Purdue University Department of Physics

Physics 22000

General Physics

Lecture 23 – Fluids in Motion

Fall 2016 Semester

Prof. Matthew Jones

SUPPLEMENTAL INSTRUCTION

Free Study Sessions!

Rachel Hoagburg

Come to SI for more help in PHYS 220

Tuesday and Thursday	7:30-8:30PM Shreve C113

Office Hour

Tuesday 1:30-2:30 4th floor of Krach

For other SI-linked courses and schedules, visit purdue.edu/si or purdue.edu/boilerguide

Static Fluids

- Pascal's First Law:
  - Changes in pressure are "instantaneously" propagated to all points in a fluid
  - In practice, changes in pressure propagate at the speed of sound in the fluid, but since this is usually very fast, we will ignore it.
- Pascal's Second Law:
  - Pressure varies with the depth in a fluid:

$$P_1 = P_2 + \rho_{fluid}(y_2 - y_1)g$$

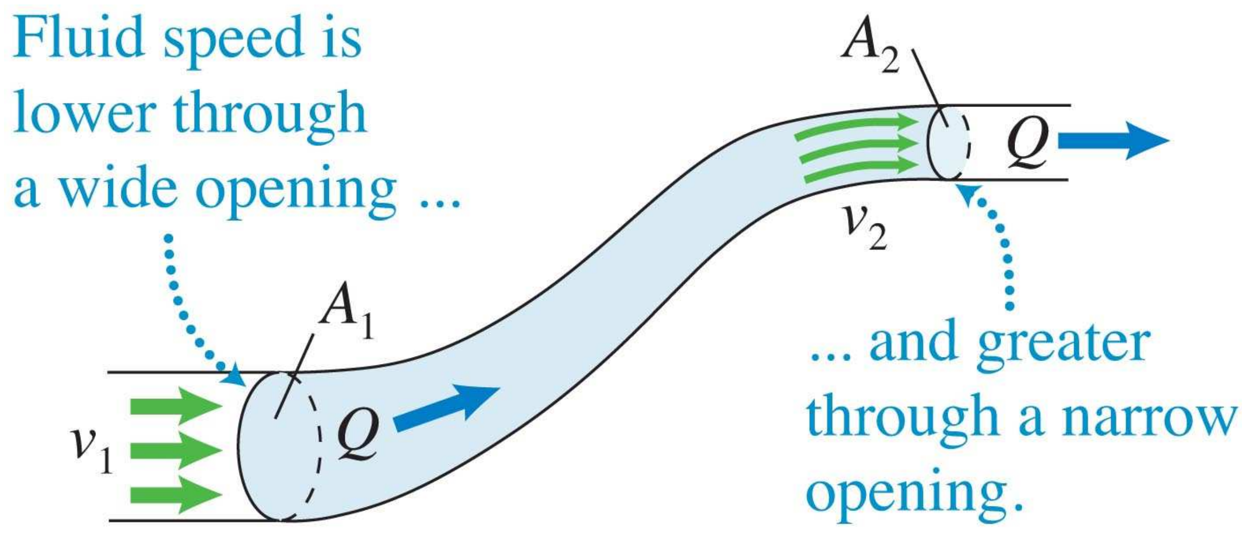
Static Fluids

- Archimedes' Principle:
  - The buoyant force is equal to the weight of the displaced fluid

$$F_{F\ on\ O} = \rho_{fluid} V_{fluid} g$$

Moving Fluids

- Conservation of mass:
  - The volume of fluid entering a pipe in time interval Δt must equal the volume of fluid leaving the pipe in the same time interval



$$Q = v_1 A_1 = v_2 A_2$$

Bernoulli's Principle

- What causes the fluid to speed up?
  - The mass accelerates due to a net force
  - In the fluid, this is the result of a difference in pressure
  - The pressure must be lower in the region where the fluid moves faster

$$P_1 - P_2 = \frac{1}{2}\rho(v_2^2 - v_1^2) + \rho g(y_2 - y_1)$$

or…

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$$

Viscous Fluid Flow

- Previously, we assumed that fluids flow without friction.
  - We assumed no interaction either between the fluid and the walls of the pipes it flows in, or between the layers of the fluid.
- This assumption is not reasonable in many processes.
- When we cannot neglect this friction inside the fluid, we call the fluid "viscous."

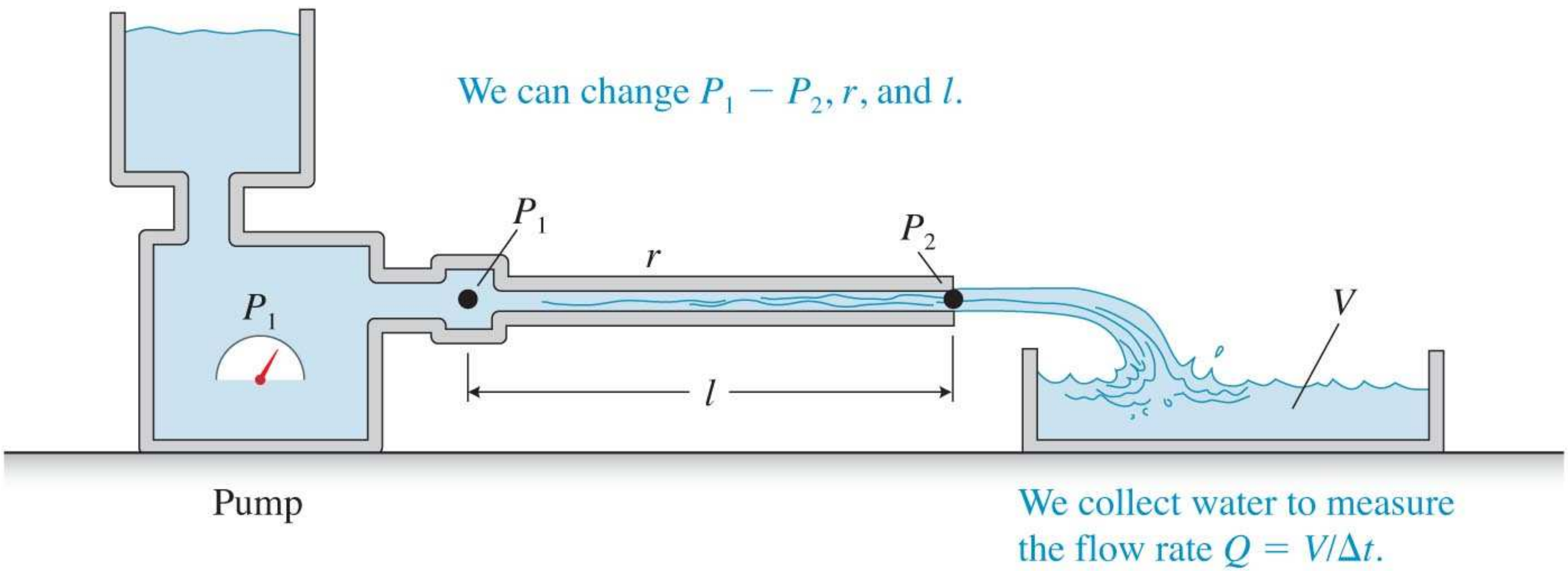
Fluid Flow Rate

Factors that affect fluid flow rate include

- Pressure difference: How hard the fluid is pushed forward.
- Radius *r* of the tube: It is more difficult to push fluid through a tube of tiny radius.
- Length of the tube: A long tube offers more resistance to flow.
- Fluid type: Some property of a fluid that characterizes its "thickness" or "stickiness" should affect the flow.

Fluid Flow Rate

- A pump that produces an adjustable pressure, thereby causing fluid to flow through tubes of different radii and lengths, allows us to test parameters that affect fluid flow rate.



Viscocity

- If we use the same pressure difference to push different fluids through the same tube, we find that the fluids have different flow rates.
  - Water flows faster than oil; oil flows faster than molasses.
- The quantity that measures this effect on flow rate is called the viscosity of the fluid.
  - Flow rate is proportional to viscosity.

Poiseuille's Law

Poiseuille's law The forward-backward pressure difference $P_1 - P_2$ needed to cause a fluid of viscosity η to flow at a rate Q through a vessel of radius r and length l is

$$P_1 - P_2 = \left(\frac{8}{\pi}\right)\frac{\eta l}{r^4}Q \qquad (11.8)$$

- The pressure difference is related to the resistance of the fluid to the flow and to the net push on the fluid related to the flow rate *Q*.

Viscosities of some Liquids and Gases

Table 11.4 Viscosities of some liquids and gases.

Substance	**Viscosity η ($N \cdot s/m^2$)**
Air (30 °C)	1.9×10^{-5}
Water vapor (30 °C)	1.25×10^{-5}
Water (0 °C)	1.8×10^{-3}
Water (20 °C)	1.0×10^{-3}
Water (40 °C)	0.66×10^{-3}
Water (80 °C)	0.36×10^{-3}
Blood, whole (37 °C)	4×10^{-3}
Oil, SAE No. 10	0.20

Example

- Because of plaque buildup, the radius of an artery in a person's heart decreases by 40%. Determine the ratio of the present flow rate to the original flow rate if the pressure across the artery, the artery's length, and the viscosity of blood are unchanged.

Example

- Roofs can be blown from houses during tornadoes or hurricanes. How does that happen?
  - On a windy day, the air inside the house is not moving, whereas the air outside the house is moving very rapidly.
  - The air pressure inside the house is greater than the air pressure outside, creating a net pressure against the roof and windows that pushes outward.

Example

- During a storm, air moves at a speed of 45 m/s (100 mi/h) across the top of a 200-m^2 flat roof of a house. Estimate the net force exerted by the air pushing up on the inside of the roof and the air pushing down on the outside of the roof. Indicate any assumptions made in your estimate.

Example

- Blood flows through the unobstructed part of a blood vessel at a speed of 0.50 m/s. The blood then flows past a plaque that constricts the cross-sectional area to one-ninth the normal value. The surface area of the plaque parallel to the direction of blood flow is about 0.60 cm^2 = 6.0 x 10^{-5} m^2. Estimate the net force that the fluid exerts on the plaque.

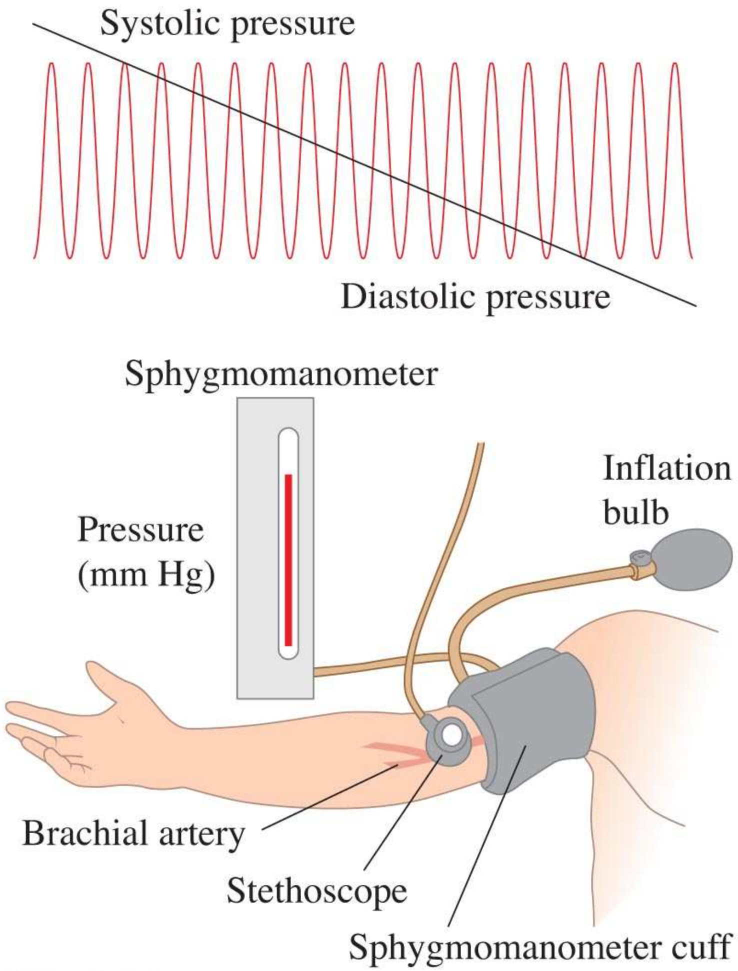
Limitations of Poiseuille's Law: Renolds Number

Limitations of Poiseuille's Law: Reynolds Number Poiseuille's law describes the flow of a fluid accurately only when the flow is streamline, or laminar. Experiments indicate that to determine when the flow is laminar or turbulent, one needs to determine what is called the Reynolds number R_e:

$$R_e = \frac{2\bar{v}r\rho}{\eta} \tag{11.9}$$

where $\bar{v}$ is the average speed of the fluid, ρ is its density, η is the viscosity, and r is the radius of the vessel that carries the fluid. Experiments show that if the Reynolds number is less than 2000, the fluid flow is laminar; if it is more than 3000, the flow is turbulent; and between 2000 and 3000 the flow is unstable and can be either laminar or turbulent.

Measuring Blood Pressure



- The air is slowly released from the cuff, decreasing the pressure.
- When the pressure in the cuff is equal to the systolic pressure, blood starts to squeeze through the artery past the cuff.
- The flow is intermittent and turbulent and causes a sound heard with the stethoscope.
- When the pressure decreases to less than the diastolic pressure, the artery is continually open and blood flow is laminar and makes no sound.

Drag Force

- Now we focus on solid objects moving through a fluid.
  - Examples: a swimmer moving through water, a skydiver falling through the air, and a car traveling through air
- The fluid in these and in other cases exerts a resistive drag force on the object moving through the fluid.
  - So far we have been neglecting this force in our mechanics problems.

Laminar Drag Force and Stokes' Law

- If an object moves relatively slowly through a fluid, the water flows around the object in streamline laminar flow, with no turbulence. However, the fluid does exert a drag force on the object.
- The equation expressing this relationship is called Stokes's law:

$$F_{D\ F\ on\ O} = 6\pi\eta r v$$

Reynolds Number

- An equation can be used to decide whether the flow of a fluid past an object is laminar or turbulent:

$$R_e = \frac{vl\rho}{\eta}$$

- If the Reynolds number is more than 1 then the flow is turbulent and we cannot use Stokes' law.
- In the case of turbulent flow, we use this equation:

$$F_{D\ F\ on\ O} \approx \frac{1}{2} C_D \rho A v^2$$

- C_D is the "coefficient of drag" which depends on the details of the geometry of the object.

Example

- Estimate the terminal speed of a 60-kg skydiver falling through air of density 1.3 kg/m^3, assuming a drag coefficient $C_D = 0.6$.

Summary

- Static fluids:
  - Pascal's first and second laws
  - Archimedes' principle
- Moving fluids:
  - Conservation of mass
  - Bernoulli's law
  - Laminar vs turbulent flow
  - Poiseuille's law
  - Reynold's number
  - Drag force for laminar and turbulent flow