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 2nd, 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 (Prof. Neumann)	5	6	7	8
	9	10	11	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

Schedule

No class

Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
April	6 (Lectures)	7	8 (Labs)	9	10 (Lectures)	11	12
	13 (Lectures)	14	15 (Labs)	16	17 (Lectures)	18	19
	20 (Lectures)	21	22 (Labs)	23	24 (Lectures)	25	26
May	27 (Lectures)	28	29 (Labs)	30	1 (Lectures)	2	3
	4 (Lectures)	5 (No class)	6	7	8	9	10

Center of gravity

- The gravitational force $\overrightarrow{F}g$ on a body effectively acts on a single point called the center of gravity (cog) of the body
- At each point:
  - $\tau_i = x_i F_{gi}$
- Sum: $\tau_{net} = \sum \tau_i = \sum x_i F_{gi}$
- As a whole, using the concept of center of gravity:
  - $\tau = x_{cog} F_g$
  - $\tau = x_{cog} \sum F_{gi}$
- Equate: $x_{cog} \sum F_{gi} = \sum x_i F_{gi}$
- Substitute: $x_{cog} \sum m_i g_i = \sum x_i m_i g_i$
- Cancel g, $x_{cog} \sum m_i = \sum x_i m_i$, $x_{cog} = \frac{1}{M} \sum x_i m_i$

Fluids at Rest
(14.1-14.5)

Key concepts

- The density of any material is defined as the material's mass per unit volume:
  - $\rho = \frac{\Delta m}{\Delta V}$, Δm: mass of the fluid contained within an element, ΔV: volume element
- Fluid is a substance that can flow. It can exert a force perpendicular to its surface. That force is defined in terms of pressure p:
  - $p = \frac{\Delta F}{\Delta A}$ in which ΔF is the force acting on a surface element of area ΔA. If the force is uniform over a flat area, this can be written as:
    - $p = \frac{F}{A}$
  - The force resulting from fluid pressure at a particular point in a fluid has the same magnitude in all directions

Key concepts

- In contrast to a solid, a liquid is a substance that flows
  - Fluids conform to the boundaries of a container in which we put them
  - Cannot sustain a force that is tangential to its surface, cannot withstand a shearing stress
  - For some materials this is hard
    - Can you name one?
- We lump liquids and gasses together and call them fluids

Key concepts

- In contrast to a solid, a liquid is a substance that flows
  - Fluids conform to the boundaries of a container in which we put them
  - Cannot sustain a force that is tangential to its surface, cannot withstand a shearing stress
  - For some materials this is hard
    - Can you name one?
      - Pitch: takes a long time to conform to the boundaries of a container, but they do so eventually and are thus classified as fluids
- We lump liquids and gasses together and call them fluids

Key concepts: Units

- The SI unit of pressure is newton per square meter called **pascal (Pa)**
- Pascal is related to some other pressure units:
  - 1 atm = 1.01×10^5 Pa = 760 torr = 14.7 $\mathrm{lb/in^2}$

The plunger of a syringe has an area of 100 mm^2.

Neglecting friction, what force must be exerted on the plunger to inject a patient whose blood pressure is 10,000 N/m^2 (about 75 Torr)?

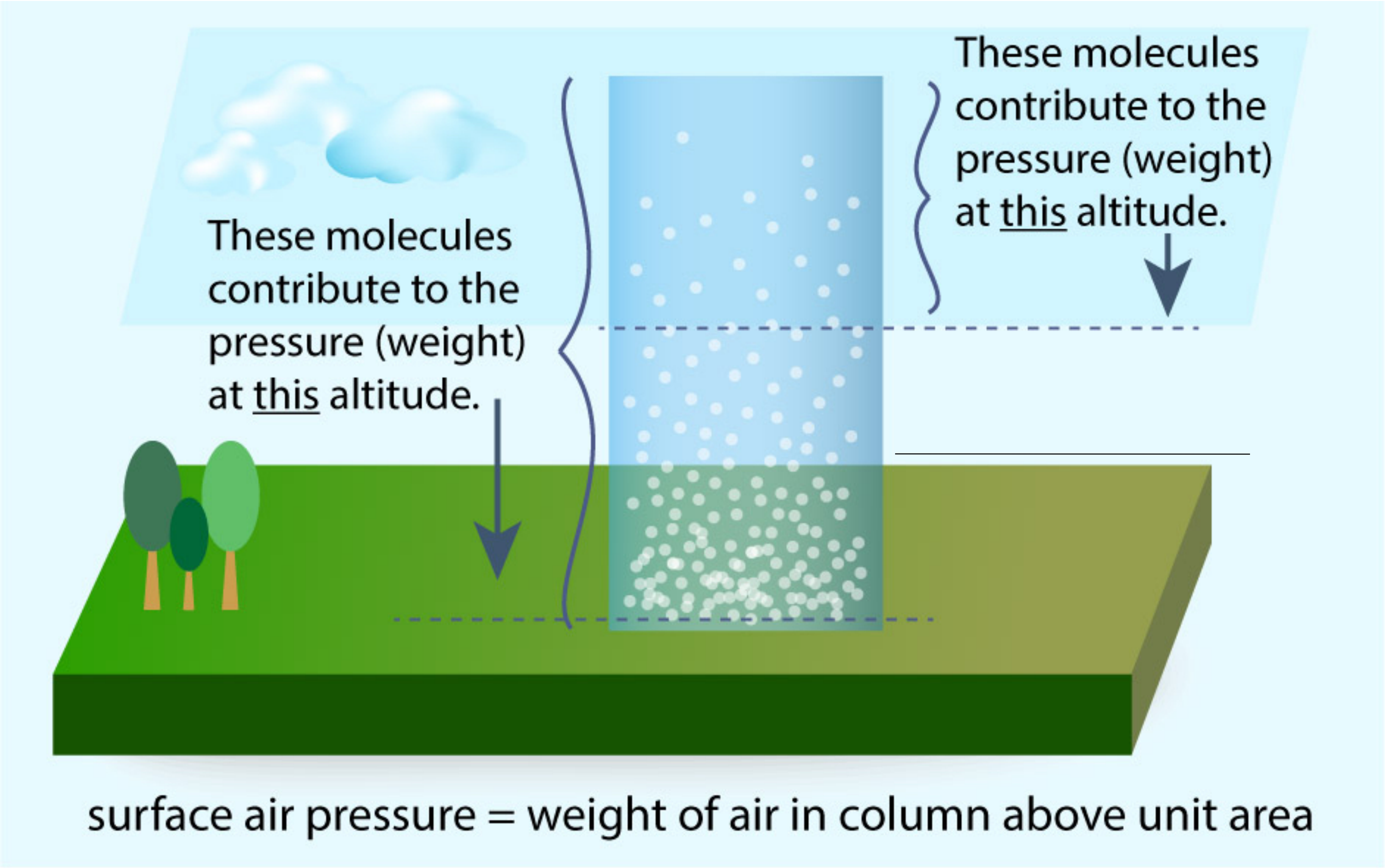
a) 1 N
b) 10 N
c) 100 N
d) 1,000 N
e) 10,000 N

The plunger of a syringe has an area of 100 mm^2.

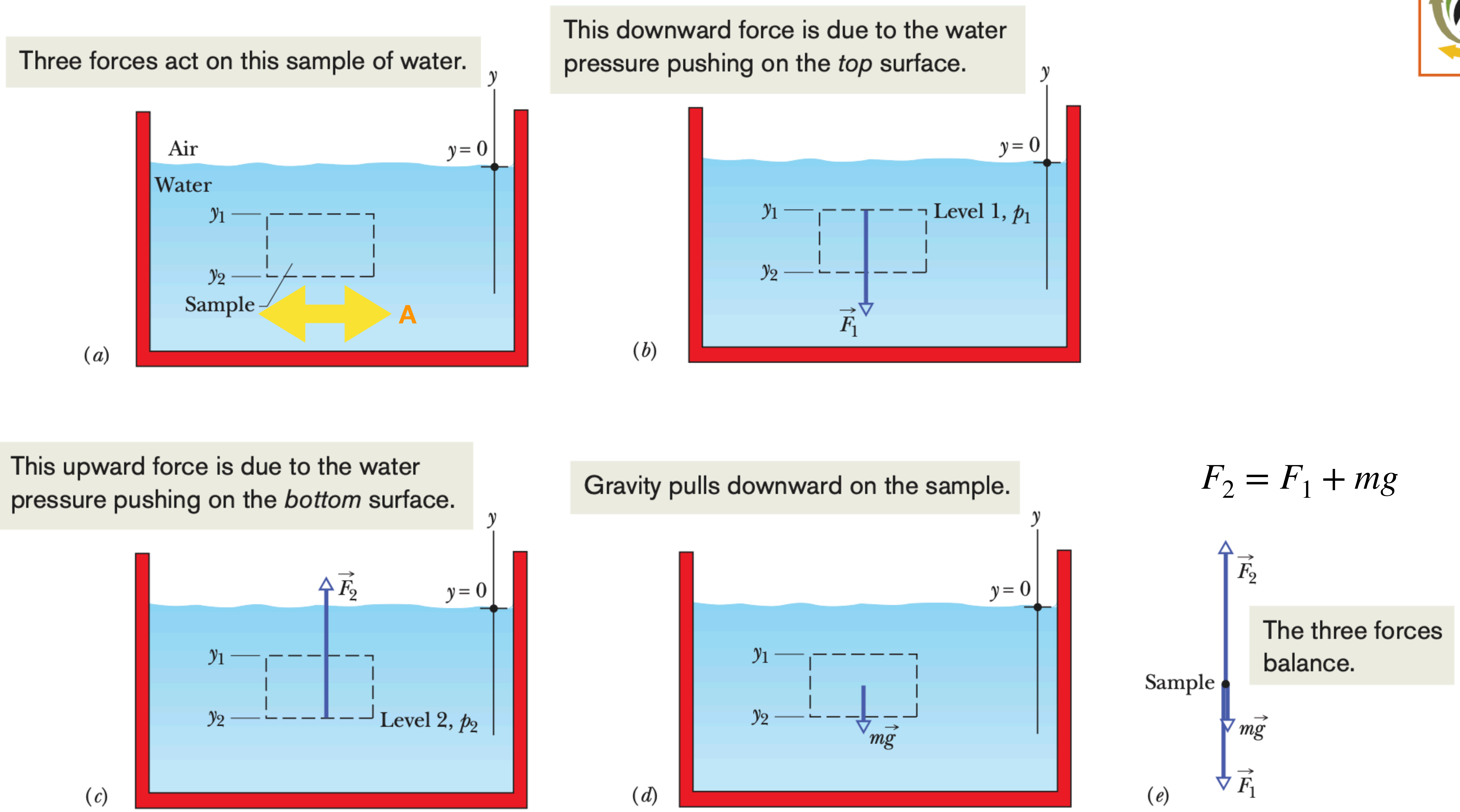
Neglecting friction, what force must be exerted on the plunger to inject a patient whose blood pressure is 10,000 N/m^2 (about 75 Torr)?

a) 1 N (Force = pressure*area, make sure units are correct)
b) 10 N
c) 100 N
d) 1,000 N
e) 10,000 N

Atmospheric Pressure



Key concepts

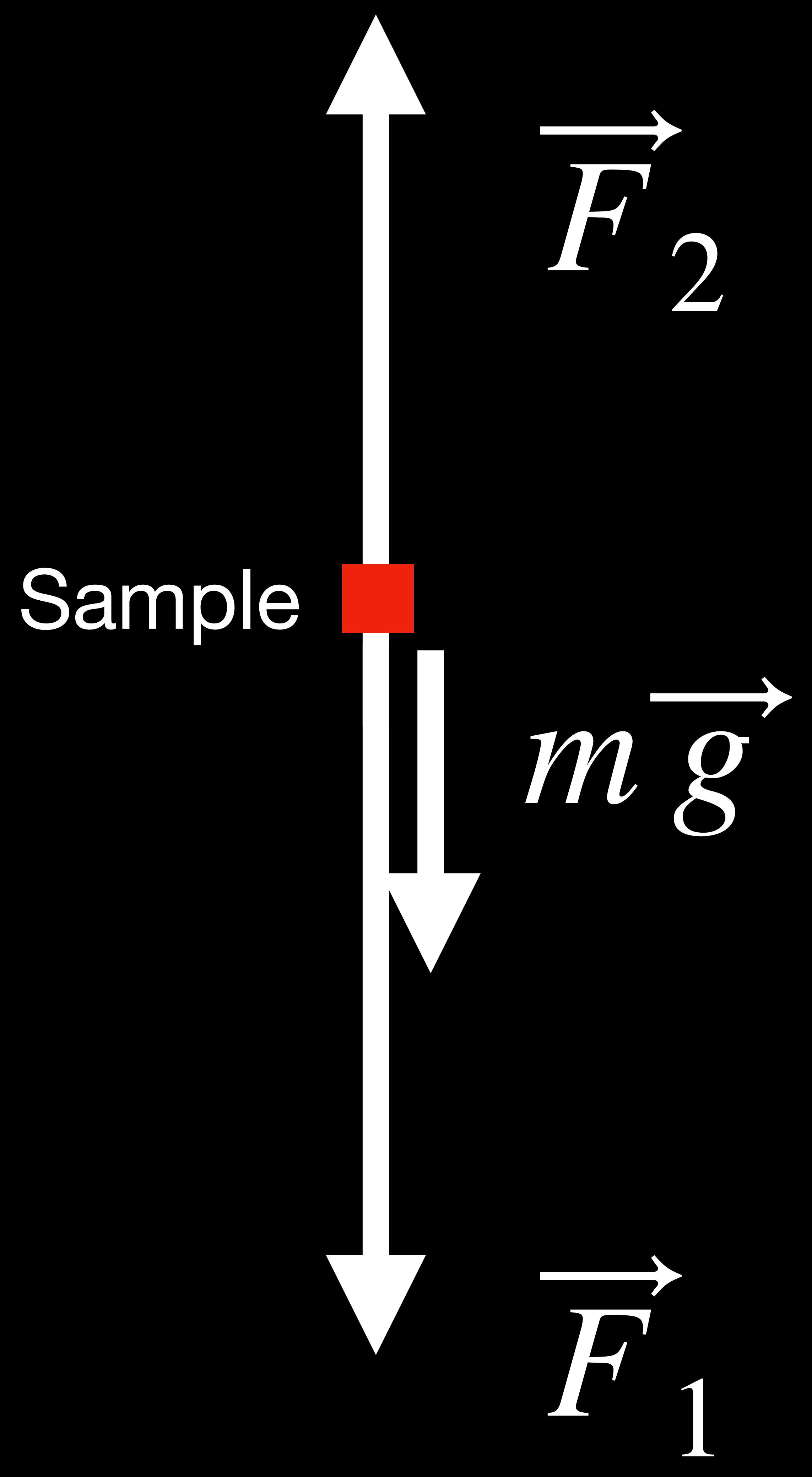


$$F_2 = F_1 + mg$$

Figure 14-2 (*a*) A tank of water in which a sample of water is contained in an imaginary cylinder of horizontal base area *A*. (*b*)–(*d*) Force $\vec{F}_1$ acts at the top surface of the cylinder; force $\vec{F}_2$ acts at the bottom surface of the cylinder; the gravitational force on the water in the cylinder is represented by $m\vec{g}$. (*e*) A free-body diagram of the water sample. In *WileyPLUS*, this figure is available as an animation with voiceover.

Key concepts

- The balance of forces is written as:
  - $F_2 = F_1 + mg$
- Writing in terms of pressures:
  - $F_1 = p_1 A$ and $F_2 = p_2 A$
- The mass m of the water in the cylinder is: $m = \rho V$, where the cylinder's volume V and the product of its face area V and height $y_1 - y_2$
- Substituting:
  - $p_2 A = p_1 A + \rho A g(y_1 - y_2)$
  - $p_2 = p_1 + \rho g(y_1 - y_2)$
- Can be used to write: $p = p_0 + \rho g h$ **(pressure at a given depth)**, $y_1 = 0$, $p_1 = p_0$ and $y_2 = -h$, $p_2 = p$



Key concepts

- Pascal's principle: A change is the pressure applied to an enclosed incompressible fluid is transmitted undiminished to every portion of the fluid and to the walls of its container
- Practical examples:
  - When you squeeze one end of a tube to get toothpaste out the other end, you are watching **Pascal's principle** in action.
  - This principle is also the basis for the Heimlich maneuver, in which a sharp pressure increase properly applied to the abdomen is transmitted to the throat, forcefully ejecting food lodged there

Key concepts

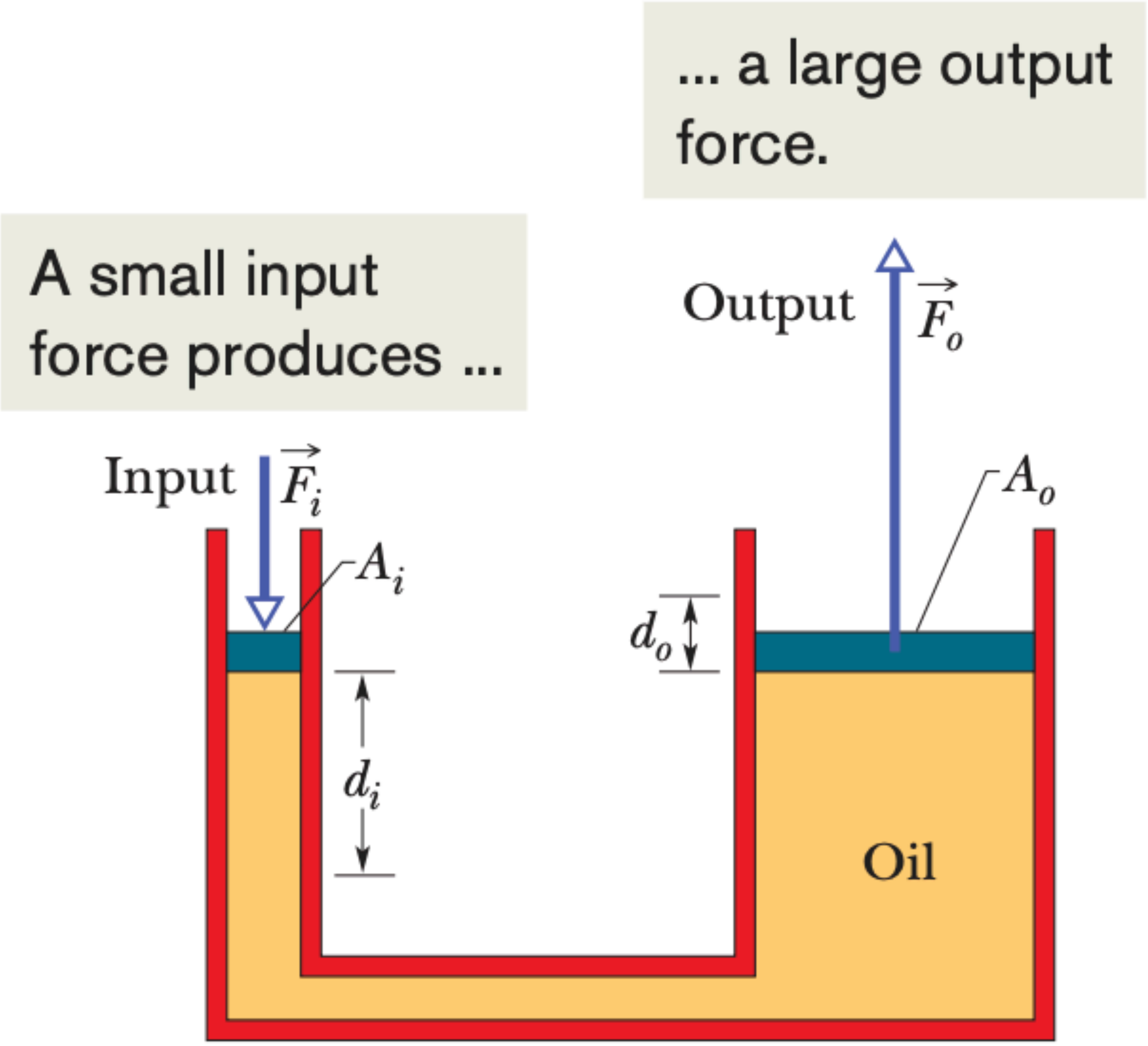


Figure 14-8 A hydraulic arrangement that can be used to magnify a force $\vec{F}_i$. The work done is, however, not magnified and is the same for both the input and output forces.

Key concepts

- Let an external force F_i be directed downward on the left-hand or input piston, whose surface area is A_i
- An incompressible liquid in the device produces an upward force of magnitude F_0 on the right-hand (or output) piston, whose surface area is A_0
- To keep the system in equilibrium, there must be a downward force of magnitude F_0 on the output piston (not shown)
- The force $\vec{F}_i$ and $\vec{F}_0$ can produce a change Δp in pressure: $\Delta p = \frac{F_i}{A_i} = \frac{F_0}{A_0}$

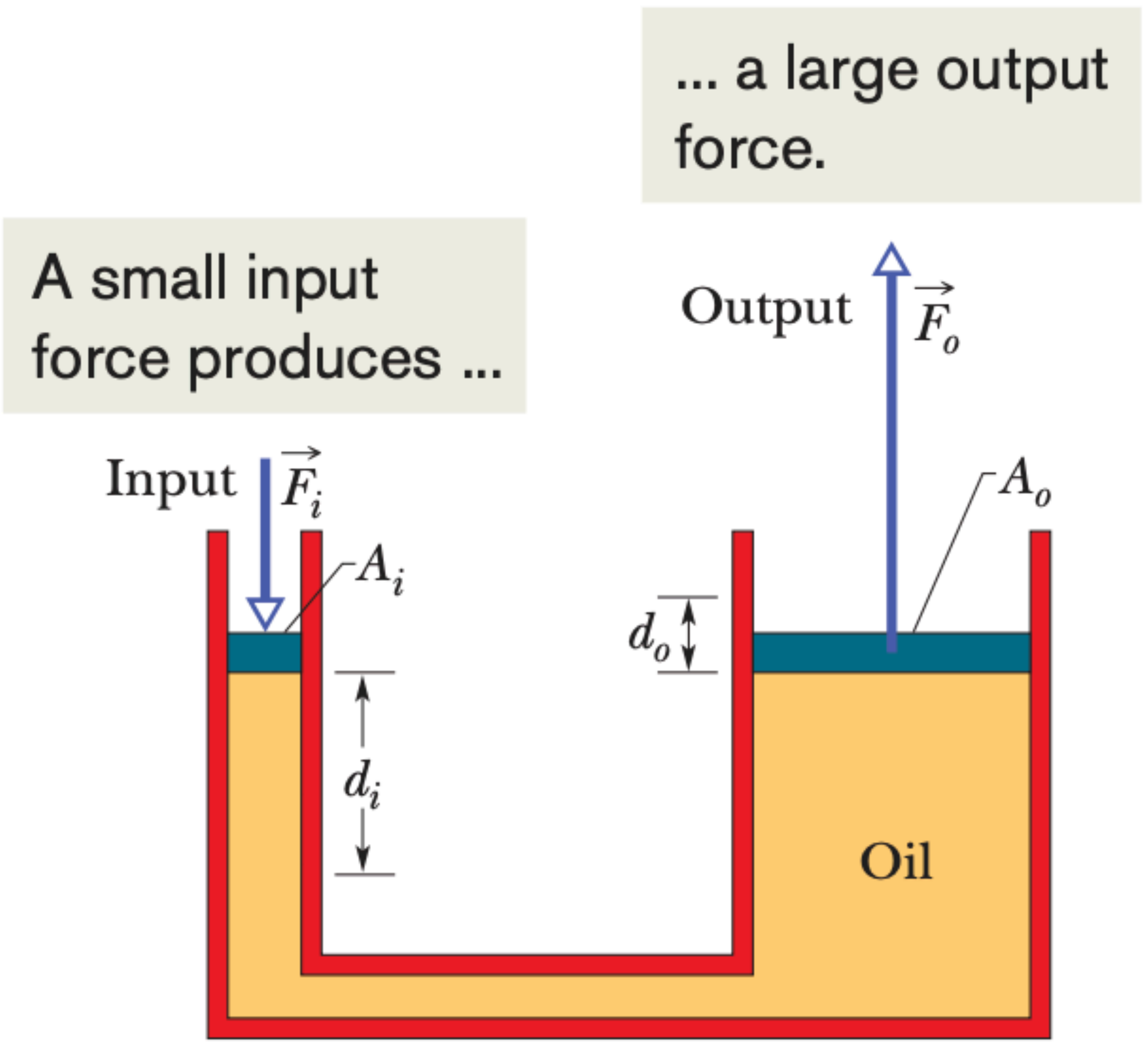


Figure 14-8 A hydraulic arrangement that can be used to magnify a force $\vec{F}_i$. The work done is, however, not magnified and is the same for both the input and output forces.

Key concepts

- The force $\overrightarrow{F}_i$ and $\overrightarrow{F}_0$ can produce a change Δp in pressure: $\Delta p = \dfrac{F_i}{A_i} = \dfrac{F_0}{A_0}$
  - $F_0 = F_i \dfrac{A_0}{A_i}$
- If V is the volume:
  - $V = A_i d_i = A_0 d_0$
  - $d_0 = d_i \dfrac{A_i}{A_0}$

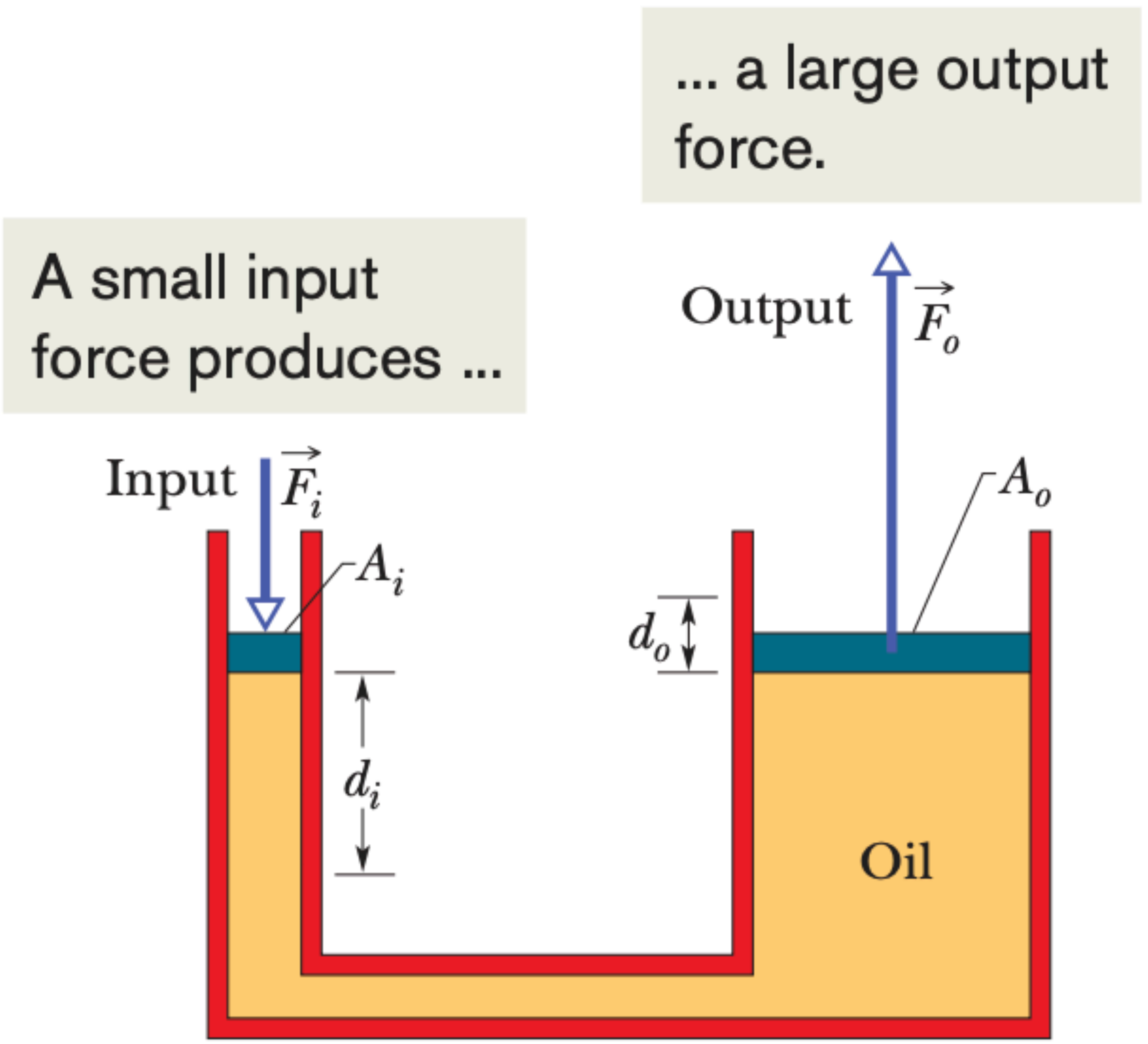


Figure 14-8 A hydraulic arrangement that can be used to magnify a force $\vec{F}_i$. The work done is, however, not magnified and is the same for both the input and output forces.

Key concepts

- In terms of work done:
- $$W = F_0 d_0 = \left(F_i \frac{A_0}{A_i}\right)\left(d_i \frac{A_i}{A_0}\right)$$

$$= F_i d_i$$

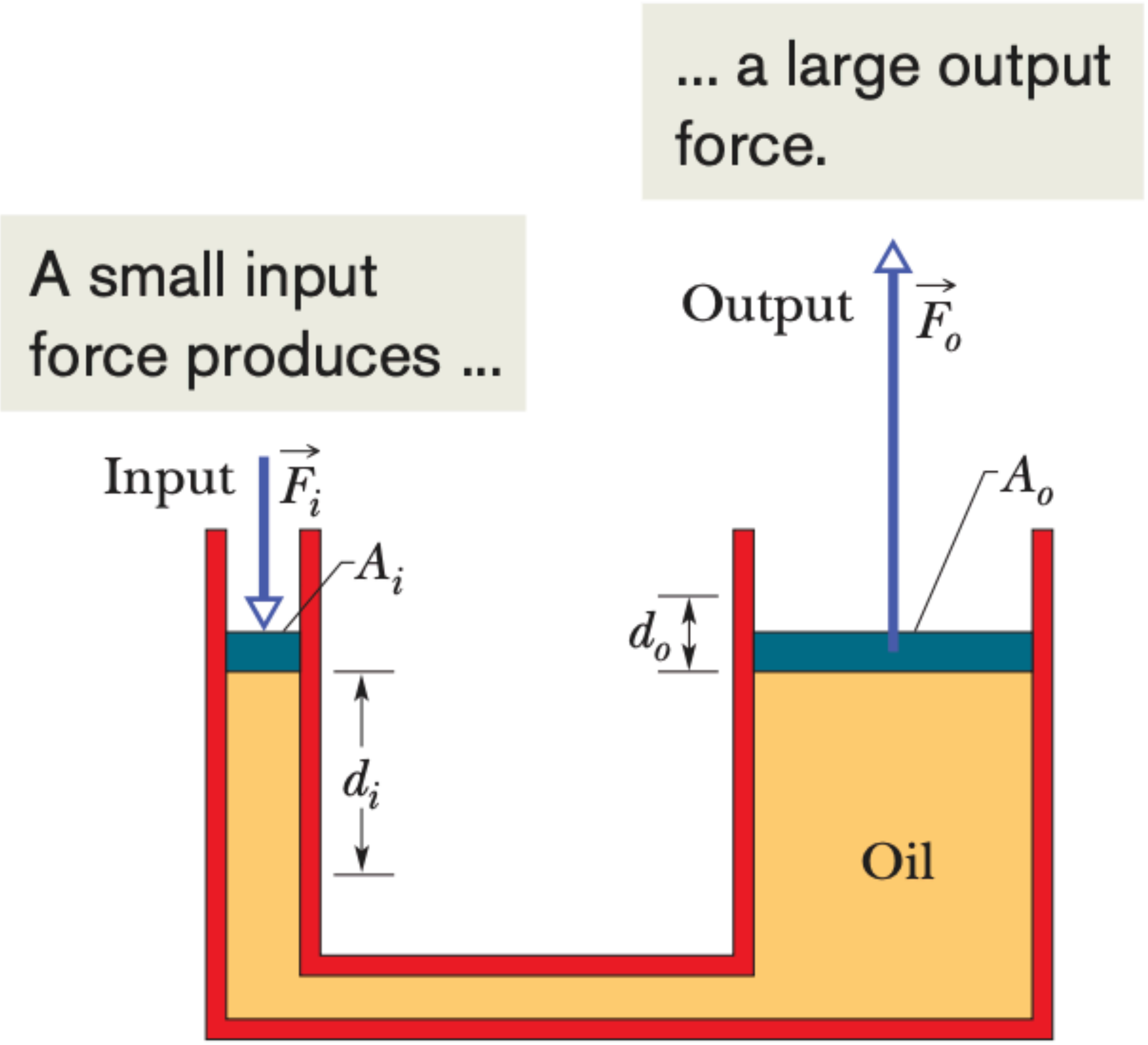


Figure 14-8 A hydraulic arrangement that can be used to magnify a force $\vec{F}_i$. The work done is, however, not magnified and is the same for both the input and output forces.

Key concepts

- Archimedes' principle states that when a body is fully or partially submerged in a fluid, the fluid pushes upward with a buoyant force with magnitude:
  - $F_b = m_f g$, where m_f is the mass of the fluid that has been pushed out of the way by the body
- When a body floats in a fluid, the magnitude F_b of the (upward) buoyant force on the body is equal to the magnitude F_g of the (downward) gravitational force on the body
- The apparent weight of the body on which the buoyant force acts is related to the actual weight by:
  - $\text{weight}_{\text{app}} = \text{weight} - F_b$

Key concepts

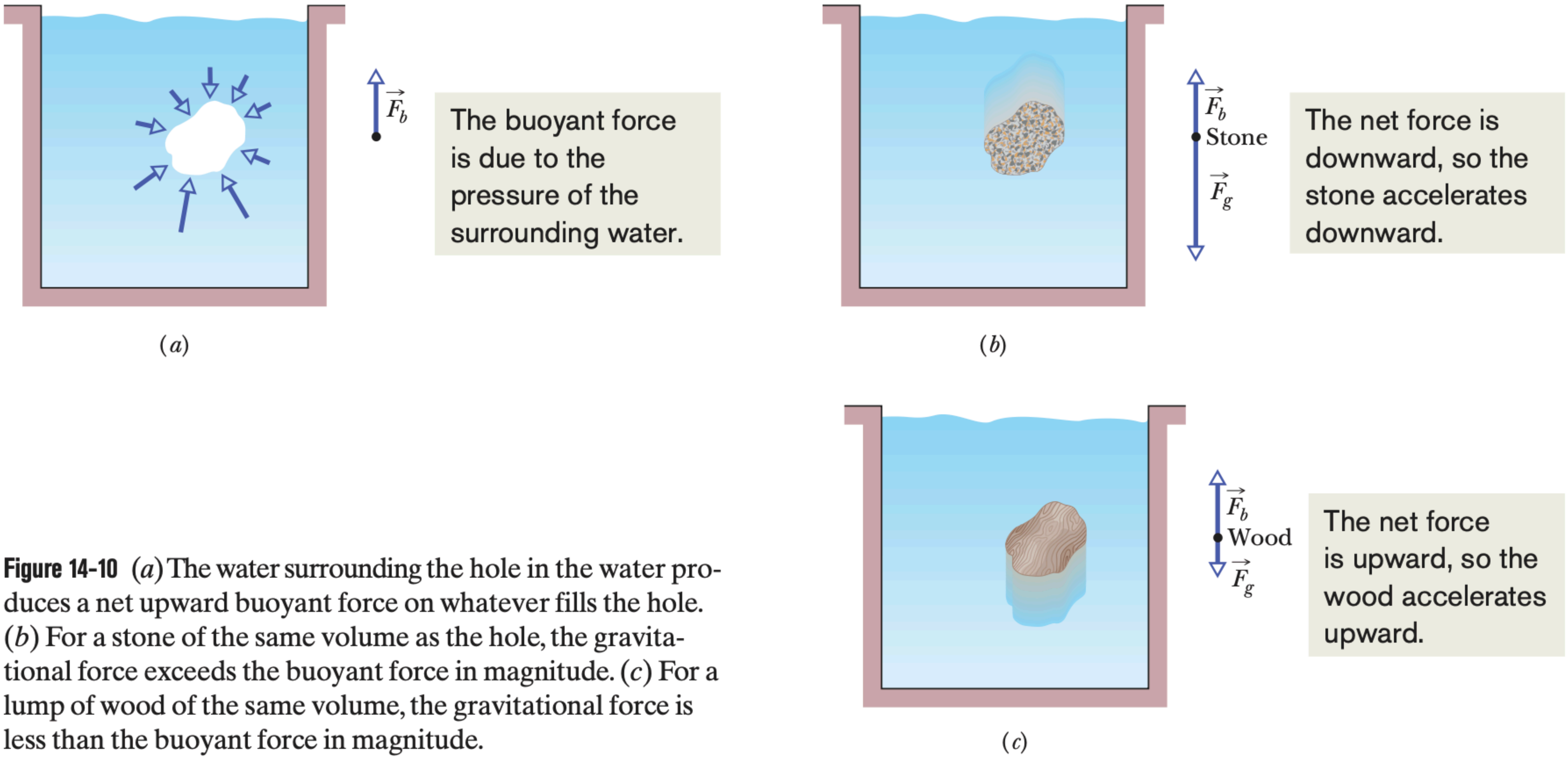


Figure 14-10 (*a*) The water surrounding the hole in the water produces a net upward buoyant force on whatever fills the hole. (*b*) For a stone of the same volume as the hole, the gravitational force exceeds the buoyant force in magnitude. (*c*) For a lump of wood of the same volume, the gravitational force is less than the buoyant force in magnitude.

Imagine holding two bricks completely under water. Brick A is just beneath the surface of the water, while brick B is at a greater depth.

Compared to the force required to hold brick A in place, the force needed to hold brick B in place is

a) larger

b) the same

c) smaller

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To hold a brick in place under water, the force you apply must balance the other two forces acting on the brick: **Gravity** and **Buoyancy**.

1. **Force of Gravity (F_g):** This depends only on the mass of the brick (m) and the acceleration due to gravity (g). Since both bricks are identical, the downward force of gravity is the same for both.
2. **Buoyant Force (F_b):** According to **Archimedes' Principle**, the buoyant force is equal to the weight of the fluid displaced by the object.
    - Since both bricks are “completely under water”, they displace the exact same volume of water.
    - In an incompressible fluid like water, the density remains constant regardless of depth.
    - Therefore, the upward buoyant force is identical for Brick A and Brick B.

Why Depth Doesn't Change the Force

It is a common misconception that because **pressure** increases with depth, the buoyant force must also increase. However, buoyancy is the *difference* in pressure between the top and the bottom of the object.

$$F_b = \rho \cdot V_{\text{displaced}} \cdot g$$

As long as the brick does not change size (it isn't compressed) and the water density stays the same, the depth of the brick does not change the buoyant force.

The Equilibrium Equation

The force you must provide (F_{applied}) to hold the brick is:

$$F_{\text{app}} = F_g - F_b$$

Since both F_g and F_b are the same for Brick A and Brick B, the force required to hold them in place is **identical**.

Two cups are filled to the same level with water. One of the two cups has a plastic ball (density less than water) floating in it.

Which weighs more?

a) The cup without the ball.

b) The cup with the ball.

c) The two weigh the same.

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To understand why, compare the components of each cup's weight:

- **Cup 1 (Water only):** The weight consists of the cup itself plus the weight of the water filled to a specific level (h).
- **Cup 2 (Water + Ball):** This cup contains the ball, but because the ball is floating, it has **displaced** a volume of water.

Why the Weights Balance

When an object floats, it obeys the law of flotation:

1. **Buoyancy and Weight:** A floating object displaces a weight of fluid exactly equal to its own weight.
2. **The Level Constraint:** For the cup with the ball to have the same water level as the cup without the ball, a volume of water equal to the submerged portion of the ball must have been "removed" or was never there to begin with.
3. **The Substitution:** The weight of the plastic ball added to the second cup is exactly equal to the weight of the water that would have occupied the space the ball is now displacing.

Mathematical Verification

Let W_{cup} be the weight of the empty cup and W_{water} be the weight of water in the first cup.

- **Weight 1** $= W_{cup} + W_{water}$
- **Weight 2** $= W_{cup} + (W_{water} - W_{displaced\_water}) + W_{ball}$

Since the ball is floating:

$$W_{ball} = W_{displaced\_water}$$

Substituting this into the second equation:

$$\text{Weight 2} = W_{cup} + W_{water} - W_{displaced\_water} + W_{displaced\_water}$$
$$\text{Weight 2} = W_{cup} + W_{water}$$

Thus, **Weight 1 = Weight 2**.

A boat carrying a heavy mass is floating on water.
The heavy mass is thrown overboard and sinks.

The water level
https://www.youtube.com/watch?v=K4Y-52gVcEA

a) rises.

b) drops.

c) remains the same.

A boat carrying a heavy mass is floating on water. The heavy mass is thrown overboard and sinks.

The water level

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a) rises.

b) drops.

c) remains the same.

To understand this, we compare the amount of water displaced in two different states:

- State 1 (Mass on the boat): The combined mass of the boat and the heavy object is floating. According to Archimedes' Principle, a floating object displaces a weight of water equal to its own weight. Since the object is “heavy” (dense), it requires a large volume of water to be displaced to support its weight while it is on the boat.
- State 2 (Mass overboard): Once the mass is thrown overboard and sinks:
    - The Boat: Now lighter, it displaces less water.
    - The Mass: Because it has sunk, it no longer displaces water equal to its weight. Instead, it only displaces a volume of water equal to its own physical volume.

Why the Level Drops

Since the object is dense enough to sink, its weight is much greater than the weight of the water it occupies by volume.

- While floating on the boat, it was forcing the boat to displace a volume of water equivalent to its weight.
- While submerged at the bottom, it only displaces water equivalent to its size.

Because the weight-equivalent volume is much larger than the size-equivalent volume for a heavy object, the total amount of water “pushed up” by the system decreases when the object is thrown overboard. Therefore, the water level in the container drops.

A flat ice sheet (density 917 kg/m^3) of uniform thickness 1.00 m is supporting a 500-kg walrus just above the surface of seawater (density 1020 kg/m^3).

Calculate the area of the ice sheet.

A flat ice sheet (density 917 kg/m^3) of uniform thickness 1.00 m is supporting a 500-kg walrus just above the surface of seawater (density 1020 kg/m^3).

4.85 m^2

To find the area of the ice sheet required to support the walrus, we use the principle of static equilibrium and Archimedes' Principle. For the walrus to be "just above the surface," the ice s
submerged, meaning its top surface is level with the water.

1. Identify the Forces

- **Downward Force (F_g):** The total weight of the system, which includes the weight of the ice sheet and the weight of the walrus.
- **Upward Force (F_b):** The buoyant force, which is equal to the weight of the seawater displaced by the entire volume of the ice sheet.

2. Set Up the Equilibrium Equation

For the ice to be just at the surface, the buoyant force must balance the total weight:

Weight of Ice+Weight of Walrus=Buoyant Force
Using the formula for weight ($W=m\cdot g$) and density ($\rho=m/V$):

$(\rho_{ice} \cdot V_{ice} \cdot g)+(m_{walrus} \cdot g)=\rho_{seawater} \cdot V_{ice} \cdot g$

3. Simplify and Solve for Area

Since the ice sheet is a flat sheet of uniform thickness, its volume is $V_{ice} = Area\cdot thickness$ (A.t). We can also cancel out the acceleration due to gravity (g):

$(\rho_{ice} \cdot A\cdot t)+m_{walrus} =\rho_{seawater} \cdot A\cdot t$
Rearrange the equation to isolate the area (A):

$m_{walrus} =A\cdot t\cdot(\varrho_{seawater} - \varrho_{ice})$
$A=t\cdot(\rho_{seawater} - \rho_{ice})m_{walrus}$

4. Final Calculation

Substitute the given values:

- $m_{walrus} =500$ kg
- $t=1.00$ m
- $\rho_{seawater} =1020$ kg/m3
- $\rho_{ice} =917$ kg/m3

$A=1.00\cdot(1020-917)500$
$A=103500$
$A\approx4.85\ m^2$
The area of the ice sheet is approximately 4.85 m².