Fluids, Thermodynamics, Waves, and Optics
Fluids

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Overview

- shear modulus
- static fluids
- pressure
- bulk modulus
- liquid pressure

Elastic Properties of Solids

We are considering 3 kinds of **elastic modulus** in terms of:

Stress

the external force acting on an object per unit cross-sectional area

$$F/A$$

Strain

the fractional amount of change in shape of the object or material

For each:

$$\text{elastic modulus} = \frac{\text{stress}}{\text{strain}}$$

[1] See Serway & Jewett, Chapter 12 section 4.

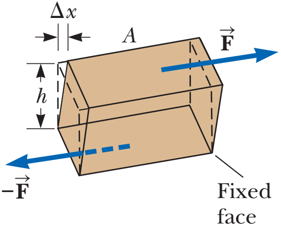
Shear Modulus: Shape Elasticity

Shear modulus, S, is a measure of the resistance to motion of parallel layers within a solid.

$$S = \frac{F/A}{\Delta x/h}$$

where

- F/A is the **shear stress**: F is a tangential force, parallel to the surface F os applied to.
- $\Delta x/h$ is the **shear strain**: Δx is the distance the face is displaced and h is the perpendicular distance between faces.



Fluids

Before looking at the third kind of elastic modulus, we will introduce fluids.

The previous two elastic moduli apply to solids.

The **bulk modulus** is relevant for both solids and fluids.

Fluids

The term **fluid** encompasses both liquids and gases.

It is a collection of molecules that are only weakly influenced by intermolecular forces and thus can flow over each other.

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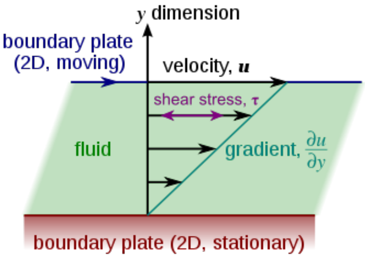
Formally,

Fluids

deform continuously under shearing stress; have a shear modulus of zero.



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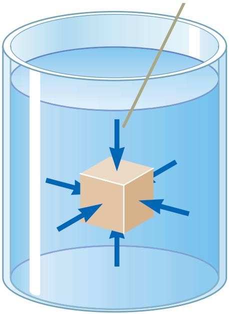
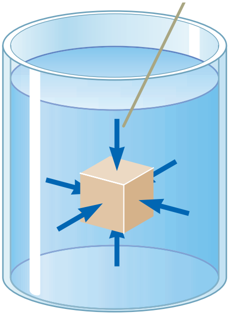
Fluid Statics

We first consider fluid statics: fluids at rest in a container.



Fluids will exert *pressure* on objects submerged in them and also on the walls of the container.

Pressure



Pressure

is the normal force per unit area on a surface:

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

Pressure

It is possible that the pressure on a surface varies over the surface. Then we will need to extend our definition:

$$\delta F = P\,\delta A$$

δF is the force on a tiny area δA.

As $\delta A \to 0$, the pressure can be a continuous function of the position on the surface.

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Units: the Pascal (after Blaise Pascal), symbol Pa
$1\ \text{Pa} = 1\ \text{N/m}^2$

Pressure

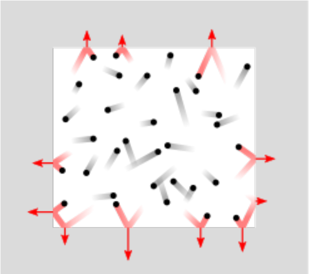
Pressure is a scalar quantity.

We relate it to force, a vector, by:

$$\delta\mathbf{F} = P\,\delta A\,\hat{\mathbf{n}}$$

where $\hat{\mathbf{n}}$ is a unit vector perpendicular to the small area δA.

In a gas or liquid, its underlying cause is molecular collisions:



[1]Diagram by Brant Carlson, on Wikipedia.

Question

Quick Quiz 14.1[1] Suppose you are standing directly behind someone who steps back and accidentally stomps on your foot with the heel of one shoe. Would you be better off if that person were

A a large, male professional basketball player wearing sneakers or

B a petite woman wearing spike-heeled shoes?

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Ambient Atmospheric Pressure

The air around us exerts force on us, the walls of the room, the floor, etc.

Is it a large pressure?

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Is it a large pressure?

In a sense, yes!

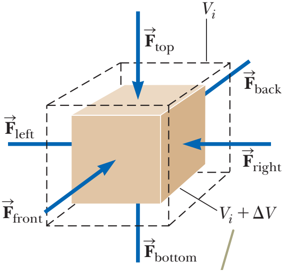
$P_0 = P_{\mathrm{atm}} = 1.013 \times 10^5$ Pa

Bulk Modulus: Volume Elasticity

Bulk modulus, B, is a measure of the resistance to compression of a material.

$$B = -\frac{\Delta P}{\Delta V / V_i}$$

The negative sign ensures B will be a positive number.



where

- $\Delta F/A$ is the **volume stress** or pressure change.
- $\Delta V/V_i$ is the **volume strain**: ΔV is the change from the initial volume V_i.

The reciprocal of the bulk modulus, $1/B$, is the **compressibility** of the material.

Pressure in a Liquid in a Gravitational Field

In a uniform gravitational field, liquid pressure depends on depth.

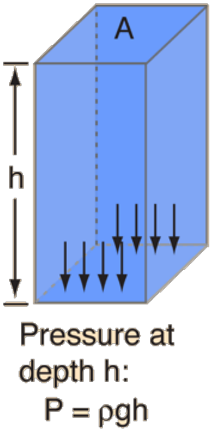
$$P_{\text{liq}} = \rho g h$$

where $\rho = m/V$ is the mass density of the liquid and h is the depth.

It does not depend on the total amount of water involved, just the depth of water.

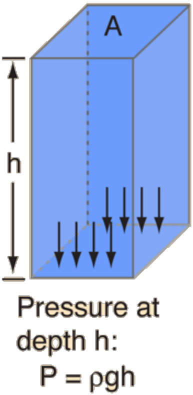
Liquid Pressure

A slice of liquid of cross section A at a depth h must support all the water in a column directly above it.



The force exerted downward by the column of water is $F = mg = \rho V g$.

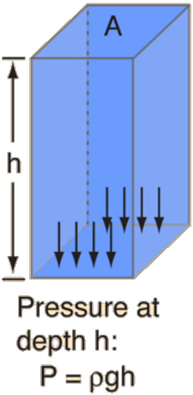
Liquid Pressure



$$F = mg = \rho V g = \rho A h g$$

[1]Figure from HyperPhysics.

Liquid Pressure



$F = mg = \rho Vg = \rho Ahg$

Pressure, $P_{\text{liq}} = \frac{F}{A} = \frac{\rho Ahg}{A} = \rho gh.$

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Total Pressure

The liquid pressure only expresses the pressure due to the weight of the fluid above.

However, this is not the total pressure in most circumstances, *eg.* diving on earth.

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The total pressure or **absolute pressure** is the sum of the pressure due to the liquid *and* the pressure due to the atmosphere.

$$P_{\text{total}} = P_0 + \rho g h$$

where $P_0 = P_{\text{atm}} = 1.013 \times 10^5$ Pa.

Summary

- static fluids
- pressure
- Pascal's law

Test Tuesday, April 17, in class.

Collected Homework due Monday, April 16.

(Uncollected) Homework

- Ch 12, onward from page 382, Obj Ques: 9; Probs: 27, 29.
- Ch 14, onward from page 435, OQs: 1; CQs: 1, 3, 7; Probs: 1, 3, 7, 9, 11, 18