at the same time, so when the block is totally submerged it has *displaced* $.125\text{ m}^3$ of water. The displaced fluid (that has been "pushed out of the way" to make room for the block) spills over the top of the tub.

If you study the pictures above and think about what each equation term means, you'll see that $V_{\text{displaced-fluid}} = V_{\text{submerged-part-of-object}} = X\, V_{\text{object}}$.

It can be shown (see Problem 6-#) that *the buoyant force acting on an object is equal to the weight of fluid displaced by the object.* This is *Archimedes' principle.*

To solve buoyancy problems, you'll need to use w = mg (from Section 3.2) and m = ρ V (from Section 6.2), where w, m, ρ and V represent weight, mass, density and volume. It is easy to understand the derivations below if you compare each line with the line above it and notice the substitution-changes (the "links" for w, m, and V). Develop a clear mental picture of what each term means, paying special attention to subscripts; they are important. Do you see why each subscript is needed?

weight force $= w_{\text{object}}$
$= (m_{\text{object}}\ g)$
$= (\rho_{\text{object}}\ V_{\text{object}})\, g$

buoyant force $= w_{\text{displ-fluid}}$
$= (m_{\text{displ-fl}}\ g)$
$= (\rho_{\text{fluid}}\ V_{\text{displ-fl}})\, g$
$= \rho_{\text{fluid}}\,(X\, V_{\text{object}})\, g$

Buoyant force equals the WEIGHT of DISPLACED FLUID. But a common way to get this weight is to find the VOLUME of DISPLACED FLUID by asking: what is the VOLUME of the SUBMERGED PART OF THE OBJECT? Do you see why the formula "buoyant force $= \rho_{\text{fluid}}\, X\, V_{\text{object}}\, g$" contains one subscript for the fluid and another for the object?

If you work a variety of problems in Section 6.91 or in your text, you'll use many of the 7 expressions above (3 for weight-force, 4 for buoyant-force). You'll also find that, as usual, there are three keys to expert problem solving: 1) understanding the connection between a physical situation and the mathematics used to describe it, 2) improving your fluency in translating information between the thinking modes [words, pictures, equations] that are described in Chapter 1A, and 3) combining imagination, decision-making and perseverence [if you try one expression for weight force or buoyant force and reach an algebraic dead end, try another expression].

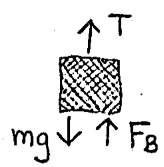
PROBLEM 6-D

Find the block's apparent weight (the rope tension) in the third picture above if the aluminum cube, which is 50 cm on each edge, remains motionless.

Water density is 1.00 g/cm^3, and the specific gravity of aluminum is 2.70.

SOLUTION 6-D

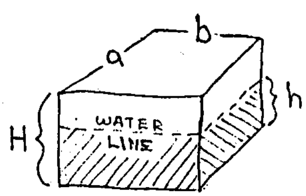
As in Chapter 3, draw a force diagram for $F=ma$, and use formulas from above for mg and F_B. Use only SI units. $V_{object} = (.50\,m)^3 = .125\,m^3$. To convert density from g/cm^3 units to SI units of kg/m^3, multiply by 1000: water density is 1.00×10^3 kg/m^3. Aluminum density is 2.70 times that of water, so it is 2700 kg/m^3. If the cube "remains motionless" it has $a = 0$. In the third picture, .3 m of the cube is submerged, so $X = .3m/.5m = .6$, and $V_{subm\text{-}fl} = .6\, V_{object}$.

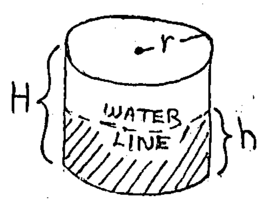


$$\begin{aligned} F &= ma \\ +T - mg + F_B &= m(0) \\ T &= +mg - F_B \\ T &= \rho_{Al}\, V_{Al}\, g - \rho_{water}\, X\, V_{Al}\, g \\ T &= (2700)(.125)(9.80) - (1000)(.6)(.125)(9.80) \end{aligned}$$

The following geometry tools will be useful for some buoyancy problems.

As shown below, the volume of a rectangular solid or right-cylinder is $V = AH$, where A is the top-area and H is the height. And the fraction of the object that is submerged is $X = h/H$, where h is the height of the submerged part of the object.





$$\begin{aligned} V_{subm} &= X\, V_{object} \\ &= X\, A\, H \\ &= (h/H)(ab)\, H \\ &= h\,a\,b \\ &= \text{shaded volume} \end{aligned}$$

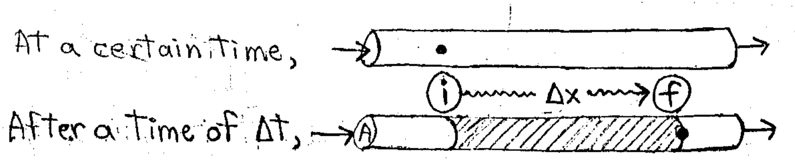
$$\begin{aligned} V_{subm} &= X\, V_{object} \\ &= X\, A\, H \\ &= (h/H)(\pi r^2)\, H \\ &= h\,\pi r^2 \\ &= \text{shaded volume} \end{aligned}$$

6.5 Fluids in Motion: Flow Rate and Bernoulli's Equation, Fluid Resistance and Viscosity

The pictures below show water flowing at a constant rate through a cylindrical pipe.

(I'm not sure why the computer did this,
but I didn't discover it until I got home
and the laserprinter isn't available now,
so I'll leave it as-is.)

During a time interval Δt a segment of water (marked •) has moved rightward a distance of Δx, and all water in the shaded cylinder has moved past the i-point.



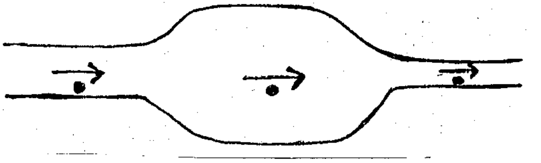
Fluid moves through the pipe at a *flow rate* "Q" that is defined as you would expect:

$$\text{FLOW RATE} \equiv Q \equiv \frac{\text{volume of fluid that moves}}{\Delta t} = \frac{V}{\Delta t} = \frac{A\,\Delta x}{\Delta t} = \frac{A\,v\,\Delta t}{\Delta t} = A\,v$$

Each Q-formula must have the same units: $V/\Delta t$ has units of $(m^3)/(s) = m^3/s$.
$A\,v$ has units of $(m^2)(m/s) = m^3/s$.

Be careful with V (volume) and v (velocity), especially when you write them by hand.

The pipe below varies in diameter. If $.4\ m^3/s$ of water flows steadily past the first •-point, do you see why $.4\ m^3/s$ will also flow steadily past the other •-points?



$$.4\ m^3/s = .4\ m^3/s = .4\ m^3/s$$
$$Q_1 = Q_2 = Q_3$$
$$A_1\ v_1 = A_2\ v_2 = A_3\ v_3$$

If the pipe is cylindrical at each •-point,

$$\pi r_1^2\ v_1 = \pi r_2^2\ v_2 = \pi r_3^2\ v_3$$

Which •-point has the largest fluid velocity? Which has the largest fluid pressure?

The answer can be found by using "ratio logic" with *Bernoulli's equation:*

$$P_1 + \rho g h_1 + \tfrac{1}{2}\rho v_1^2 = P_2 + \rho g h_2 + \tfrac{1}{2}\rho v_2^2 = \text{a constant}$$

where P_1, h_1 and v_1 are the fluid pressure, height and fluid velocity at Point #1.

RATIO LOGIC: If "A + B = a constant", when A increases, B decreases. Bernoulli's equation states that "$P + \rho gh + \frac{1}{2}\rho v^2$" remains constant. All three •-points have the same h. Fluid velocity is largest at the third •, so (because the sum is constant) it has the smallest P. Fluid pressure is lowest at the point where fluid velocity is largest! Surprising yet true.

Bernoulli's equation is valid if a fluid is *incompressible* (with constant density) and *nonviscous* (so no energy is lost due to friction) with a steady rate of flow that is *streamlined* (smooth, not turbulent).

Problems 6-# to 6-# show how the flow-rate equation and Bernoulli's equation are used for solving problems, and to show why baseballs curve and why airplanes fly.

==[the following section needs work]

Fluid Resistance and Viscosity

In previous chapters, especially in Section 2.5's description of "free flight", we ignored the effects of air resistance. Is this assumption justified? The answer to this question depends on four factors: speed, density, shape, and fluid viscosity.

Speed: If you travel in a 55 mile/hour car and hold your arm out the window, you feel a large force act on your arm. But at 5 miles/hour you can barely feel the force.

Density: If you drop a high-density bowling ball and low-density basketball out the window of a 55 mile/hour car, the low-density basketball is affected more.==awk

Shape: If you drop two pieces of paper, one flat (□) and the other crumpled into a tight ball (•), the ball falls more quickly because it has a smaller surface area.

Viscosity: If a steel ball drops into air, water & honey, it falls fastest through air and slowest through honey. The fluid property that causes this difference is called *viscosity;* air has low viscosity, honey has high viscosity.

The relative velocity of an object with respect to a fluid can be caused by object movement (like the car moving along a highway) or fluid movement (like a tail-wind or head-wind). Density and shape are properties of the object only, while viscosity is a property of the fluid only. ==[is this true?

The following conditions tend to make it valid to assume that the effects of "fluid drag" are negligible: low speed, a high-density object with small surface area, and a low-viscosity fluid.

The principles of fluid resistance can be used to analyze fluid movement in a pipe. ==[cut this? expand it?] refer to other kinds of formulas? do usual: learn letter meaning,... { too much emphasis on this? was it done earlier in chapter, or was it yesterday for 14-17 that I remember? }

6.90 Memory-Improving Flash Cards

6.1	Solids, liquids & gases differ in __ , __ , __ and __ . (See summary for details.)	ability to flow, maintenance of shape, filling of container, ease of volume change
6.1	__ are fluids.	liquids and gases
6.2	12 in & 1 ft __ , 2700 kg Al & 1 m^3 __ .	are equal, are "equivalent"
6.2	The density of an object is defined as __ . Pressure is defined as __ .	mass of object / volume of object "perpendicular force" / surface area
6.2	When an equation has 3 variables, __ .	if you know any 2, you can find the other
6.2	If 2.7 g/cm^3, __ kg/m^3, specific gravity = __ .	$2.7 \times 10^3 = 2700$, 2.7
6.3	Stress can be __ or __ , __ , __ .	tensile (pull), compressional (push) volume (inward pressure), shear ($\rightleftarrows$)
6.3	Moduli are called __ , __ , __ .	Young's (or elastic or stretch), bulk, shear
6.3	Equations have format of __ . Cause-effect is __ . Strain indicates the __ of __ .	stress = modulus x strain stress causes strain (or stress→strain) fractional change ; length, volume or shape
6.3	Stress ranges from zero to __ to __ onward. In the 3 ranges, an object's distortion is __ .	elastic limit , ultimate strength temporary, permanent, (fracture)
6.4	Static fluids: 4 pressure fundamentals are __ .	same height → same P, same P at boundary, $P_{bottom} = P_{top} + \rho gh$, same P all directions
6.4	Gauge pressure is __ , and is defined as __ .	"excess" pressure, $P_{fluid} - P_{atmosphere}$
6.4	If P at one point in static fluid ↑ by 500 Pa, __ . If left & right pistons are at same height, __ . ± : If piston on other side is larger, __ .	P at all points in fluid ↑ by 500 Pa. left & right pistons feel same P (same F/A) other-F ↑ , other-Δx ↓ , work stays same
6.4	In buoyancy problems, common forces are __ .	T (or N), mg, $F_{Buoyant}$
6.4	Buoyant force occurs because __ .	⇑ P on object-bottom > ⇓ P on object-top
6.4	X: submerged object __ , floating object __ . Four important formulas (with links) are __ . A formula with "mixed subscripts" is __ .	1.00, submerged height / total height $F_B = w_{displaced\text{-}fluid}$, $w = mg$, $m = \rho V$ $V_{displ\text{-}fluid} = V_{submerged\text{-}object} = X\, V_{object}$ buoyant force = $\rho_{fluid} \times V_{object}\, g$
6.5	Flow rate (__) ≡ __ = __ ; both have __ . In a pipe with steady flow, __ .	Q, V / t , A v , same units of m^3/s flow rate is same through all parts of pipe
6.5	__ is constant, so if __ the fluid-P decreases.	$P + \rho gh + \frac{1}{2}\rho v^2$, h ↑ or v ↑
6.5	Fluid drag ↓ if __ (both), __ (object), __ (fluid).	low v ; high ρ and low A ; low viscosity