Lectures: Physics 3306

Provides an introduction to a wide variety of topics in classical (pre-quantum) physics as a bridge to prepare students for subsequent upper-level courses in physics. The topics covered include thermodynamics, fluid mechanics, mechanical waves, optics, radiation, electromagnetic phenomena, atoms, and laboratory techniques. Prerequisites: C- or better in PHYS 1106; and in PHYS 1304 or PHYS 1308.

Saptaparna Bhattacharya

February 6th, 2026

Based on Simon Dalley's lectures taught in Spring 2025

Labs

Lectures

Schedule

No class

Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
January	19	20	21 ✅	22	23 ✅	24	25
	26 ❄️🌨️❄❄❄	27	28 ❄️🌨️❄❄❄	29	30 ✅	31	1
February	2 ✅	3	4 ✅	5	6 ✅	7	8
	9	10	11 HWB due	12	13	14	15
	16	17	18	19	20	21	22
	23	24	25	26	27	28	1
March	2	3	4	5	6	7	8
	9	10	11	12	13	14	15
	16	17	18	19	20	21	22
	23	24	25	26	27	28	29
April	30	31	1	2	3	4	5

Labs

Lectures

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April	6	7	8	9	10	11	12
	13	14	15	16	17	18	19
	20	21	22	23	24	25	26
May	27	28	29	30	1	2	3
	4	5	6	7	8	9	10

Fluids in motion

Book: 14.6-14.7

Continuity

Equation of continuity

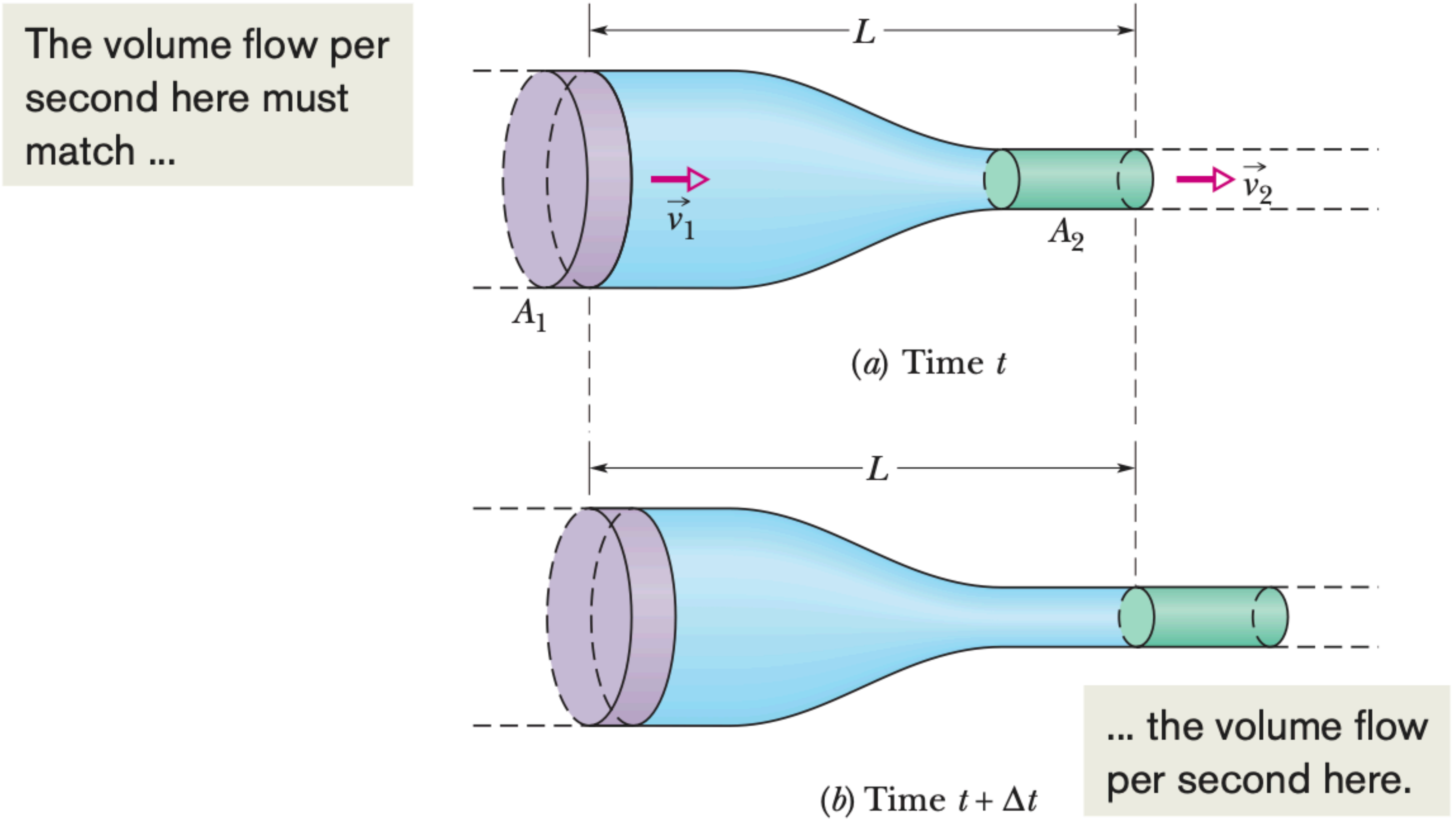


Figure 14-15 Fluid flows from left to right at a steady rate through a tube segment of length L. The fluid's speed is v_1 at the left side and v_2 at the right side. The tube's cross-sectional area is A_1 at the left side and A_2 at the right side. From time t in (a) to time $t + \Delta t$ in (b), the amount of fluid shown in purple enters at the left side and the equal amount of fluid shown in green emerges at the right side.

Equation of continuity

- The volume ΔV of a fluid that has passed through the dashed line at time interval Δt is:
  - $\Delta V = A\Delta x = Av\Delta t$
  - Applying to figure on previous slide
    - $\Delta V = A_1 v_1 \Delta t = A_2 v_2 \Delta t$
    - $A_1 v_1 = A_2 v_2$
    - This is the equation of continuity!

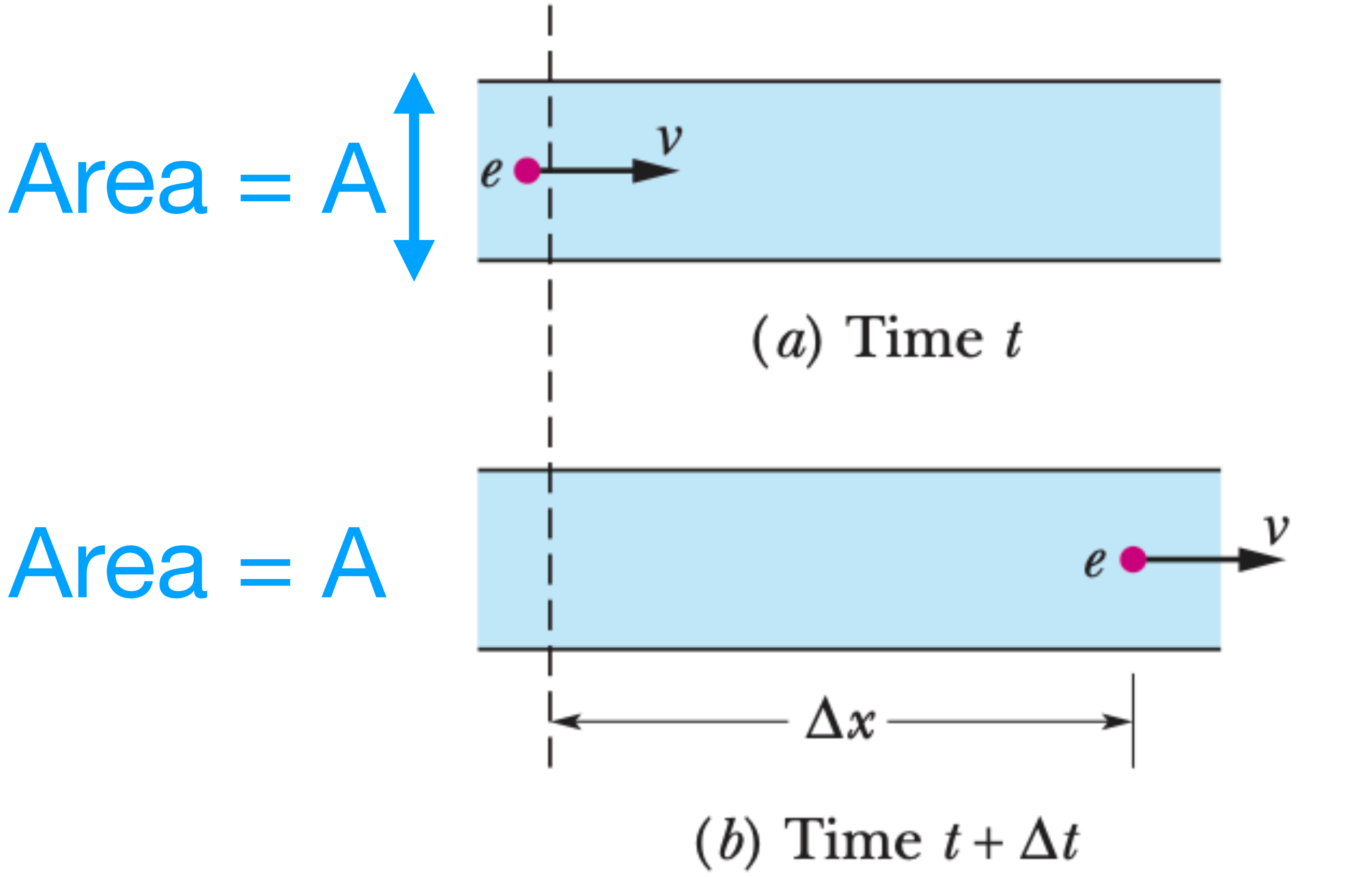
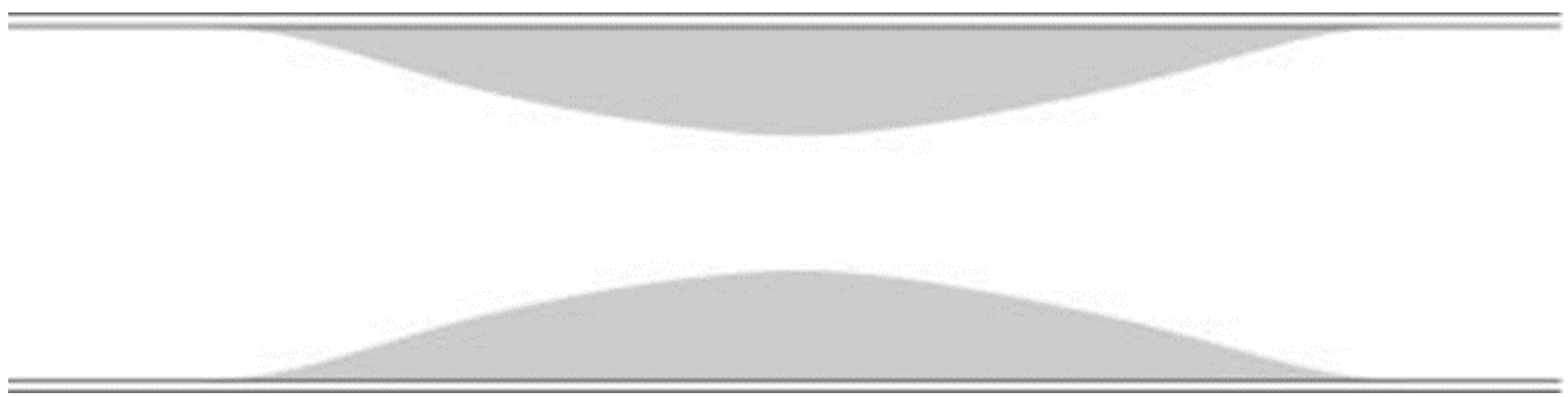


Figure 14-16 Fluid flows at a constant speed v through a tube. (a) At time t, fluid element e is about to pass the dashed line. (b) At time $t + \Delta t$, element e is a distance $\Delta x = v\,\Delta t$ from the dashed line.

Blood flows through a coronary artery that is partially blocked by deposits along the artery wall.
Through which part of the artery is the flow speed largest?

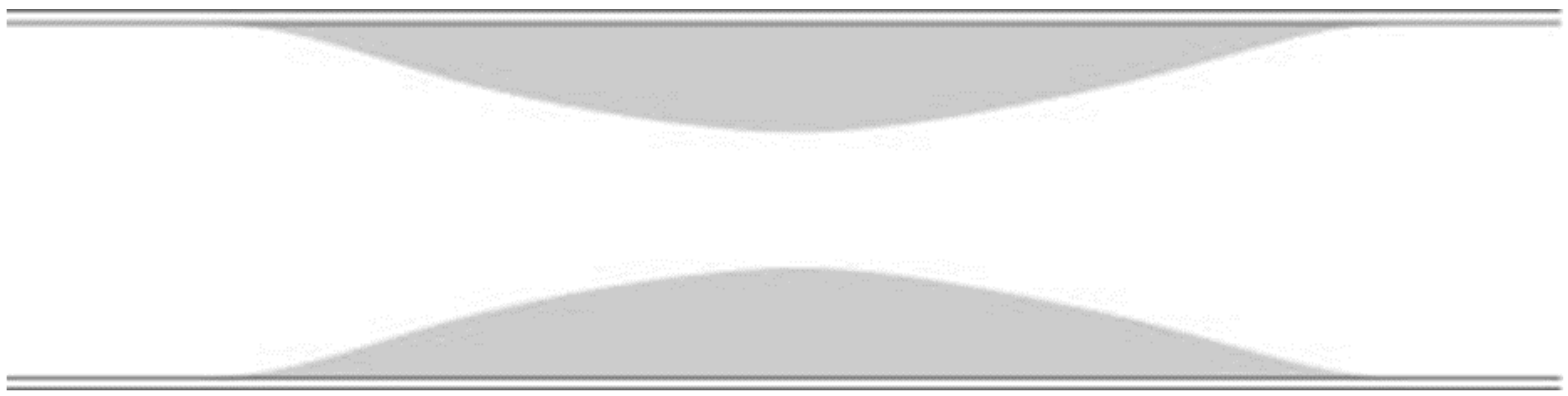


a) The narrow part.

b) The wide part.

c) The flow speed is the same in both parts.

Blood flows through a coronary artery that is partially blocked by deposits along the artery wall. Through which part of the artery is the flow speed largest?



a) The narrow part.

b) The wide part.

c) The flow speed is the same in both parts.

The correct answer is **a) The narrow part.**

This is a classic application of fluid dynamics that often feels counterintuitive, but it follows a very logical rule called the **Equation of Continuity**.

Why the Narrow Part is Faster

Think of a garden hose. If you put your thumb over the opening to make the exit **narrower**, the water sprays out much **faster**. The same principle applies to blood flowing through an artery.

1. Conservation of Mass

Since blood is an incompressible fluid, the amount of blood entering one end of the artery must equal the amount of blood leaving the other end in the same amount of time. We call this the **volume flow rate**.

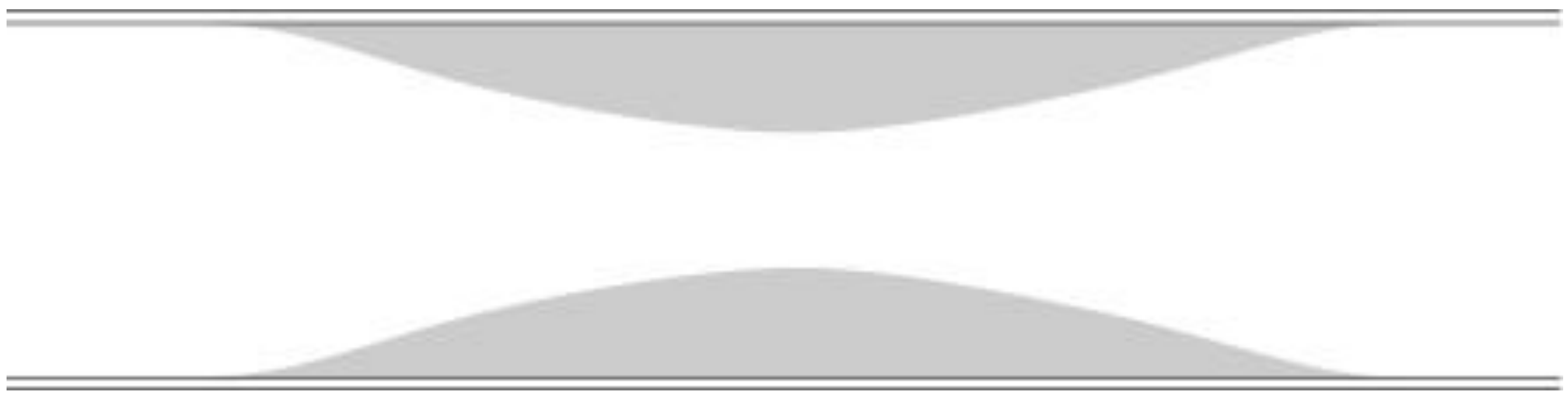
2. The Relationship: Area vs. Velocity

Because the total volume of fluid passing through any cross-section per second is constant, the math looks like this: $A_1v_1 = A_2v_2$

- **A** is the cross-sectional area of the artery.
- **v** is the velocity (speed) of the blood.

If the area (**A**) gets smaller in the blocked, narrow section, the velocity (**v**) must increase to "keep up" so that the same amount of blood can squeeze through in the same amount of time.

Blood flows through a coronary artery that is partially blocked by deposits along the artery wall. Through which part of the artery is the flux (volume of blood per unit time) largest?



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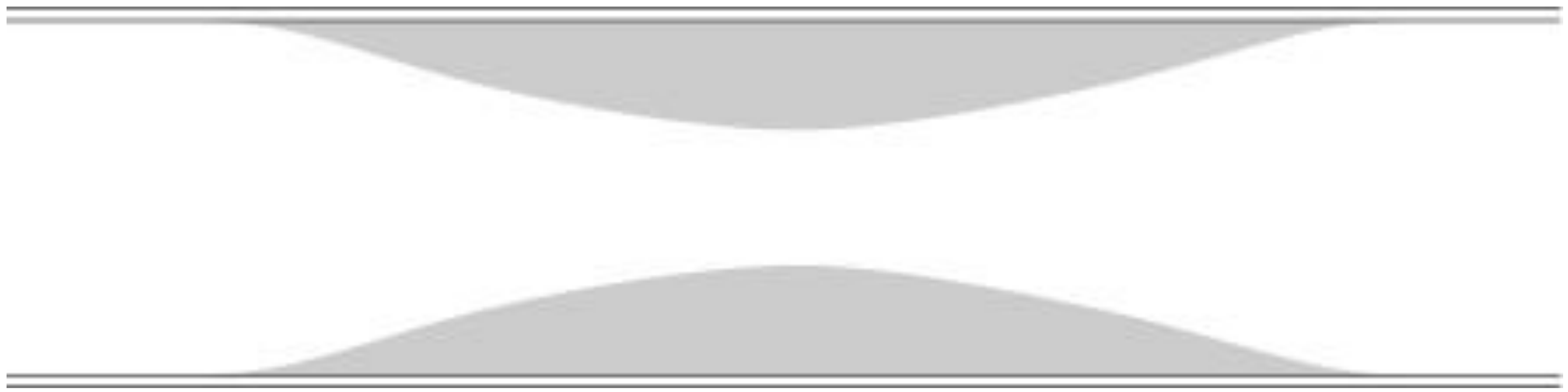

a) The narrow part.

b) The wide part.

c) The flux is the same in both parts.

The correct answer to the second question is **c) The flux is the same in both parts.**

While it might feel like the "narrow" part is doing more work, the laws of physics—specifically the **Equation of Continuity**—dictate that the volume of blood passing through any given point must remain constant.

The Explanation: Continuity of Flow

In fluid dynamics, we assume that blood is an incompressible fluid. This leads to a fundamental principle: what goes in must come out.

- **Conservation of Mass:** Since no blood is being added or removed between the wide and narrow sections, the **volume flow rate** (or flux) must be identical throughout the tube.
- **Volume Flow Rate (Q):** This is defined as the cross-sectional area (A) multiplied by the velocity of the fluid (v):
  $$Q = A_1 v_1 = A_2 v_2$$

Why this is different from the first question

It is easy to get these two concepts mixed up because they describe different aspects of the same movement:

1. **Flow Speed (Velocity):** The speed is **largest in the narrow part** because the blood must speed up to squeeze the same amount of volume through a smaller opening.

2. **Flux (Volume Flow Rate):** The flux is **the same in both parts** because it represents the total amount of blood passing a point per second. If the flux were higher in the wide part, blood would "pile up" at the narrow entrance; if it were higher in the narrow part, a vacuum would be created.

Bernoulli's Equation

- Bernoulli's principle follows from conservation of energy
- What is conservation of energy?

Bernoulli’s Equation

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1. The Bouncing Ball that Stops

If you drop a tennis ball, it bounces a few times and then eventually just sits still on the floor.

The Appearance: The ball had “potential energy” at the top and “kinetic energy” while moving. When it stops, that energy seems to have vanished into thin air.

The Simple Reality: The energy didn't disappear; it changed shape. Every time the ball hits the floor, it compresses. This friction between the ball’s molecules creates a tiny amount of heat. Some energy also escapes as sound (the "thump" you hear). If you had a super-sensitive thermometer, you’d see the ball and the floor are slightly warmer after the bounce.

2. A Toy Car with a Pull-Back Motor

You pull a small toy car backward, let go, and it zooms across the room much faster than your hand moved.

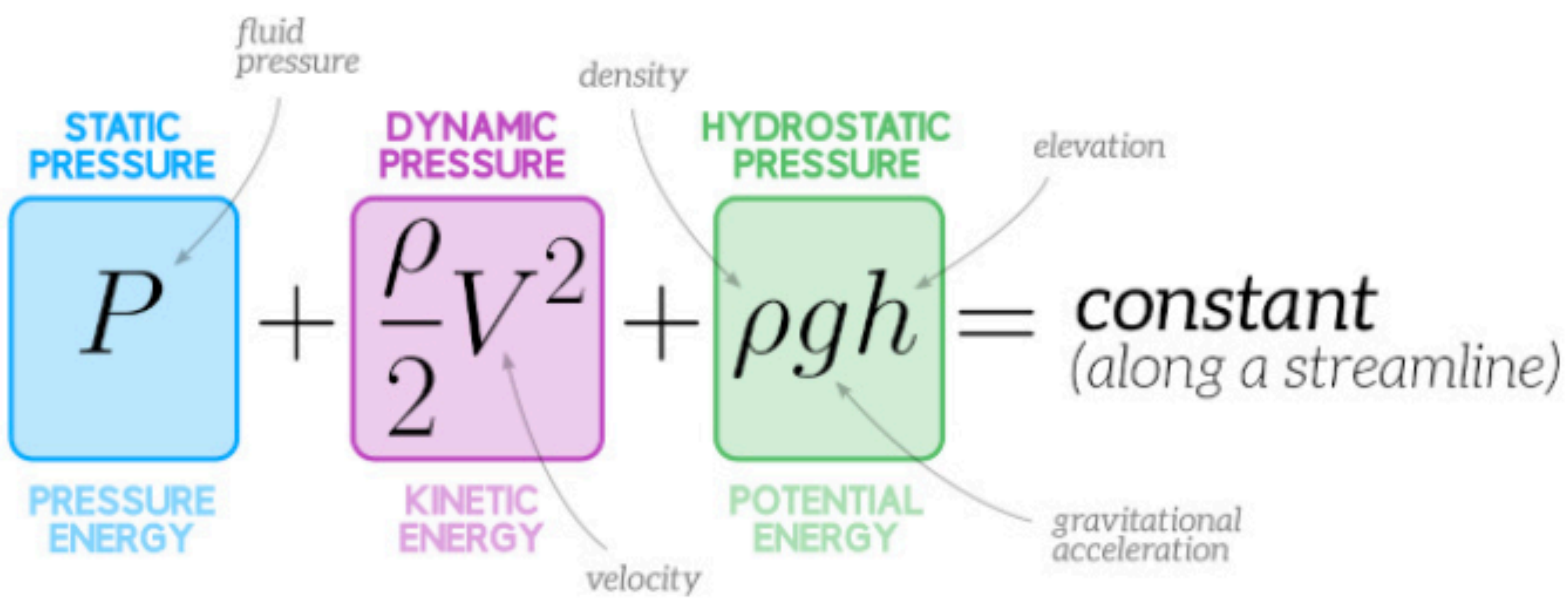
The Appearance: It looks like the car is "generating" speed and motion from nothing once you let go.

The Simple Reality: You did the work upfront. When you pulled the car back, you tightened a coiled torsion spring inside. You were converting the chemical energy in your muscles into elastic potential energy. The car is just "spending" the energy you already gave it.

Bernoulli's Equation

- Applying the principle of conservation of mechanical energy to the flow of an ideal fluid leads to Bernoulli's equation:
- $p + \frac{1}{2}\rho v^2 + \rho g y =$ a constant

The constant consists of kinetic and potential energy per unit volume of the fluid and the net work done on it per unit volume by external forces. Thus the change in mechanical energy equals the work done, which is the manifestation of energy conservation. When v = 0, this equation reduces to Archimedes principle since the change in pressure is associated with the buoyant force and the change in potential energy per unit volume is associated with associated with the weight of fluid displaced.



Bernoulli's Equation

- Let y_1, v_1, and p_1 be the elevation, speed and pressure of the fluid entering at the left and y_2, v_2, and p_2 be the same quantities for the fluid emerging from the right
- $p_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = p_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$
- Kinetic energy density: $\frac{1}{2}\rho v^2$
- What happens to this equation for fluids at rest?

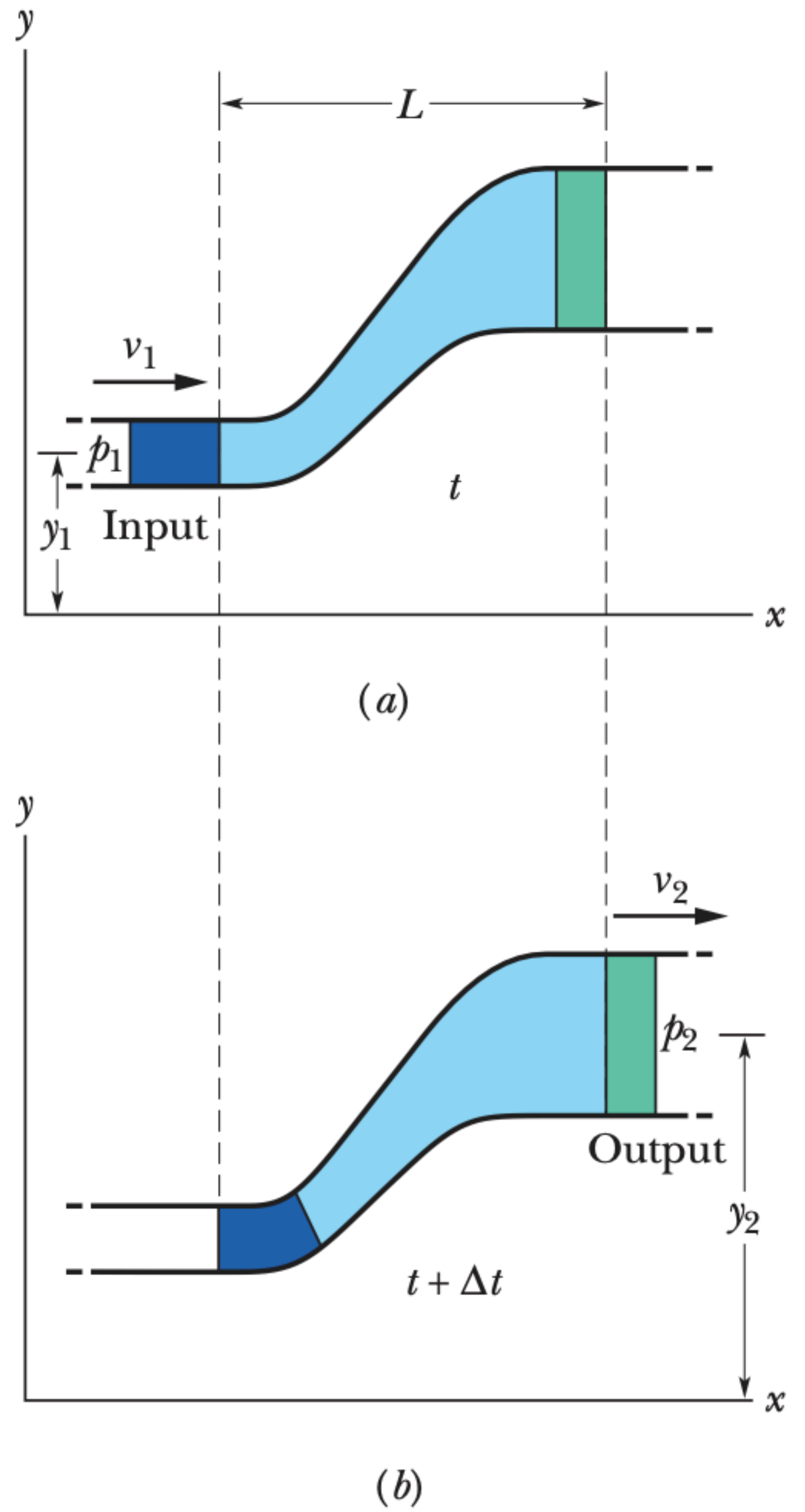


Figure 14-19 Fluid flows at a steady rate through a length L of a tube, from the input end at the left to the output end at the right. From time t in (a) to time $t + \Delta t$ in (b), the amount of fluid shown in purple enters the input end and the equal amount shown in green emerges from the output end.

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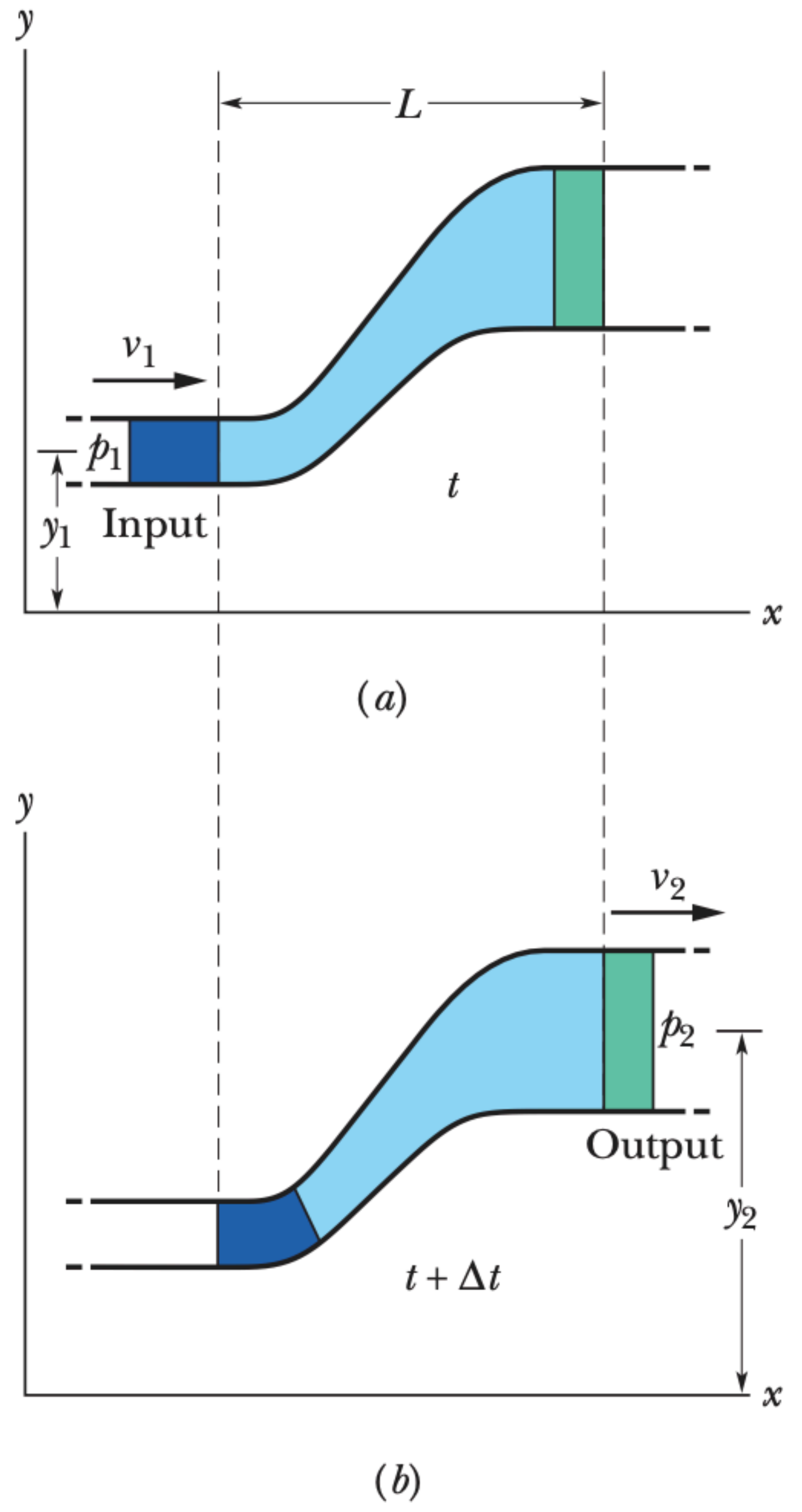

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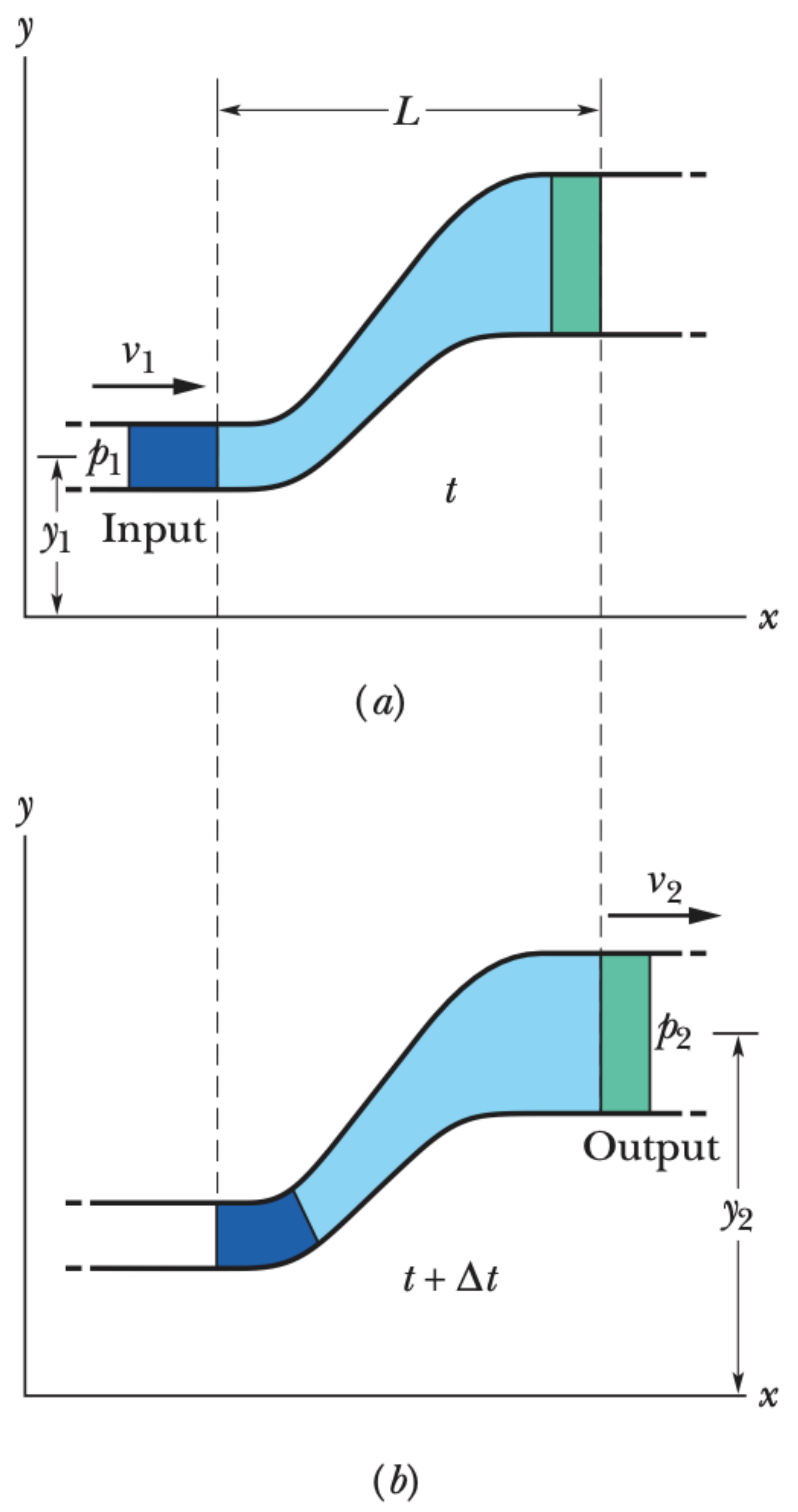

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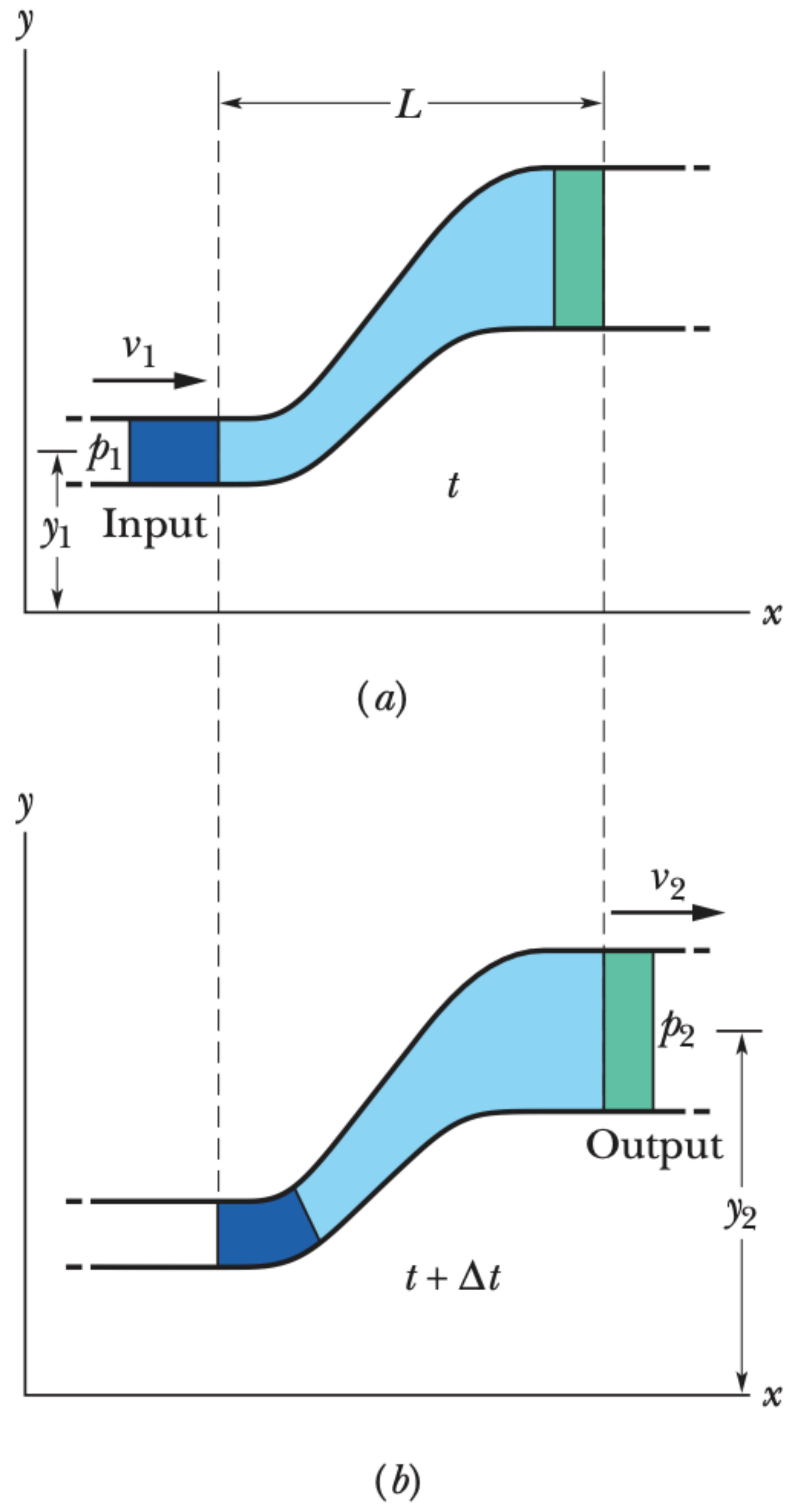
- Kinetic energy density: $\frac{1}{2}\rho v^2$
- What happens to this equation if we take y to be a constant?
  - $p_1 + \frac{1}{2}\rho v_1^2 = p_2 + \frac{1}{2}\rho v_2^2$
  - If the speed of a fluid element increases as the element travels along a horizontal streamline, the pressure of the fluid must decrease, and conversely.



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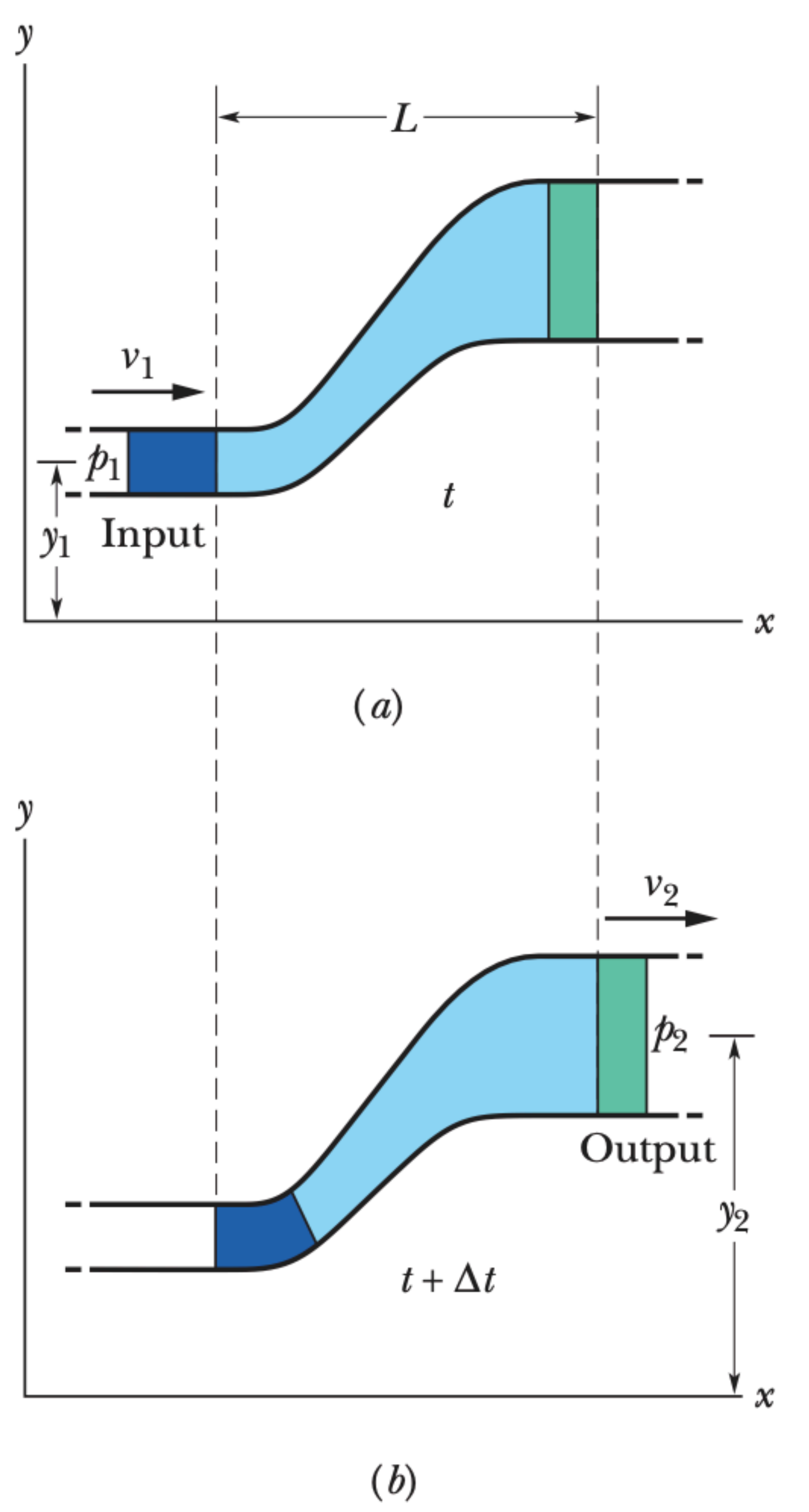
Bernoulli's Equation: Proof

- Apply energy conservation if the form of the work-kinetic energy theorem
  - Work $(W) = \Delta K$
  - Change in kinetic energy = total work done
  - $\Delta K = \frac{1}{2}\Delta m v_2^2 - \frac{1}{2}\Delta m v_1^2$
  - $\Delta K = \frac{1}{2}\rho \Delta V (v_2^2 - v_1^2)$
- Work done by the system arises from two sources
  - Gravity is also acting on the system!
  - $W_g = -\Delta m g (y_2 - y_1)$
  - $W_g = -\rho \Delta V g (y_2 - y_1)$



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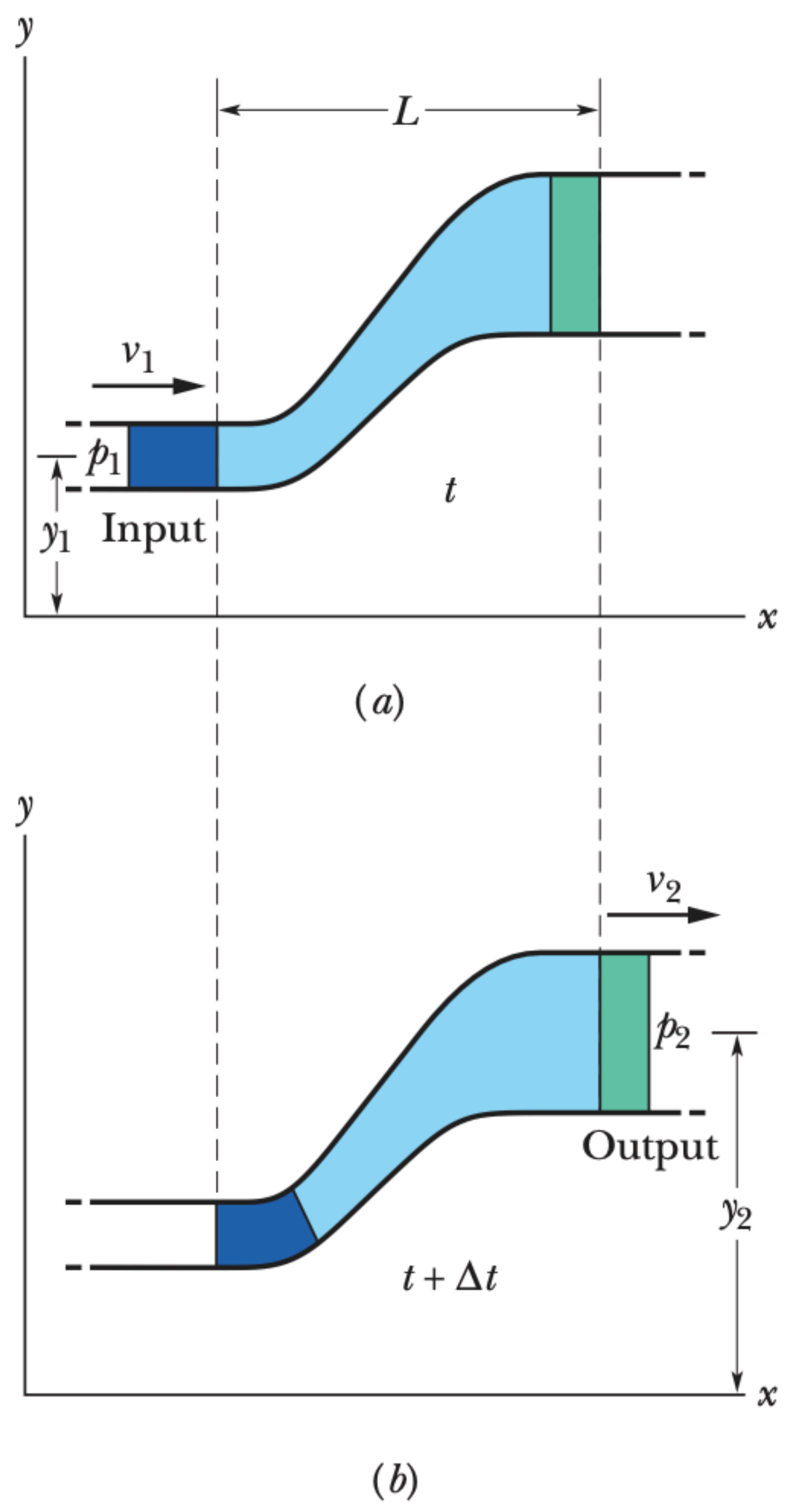
Bernoulli's Equation: Proof

- Work done on the system (at the input end) to push the entering fluid into the tube and by the system (at the output end) to push forward the fluid that is located ahead of the emerging fluid
- Work done by a force of magnitude F, acting on a fluid sample contained in a tube of area A to move the fluid through a distance Δx is:
  - $F\Delta x = (pA)(\Delta x)$
  - $F\Delta x = p(A\Delta x)$
  - $F\Delta x = p\Delta V$



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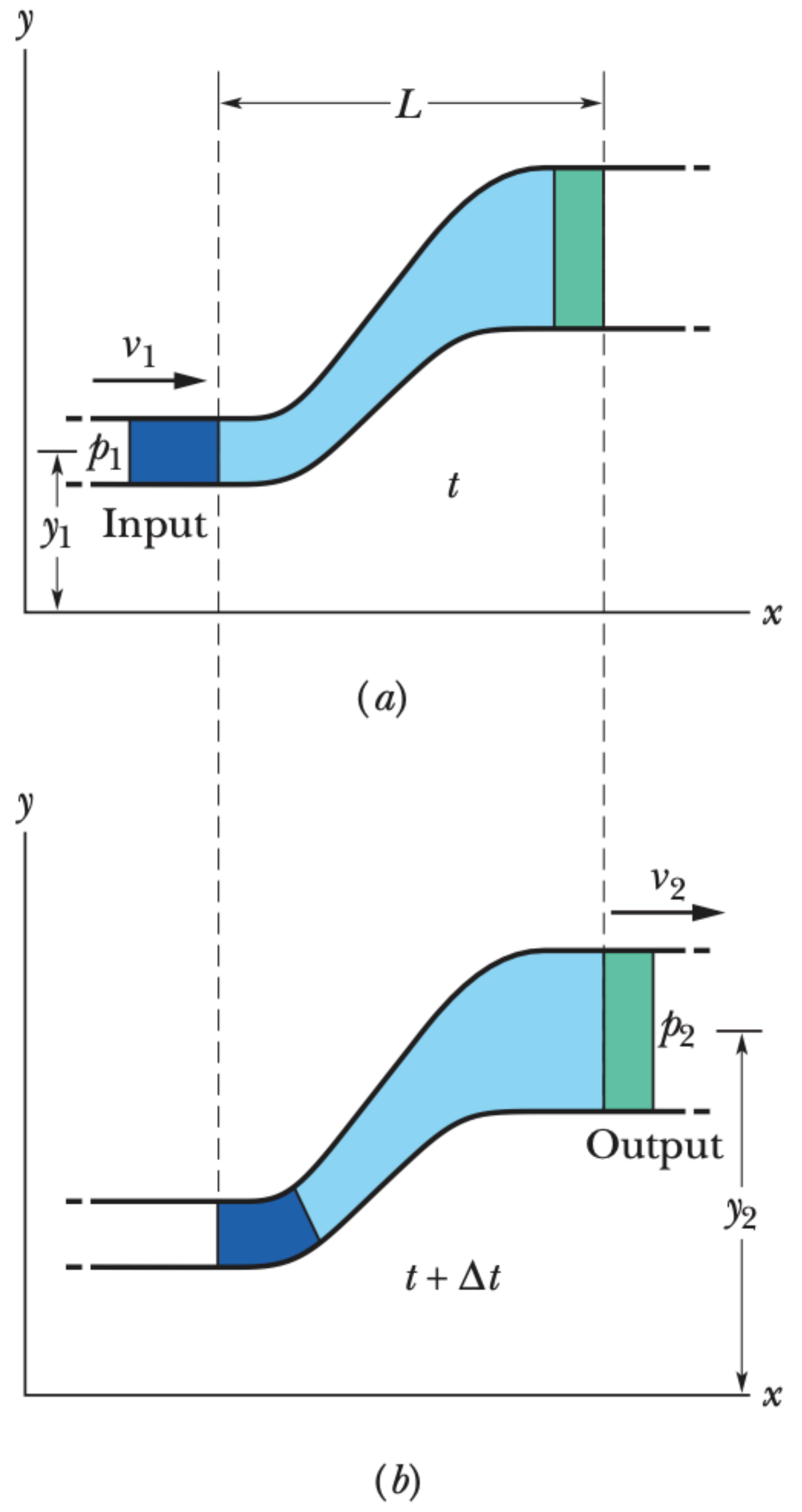
Bernoulli's Equation: Proof

- Work done on the system is:
  - $p_1 \Delta V$
- Work done by the system is:
  - $-p_2 \Delta V$
- Sum:
  - $W_p = -p_2 \Delta V + p_1 \Delta V$
  - $W_p = -(p_2 - p_1)\Delta V$
- $W = w_g + W_p = \Delta K$
- $-\rho g \Delta V(y_2 - y_1) - \Delta V(p_2 - p_1) = \frac{1}{2}\rho \Delta V(v_2^2 - v_1^2)$



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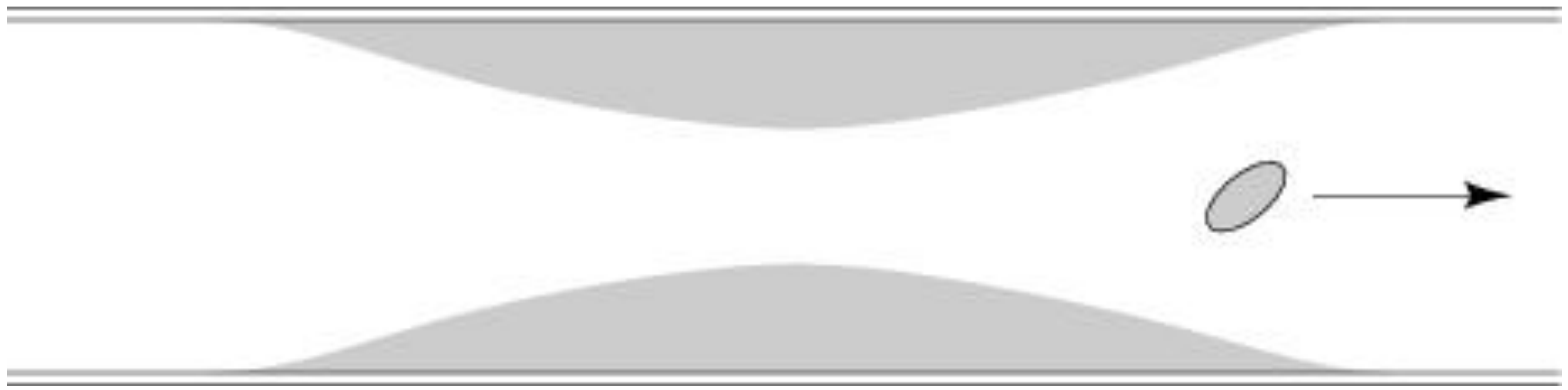
A blood platelet drifts along with the flow of blood through an artery that is partially blocked by deposits. As the platelet moves from the narrow region to the wider region, it experiences



a) an increase in pressure.

b) no change in pressure.

c) a decrease in pressure.

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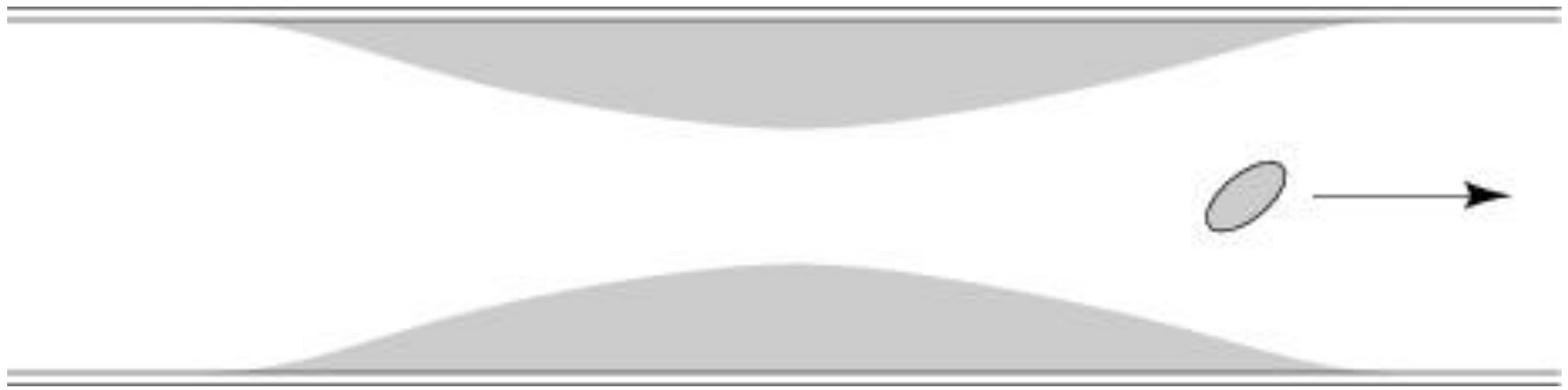

a) an increase in pressure.

b) no change in pressure.

c) a decrease in pressure.

a) An increase in pressure.

The Explanation

This question tracks a platelet moving from the **narrow region** to the **wider region**. To solve this, we just need to reverse the logic we used for the blockage itself.

1. The Speed Change (Continuity)

As the blood moves from the narrow constriction back into the wider part of the artery, the cross-sectional area increases. To maintain a constant volume flux, the blood must **slow down**.

- **Narrow part:** High velocity (v).
- **Wide part:** Low velocity (v).

2. The Pressure Change (Bernoulli)

Recall that Bernoulli's Principle states that in a fluid flow, an increase in velocity occurs simultaneously with a decrease in pressure (and vice-versa).

- In the **narrow part**, the speed was high, so the pressure was at its **lowest**.
- In the **wider part**, the speed decreases, which causes the internal pressure to **increase**.

Summary of the Platelet's Journey

As that platelet drifts out of the "bottleneck" of the blockage:

- It **decelerates** because the path has widened.
- It experiences **higher pressure** pushing against it from the surrounding fluid.

Water is being pumped into one end of a long pipe at a rate of 24 L/min (L = Liter). It emerges at the other end at 40 L/min.

What are possible reasons for this change?

a) the water is being pumped uphill

b) the water is being pumped downhill

c) the diameter of the pipe is not constant

d) water is leaking out of the pipe somewhere

e) None of the above

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a) the water is being pumped uphill

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c) the diameter of the pipe is not constant

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e) None of the above

The correct answer is **e) None of the above.**

The Explanation: Conservation of Mass

In a closed system with an incompressible fluid (like water), the **mass flow rate**—and by extension, the **volume flow rate** (flux)—must be conserved. This is the "What goes in must come out" rule we used for the artery problems.

Why the other options don't work:

- **a) and b) Pumping uphill or downhill:** Changing the elevation of the pipe affects the **speed** and **pressure** of the water (Bernoulli's Principle), but it does not change the total amount of water passing through. If 24 L enters every minute, 24 L must exit every minute, regardless of gravity.
- **c) Changing the diameter:** As we saw in the artery example, changing the diameter of the pipe changes the **flow speed**, but the **flux** (L/min) remains constant.
- **d) Water leaking out:** If water were leaking *out* of the pipe, the flow rate at the end would be **less** than 24 L/min, not more.

Why "None of the above"?

For the output to be **40 L/min** when only **24 L/min** is being pumped in, there would have to be an additional source of water entering the pipe somewhere in the middle (like a second pump or a "T" junction). Without an extra source, it is physically impossible for more water to emerge from a pipe than was put into it.

If you were to blow over the top surface of a sheet of paper, what would happen?

a) The paper would rise

b) The paper would lower

c) The paper would stay in the same position

If you were to blow over the top surface of a sheet of paper, what would happen?

a) The paper would rise

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c) The paper would stay in the same position

The correct answer is **a) The paper would rise.**

The Explanation: Bernoulli’s Principle in Action

This is a perfect real-world demonstration of the same physics we saw in the blocked artery. It all comes down to the relationship between air speed and air pressure.

1. Creating a Speed Difference

When you blow over the top of the paper, you are creating a stream of **fast-moving air** on the top surface. The air underneath the paper remains relatively **still**.

2. Creating a Pressure Difference

According to **Bernoulli's Principle**, the fast-moving air on top exerts **less pressure** than the slow-moving (stationary) air underneath.

- **Top Surface:** High speed = Low pressure.
- **Bottom Surface:** Low speed = High pressure.

3. The Resulting Lift

Because the pressure underneath the paper is now higher than the pressure on top, there is a net upward force. This "lift" overcomes the weight of the paper and causes it to rise toward the stream of air. This is the same fundamental principle that allows massive airplane wings to generate lift!

Airflow across a wing

https://www.youtube.com/watch?v=UqBmdZ-BNig

e.g. Bird Wings

https://www.youtube.com/watch?v=4jKokxPRtck

Blood (density 1060 kg/m^3) at pressure 110 Torr is moving out of the heart through an artery of diameter of 0.19 cm at a speed of 1.9 m/s. The artery then descends 10 cm to a lower level where its diameter decreases to 0.14 cm.
(1000 N/m^2 = 7.5 Torr).

a)What is the force in Newtons exerted by the heart on the blood as it leaves?

b) What is the speed of the blood at the lower level?

c)What is the blood pressure in Torr at the lower level?

Fluid Dynamics Solution: Coronary Artery Blood Flow

Part A: Force Exerted by the Heart

First, we convert the blood pressure from Torr to Pascals (N/m^2) and calculate the cross-sectional area of the artery.

1. **Pressure Conversion:**

$$P_1 = 110 \text{ Torr} \times \left(\frac{1000 \text{ N/m}^2}{7.5 \text{ Torr}} \right) \approx 14,666.67 \text{ Pa}$$

2. **Area Calculation:** The diameter $d_1 = 0.19 \text{ cm} = 0.0019 \text{ m}$. Thus, the radius $r_1 = 0.00095 \text{ m}$.

$$A_1 = \pi r_1^2 = \pi (0.00095 \text{ m})^2 \approx 2.835 \times 10^{-6} \text{ m}^2$$

3. **Force Calculation:**

$$F = P_1 A_1 = (14,666.67 \text{ N/m}^2)(2.835 \times 10^{-6} \text{ m}^2)$$

$$\mathbf{F \approx 0.0416} \text{ N}$$

Part B: Speed of Blood at the Lower Level

Using the **Equation of Continuity** ($A_1v_1 = A_2v_2$), we find the velocity at the second location where the diameter is 0.14 cm.

$$v_2 = v_1 \left(\frac{A_1}{A_2}\right) = v_1 \left(\frac{d_1}{d_2}\right)^2$$

$$v_2 = 1.9 \text{ m/s} \times \left(\frac{0.19 \text{ cm}}{0.14 \text{ cm}}\right)^2$$

$$v_2 = 1.9 \times (1.357)^2 \approx 1.9 \times 1.842$$

$$\mathbf{v_2} \approx \mathbf{3.50} \text{ m/s}$$

Part C: Blood Pressure at the Lower Level

We apply **Bernoulli's Equation**, letting the lower level be $h_2 = 0$ and the upper level be $h_1 = 0.10$ m.

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

1. **Solving for P_2:**

$$P_2 = P_1 + \frac{1}{2}\rho(v_1^2 - v_2^2) + \rho g h_1$$

2. **Substitution of Values:** Using $\rho = 1060$ kg/m^3 and $g = 9.8$ m/s^2:

$$P_2 = 14,666.67 + \frac{1}{2}(1060)(1.9^2 - 3.5^2) + (1060)(9.8)(0.10)$$

$$P_2 = 14,666.67 + 530(3.61 - 12.25) + 1038.8 \approx 11,126.27 \text{ Pa}$$

3. **Conversion to Torr:**

$$P_2 = 11,126.27 \text{ Pa} \times \left(\frac{7.5 \text{ Torr}}{1000 \text{ Pa}}\right)$$

$$\mathbf{P_2} \approx \mathbf{83.45} \text{ Torr}$$