PURDUE UNIVERSITY DEPARTMENT OF PHYSICS

Physics 22000

General Physics

Lecture 21 – Fluids in Motion

Fall 2016 Semester

Prof. Matthew Jones

Second Midterm Exam

Wednesday, November 16th, 8:00-9:30 pm

Location: Elliot Hall of Music - ELLT 116.

Covering material in chapters 6-10

Multiple choice, probably about 25 questions, 15 will be conceptual, 10 will require simple computations.

A formula sheet will be provided.

You can bring one page of your own notes.

I put a couple exams from previous years on the web page… solutions will be posted soon.

Topics on Midterm #2

- Work and Energy
  - Collisions: elastic and inelastic
- Extended bodies at rest
  - Static equilibrium
- Rotational motion
  - Kinematics
  - Rotational inertia
  - Rotational momentum
- Gases
  - Atomic mass
  - Ideal gas law
- Static fluids
  - Pascal’s laws
  - Archimedes’ principle

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

Fluids in Motion

- So far we have only studied fluids at rest
  - Pascal's laws, Archimedes' principle
- What happens when a gas or liquid moves across a surface?
  - What is the pressure at different points near the surface?
  - How fast are different parts of the fluid moving?

Fluids moving across surfaces: Qualitative analysis

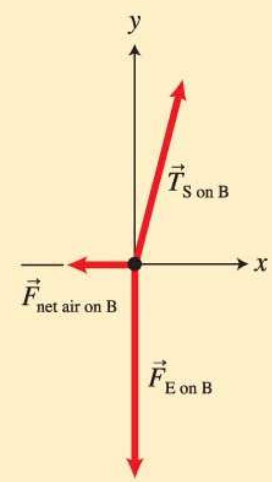
- How does air blowing over the top of a beach ball lift and support the ball?
  - We must compare the forces that stationary air exerts on a surface to the forces exerted on the surface by moving air.
  - We can deduce the direction of the net force due to air pressure exerted on different sides of the ball.

Observational Experiment

OBSERVATIONAL EXPERIMENT TABLE

11.1 Does fluid pressure against a surface depend on the motion of the fluid across the surface?

VIDEO 11.1

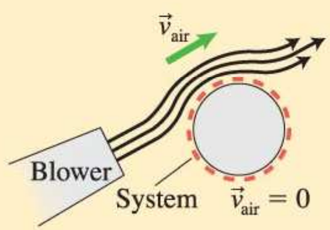
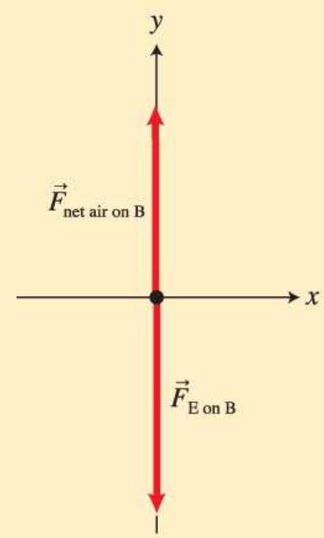
Observational experiment	Analysis
Experiment 1. We blow air through a straw between two lightbulbs hanging from strings. The bulbs move closer to each other. 	Choose the right bulb as the system. After it comes to equilibrium, the forces exerted on the bulb are balanced. The vertical component of the force exerted by the string balances the downward force exerted by Earth. The horizontal component of the force exerted toward the right by the string must balance the net force exerted by the air. Thus, the force exerted toward the left by the non-moving air on the right side of the bulb must be greater than the force exerted toward the right by the air moving on the left side of the bulb. The pressure of moving air must be lower than the pressure of nonmoving air. 

Observational experiment

OBSERVATIONAL EXPERIMENT TABLE

11.1 Does fluid pressure against a surface depend on the motion of the fluid across the surface? *(Continued)*

VIDEO 11.1

Observational experiment	Analysis
Experiment 3. We blow a stream of air across the top of a large air-filled balloon. The moving air allows it to float with no other support. 	Choose the floating balloon as the system. Earth exerts a downward gravitational force. To remain stationary, the net force caused by the air must point upward toward the moving-air side of the balloon. This can only happen if the air pressure pushing the balloon up is greater than the air pressure pushing the balloon down. Therefore, we can conclude that the air pressure on top of the balloon (the side of the moving air) is less than that on the bottom of the balloon (the side of the stationary air) 

Pattern

Based on the analysis of each experiment using the force diagrams, we can infer that moving air exerts a smaller force on the system and consequently has a smaller pressure then stationary air.

Fluids moving across surfaces: Qualitative analysis

- Stationary air exerted more pressure on the object than the moving air.
  - Explanation 1: Temperature. The pressure on one side of an object decreases because a moving fluid is warmer than a stationary fluid.
  - Explanation 2: Fluid speed. The pressure that a fluid exerts on a surface decreases as the speed with which the fluid moves across the surface increases.

Testing Experiments

TESTING EXPERIMENT TABLE

11.2 **Testing the two explanations for why moving fluid exerts a lower pressure on a surface than stationary fluid.**

VIDEO 11.2

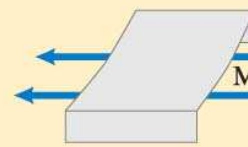
Testing experiment	Prediction	Outcome
Experiment 1. What happens to a piece of paper held at the corners when you blow hard across the *top* surface of the paper? 	***Prediction based on Explanation 1:*** The moving air originating inside your body is warmer than the external air below the paper. The warm air above the paper rises, reducing the pressure on the top surface. The paper will rise. ***Prediction based on Explanation 2:*** There is less pressure on the top surface where the air is moving compared to the pressure from the stationary air below the paper. The greater pressure from below will cause the paper to rise.	The paper rises when blowing air across the top. 

Testing Experiments

TESTING EXPERIMENT TABLE

11.2 **Testing the two explanations for why moving fluid exerts a lower pressure on a surface than stationary fluid.** ***(Continued)***

VIDEO 11.2

Testing experiment	Prediction	Outcome
Experiment 2. What happens if you vigorously blow air through a straw *under* a card folded in an inverted-U shape? 	***Prediction based on Explanation 1:*** The card should bend up because the warm air from your breath is less dense than surrounding air and tends to rise. ***Prediction based on Explanation 2:*** The air moving under the card exerts less pressure on the bottom surface than the stationary air above the card—the card should bend down.	The card bends down. 

Conclusion

- In Experiment 1, both explanations correctly predicted the outcome. Thus, neither explanation can be rejected based on this experiment.
- In Experiment 2, the outcome matches the prediction based on Explanation 2 and is opposite the prediction based on Explanation 1. We can reject Explanation 1 based on the outcome of this experiment.

Bernoulli's Principle

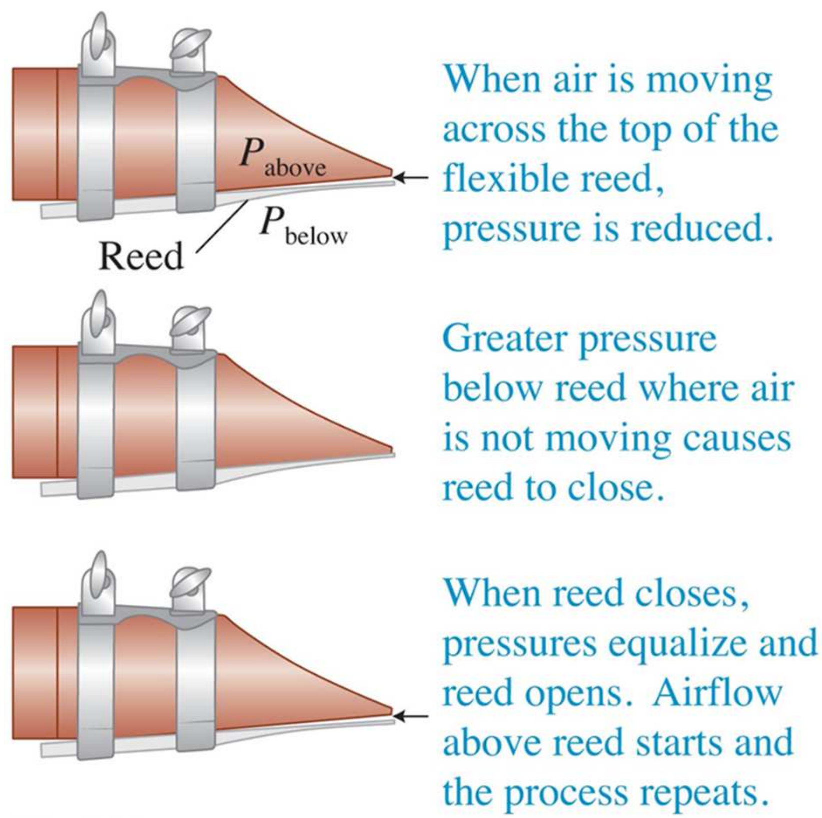
Bernoulli's principle The pressure that a fluid exerts on a surface *decreases* as the speed with which the fluid moves across the surface *increases*.

- Bernoulli's principle has many important applications and implications:
  - Airplane wings
  - Carburetors (an archaic fuel injection system)
  - Biological systems: fluid flow through blood vessels

Clarinet Reed

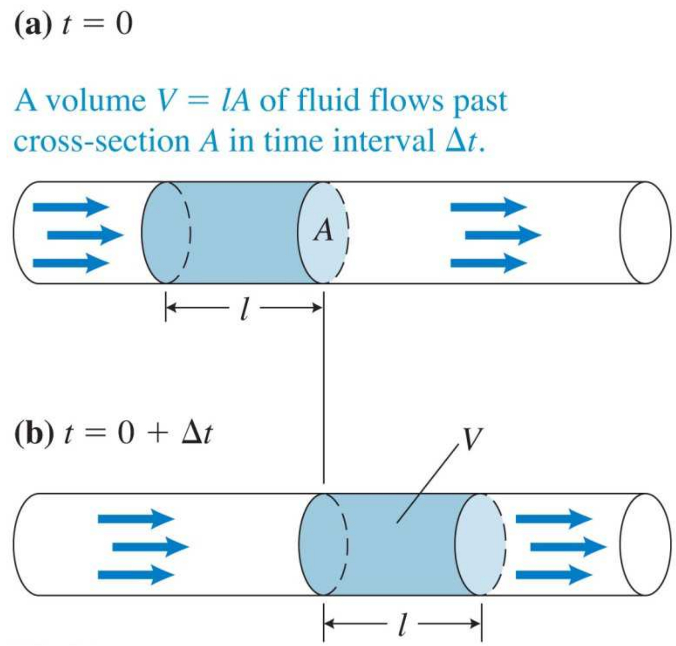
A musician blows air into a clarinet, moving air across the top of a reed.

- Air pressure across the top of the reed decreases relative to the pressure below the reed. In response, the flexible reed rises and closes the mouthpiece of the clarinet.
- Once it is closed, airflow stops, the pressure equalizes, and the reed opens.
- The rhythmic opening and closing of the reed initiates the sound heard from a clarinet.



Flow Rate and Fluid Speed

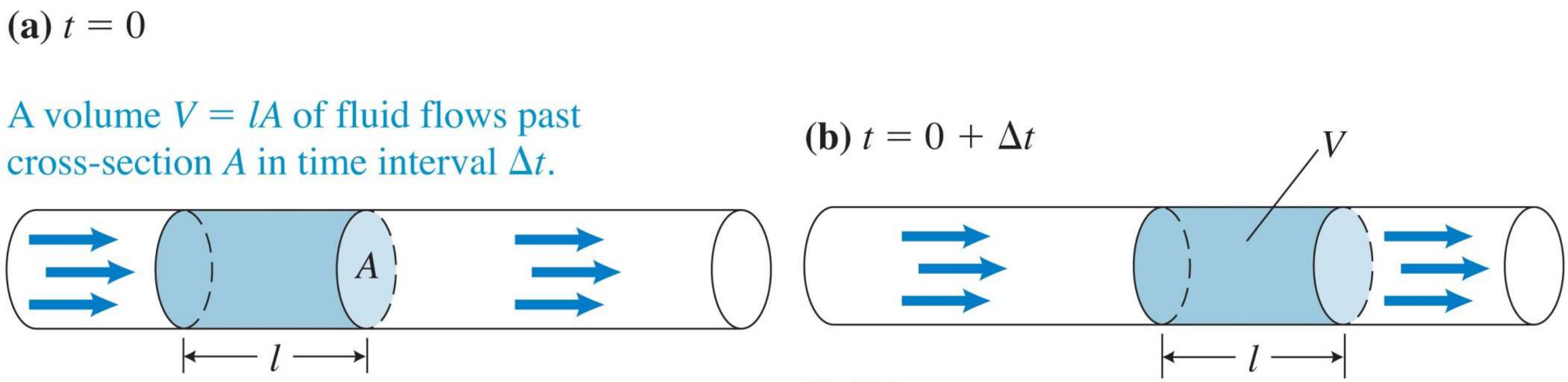
- Flow rate is defined as the volume *V* of fluid that moves through a cross section of a pipe divided by the time interval Δt during which it moved:



$$Q = \frac{V}{\Delta t}$$

- The SI unit of flow rate is m^3/s

Flow Rate and Speed of a Moving Fluid



- The darkened volume of fluid passes a cross section of area A along the pipe.
  - The back part of this fluid volume has, in effect, moved forward to this position.
  - Fluid flow rate: $Q = V/\Delta t = lA/\Delta t = (l/\Delta t)A = vA$

$$Q = \frac{V}{\Delta t} = vA$$

Tip...

TIP The symbols *V*, *t*, and *Q* are also used in other aspects of physics. For example, a lowercase *v* denotes speed, the capital letter *T* is used for temperature, and in future chapters we will use *Q* for two other unrelated quantities. Because these symbols are often used to indicate different quantities, it is important when working with equations to try to visualize their meaning with concrete images (for example, the volume of water flowing out of a faucet during 1 s).

Quantitative Example

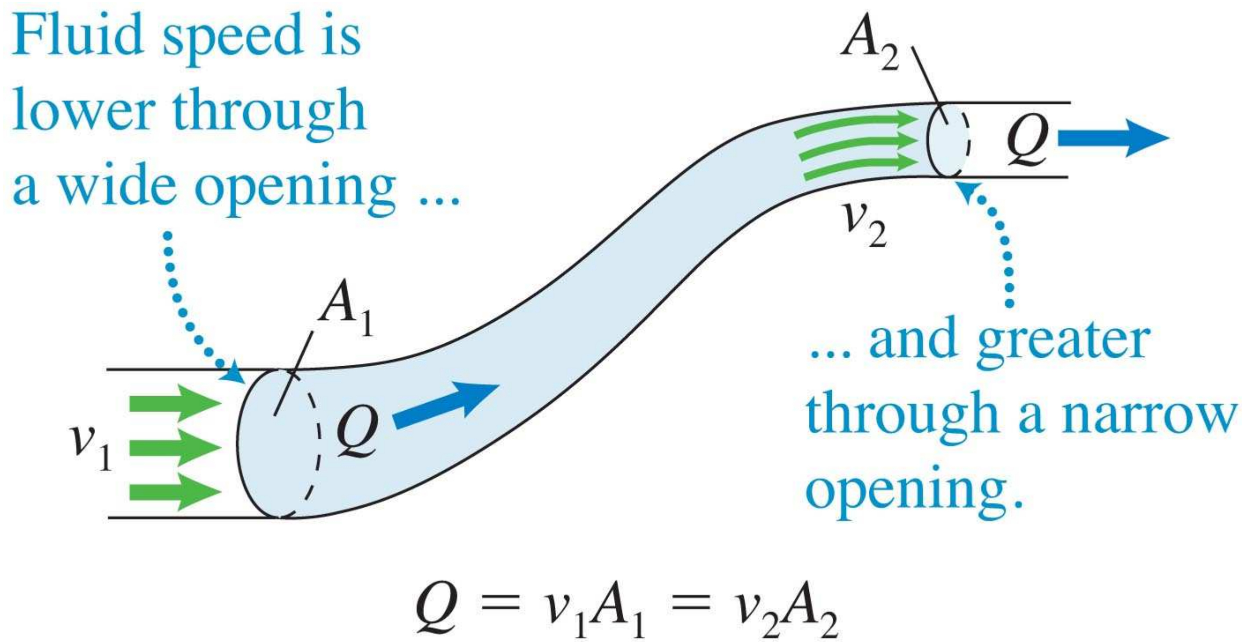
- The heart pumps blood at an average flow rate of 80 cm^3/s into the aorta, which has a diameter of 1.5 cm. Determine the average speed of the blood flow in the aorta.

$$Q = vA$$

$$v = \frac{Q}{A} = \frac{Q}{\pi r^2}$$

$$= \frac{80\ cm^3/s}{\pi(0.75\ cm)^2} = 45\ cm/s$$

Continuity Equation



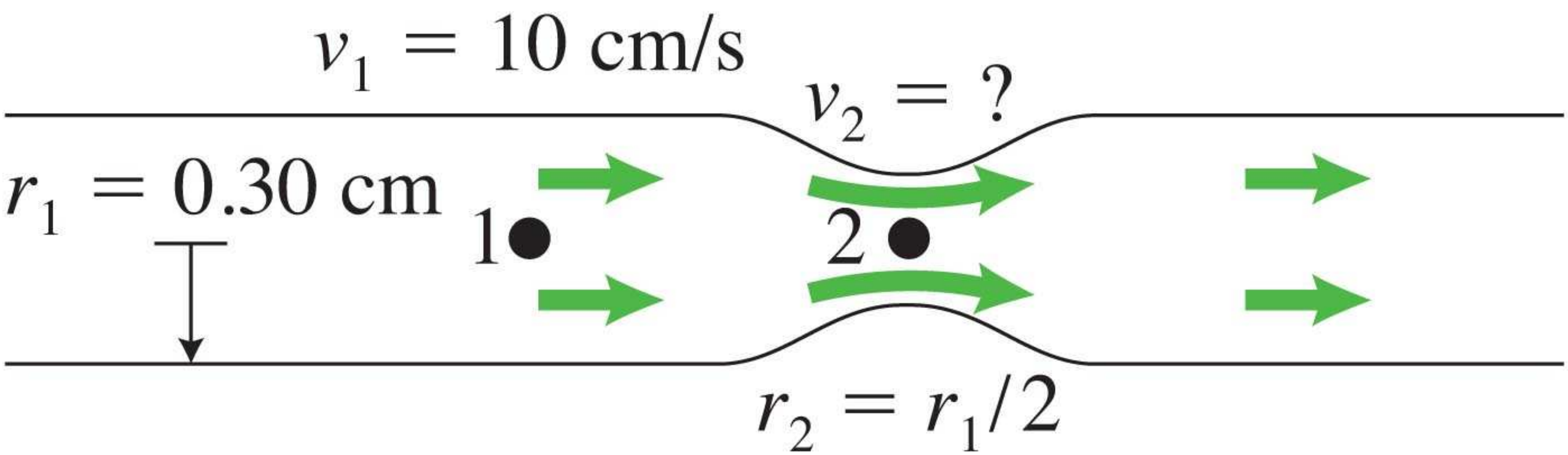
- The flow rate past cross section 1 will equal that past cross section 2.

$$Q_1 = v_1A_1 = v_2A_2 = Q_2$$

- v_1 is the average speed of the fluid passing the cross section A_1 and v_2 is the average speed of the fluid passing cross section A_2.

Quantitative Exercise

- Blood normally flows at an average speed of about 10 cm/s in a large artery with a radius of about 0.30 cm. Assume that the radius of a small section of the artery is reduced by half because of atherosclerosis, a thickening of the arterial walls. Determine the speed of the blood as it passes through the constriction.



Causes and Types of Fluid Flow

Fluid flow is caused by differences in pressure.

- When the pressure in one region of the fluid is lower than the pressure in another region, the fluid tends to flow from the higher-pressure region toward the lower-pressure region.
- For example, large masses of air in Earth's atmosphere move from regions of high pressure into regions of low pressure.

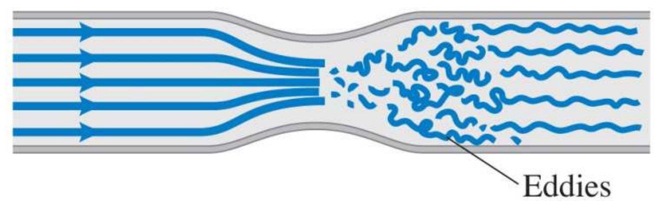
Streamline flow of water through a tube

Streamline Flow and Turbulent Flow

- Streamline flow: Every particle of fluid that passes a particular point follows the same path as particles that preceded it.
- Turbulent flow: Characterized by agitated, disorderly motion.

Streamline flow of water through a tube

Turbulent flow of water through a narrow part of a tube

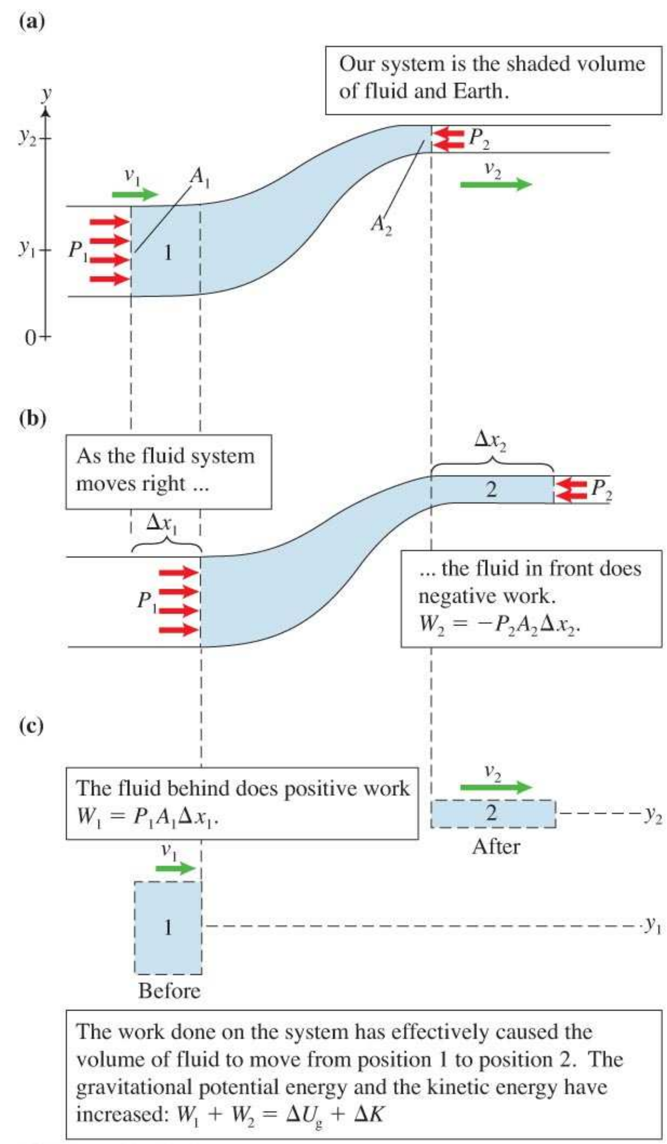


Bernoulli's Equation

- Bernoulli's equation is the quantitative version of Bernoulli's principle:

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

(It's just a statement about work and energy…)



Bernoulli's Equation

Bernoulli's equation relates the pressures, speeds, and elevations of two points along a single streamline in a fluid:

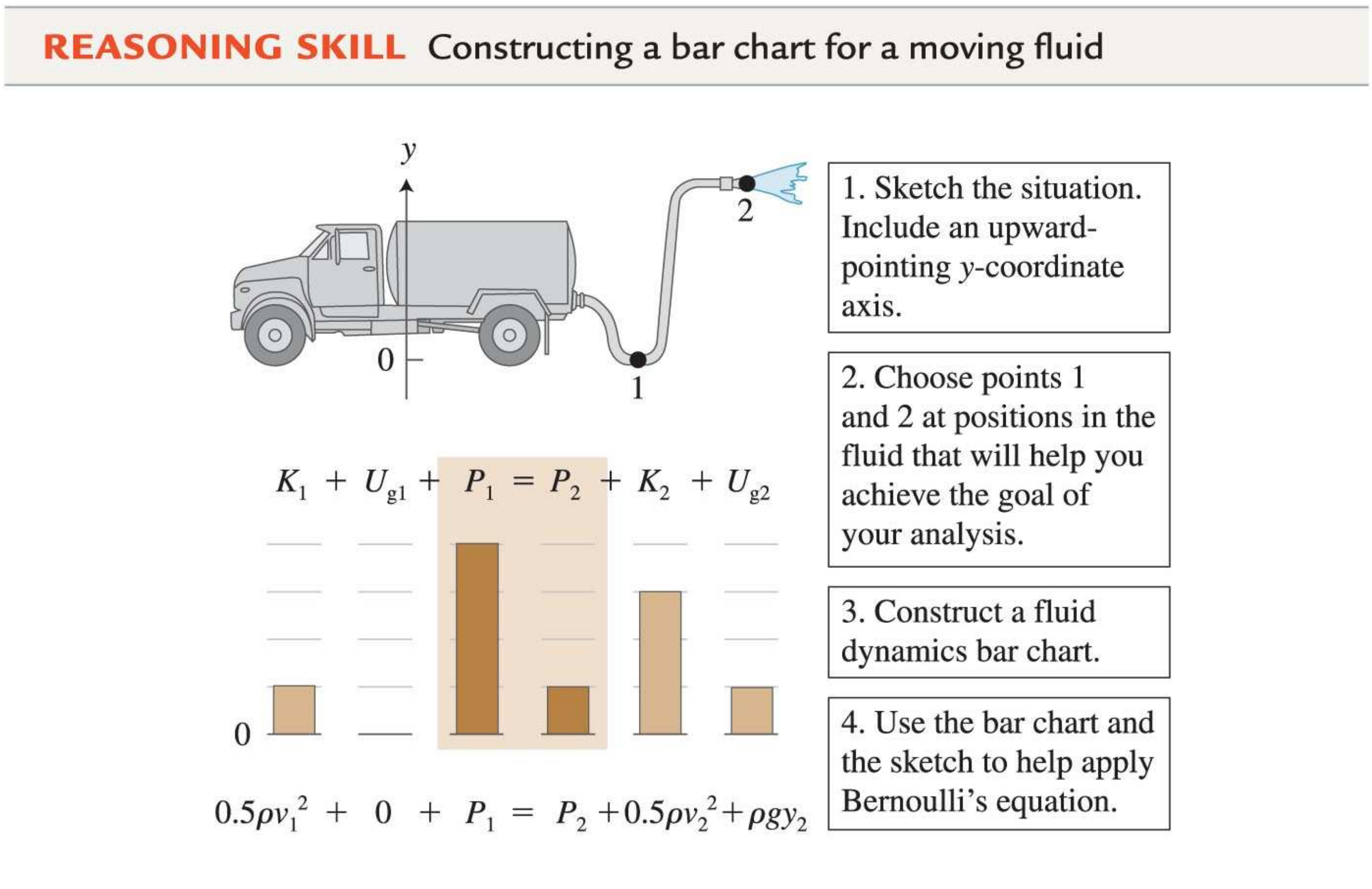
$$P_1 - P_2 = \frac{1}{2}\rho\left(v_2{}^2 - v_1{}^2\right) + \rho g\left(y_2 - y_1\right) \quad (11.5)$$

The equation can be rearranged into an alternate form:

$$\frac{1}{2}\rho v_1{}^2 + \rho g y_1 + P_1 = P_2 + \frac{1}{2}\rho v_2{}^2 + \rho g y_2 \quad (11.6)$$

The sum of the kinetic and gravitational potential energy densities and the pressure at position 1 equals the sum of the same three quantities at position 2.

Using Bernoulli Bar Charts to Understand Fluid Flow



Example

- What is the speed with which water flows from a hole punched in the side of an open plastic bottle? The hole is 10 cm below the water surface.