Physics Unit 5
This Slideshow was developed to accompany the textbook

*OpenStax Physics*

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*By OpenStax College and Rice University*

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Some examples and diagrams are taken from the textbook.

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## 05-01 FLUIDS AND DENSITY

<table>
<thead>
<tr>
<th>Phases of Matter</th>
<th>Liquid</th>
</tr>
</thead>
<tbody>
<tr>
<td>♦ Solid</td>
<td>♦ Liquid</td>
</tr>
<tr>
<td>🔄 Atoms in close contact so they can’t move much</td>
<td>🔄 Atoms move past each other</td>
</tr>
<tr>
<td>🔄 Set volume and shape</td>
<td>🔄 Set volume</td>
</tr>
<tr>
<td>🔄 Can’t compress</td>
<td>🔄 Takes shape of container</td>
</tr>
<tr>
<td>🔄 Can’t compress</td>
<td>🔄 Hard to compress</td>
</tr>
</tbody>
</table>
05-01 FLUIDS AND DENSITY

Gas
- Atoms far apart
- Neither set volume or shape
- Compressible

Fluids
- Flow
- Both liquids and gases
05-01 FLUIDS AND DENSITY

Density

\[ \rho = \frac{m}{V} \]

Where

\( \rho \) = density
\( m \) = mass
\( V \) = Volume

Things with small density float on things with more density

Solids most dense
Gases least dense

See Table 11.1
Can use density to determine unknown material

An ornate silver crown is thought to be fake. How could we determine if is silver without damaging the crown?

Find its mass using a balance. (It is 1.25 kg)

Find its volume by submerging in water and finding volume of displace water. (It is $1.60 \times 10^{-4} \text{ m}^3$)

Find the density

$\rho = 7.81 \times 10^3 \text{ kg/m}^3$

Table 11.1 says it is steel

Silver’s density is $10.5 \times 10^3 \text{ kg/m}^3$

$$\rho = \frac{m}{V}$$

$$\rho = \frac{1.25 \text{ kg}}{1.60 \times 10^{-4} \text{ m}^3} = 7.81 \times 10^3 \text{ kg/m}^3$$
05-01 FLUIDS AND DENSITY

Do the Density Lab

Objective
- Find the density in a coin and use it to help identify the metal.
- Use a Vernier caliper.

Materials
- Coins of standard metals
  - Japan 1 Yen (1955-1989)
  - Denmark 2 øre (1948-1972)
  - Italy 50 Lire (1955-1989)
  - France 1 Franc (1959-2001)
- Vernier caliper
05-01 HOMEWORK

- Don’t be dense, you can solve these problems
- Read 11.3, 11.4
The molecules in a fluid are free to wander around.

In their wanderings they sometimes collide with the sides of their container (i.e. balloon).

The more the molecules collide with the walls, the more force is felt.
05-02 PRESSURE AND DEPTH

\[ P = \frac{F}{A} \]

- P = Pressure
- F = Force perpendicular to surface
- A = Area of surface

♦ Unit: N/m² = Pa (pascal)
♣ 1 Pa is very small so we usually use kPa or atm
A parallel force would cause the fluid to flow because of Newton’s 3rd law
05-02 PRESSURE AND DEPTH

You are drinking a juice box. In the process you suck all the juice and air out of the box. The top of the box is 7.5 cm by 5 cm. If the air pressure is $1.013 \times 10^5$ Pa, how much force is acting on the top of the box?

$380 \text{ N} = 85 \text{ lbs}$

Would the force of the side of the box be more or less than the top?

More because more area

\[
A = 0.075 \text{ m} \times 0.05 \text{ m} = 0.00375 \text{ m}^2
\]

\[
P = \frac{F}{A} \Rightarrow 1.013 \times 10^5 \text{ Pa} = \frac{F}{0.00375 \text{ m}^2} \Rightarrow F = (1.013 \times 10^5 \text{ Pa})(0.00375 \text{ m}^2)
\]

\[
= 379.875 \text{ N}
\]
The force that squashes the juice box is from the weight of all the air above it.

Atmospheric Pressure at Sea Level

\[ 1.013 \times 10^5 \text{ Pa} = 1 \text{ atmosphere (1 atm)} \]
Do the Pressure vs. Depth Lab

When will the water flow out the farthest: when the water is nearly full, half-full, or nearly empty?

Hold the bottle over the bucket so that the water will flow out the hole into the bucket and loosen the bottle cap. Observe the flow of water. PUT THE CAP BACK ON!

Describe how the distance the water flowed out changed as the depth of the water changed.

The pressure of a fluid ________________ as depth increases. So pressure and depth are ________________ proportional. This can be written as ________________

Next Page

Increases; directly; P = kh
Increases; directly; $P = k \rho$

$P = \rho gh$

There is no pressure in the bottle to push the water out.
The column of static fluid experiences several vertical forces.

Since the fluid is not moving, it is in equilibrium and $\Sigma F = 0$.

There are horizontal forces also, but they will cancel each other.
\[ \sum F = P_2A - P_1A - mg = 0 \]
\[ P_2A = P_1A + mg \]
\[ \rho = \frac{m}{V} \rightarrow m = \rho V \]
\[ P_2A = P_1A + \rho Vg \]

\[ V = Ah \]
\[ P_2A = P_1A + \rho gAh \]
\[ P_2 = P_1 + \rho gh \]

\[ P = \rho gh \] where \( P \) is the pressure due to the fluid at a depth \( h \) below the surface.
05-02 PRESSURE AND DEPTH

♦ If the pressure is known at a depth, the pressure lower down can be found by adding $\rho gh$

♦ This assumes $\rho$ is constant with depth

♦ This is a good estimate for liquids, but not for gasses unless $h$ is small
Would Hoover Dam need to be just as strong if the entire lake behind the dam was reduced to an inch of water behind the dam, but the same depth as the lake?

Yes, the pressure depends only on the depth.
What is the total pressure at points A and B?

\[ P_1 = 1.013 \times 10^5 \text{ Pa} \]
\[ h = 5.50 \text{ m} \]
\[ \rho = 1000 \text{ kg/m}^3 \]

\[ P_A = P_1 + \rho gh \rightarrow 1.013 \times 10^5 \text{ Pa} + \left( 1000 \frac{\text{kg}}{\text{m}^3} \right)(9.80 \frac{\text{m}}{\text{s}^2})(5.50 \text{ m}) \]
\[ = 1.55 \times 10^5 \text{ Pa} \]

The pressures are the same because the depth is the same. It doesn’t matter that B has rock above it.
05-02 HOMEWORK

- Yes, there is a lot of pressure riding on this assignment

- Read 11.5, 11.6
Do the Pascal’s Principle Lab.

Did anything surprising happen?
The fluid has no where to go. It flows in the container, but cannot go anywhere so the whole pressure increases.
How much force must be exerted at A to support the 850-kg car at B? The piston at A has a diameter of 17 mm and the piston at B a diameter of 300 mm.

\( F = 26.7 \text{ N} \)

\[
P = \frac{F}{A}
\]

\[
F_{\text{car}} = 850 \text{ kg} \left( 9.8 \frac{m}{s^2} \right) = 8330 \text{ N}
\]

\[
A_{\text{car}} = \pi (0.150 \text{ m})^2 = 0.0705858 \text{ m}^2
\]

\[
F_A = ?
\]

\[
A_A = \pi (0.0085m)^2 = 0.00022698 \text{ m}^2
\]

\[
\frac{F}{A} = \frac{F}{A}
\]

\[
\frac{8330 \text{ N}}{0.0705858 \text{ m}^2} = \frac{F}{0.00022698 \text{ m}^2}
\]

\[F = 26.7 \text{ N}\]
05-03 PASCAL’S PRINCIPLE AND MEASURING PRESSURE

 Dakota Pressure

 Used by pressure gauges
 Measures pressure relative to atmospheric pressure

 Absolute Pressure

 Sum of gauge pressure and atmospheric pressure

 $P_{abs} = P_{gauge} + P_{atm}$
05-03 PASCAL’S PRINCIPLE AND MEASURING PRESSURE

- Open-Tube Manometer
  - U-shaped tube with fluid in it
  - One end is connected to the container of which we want to measure the pressure
  - The other end is open to the air
  - \( P_2 = \rho gh + P_{atm} \)

\[ \begin{align*}
  \cdot P_2 &= P_{abs} \\
  \cdot P_2 - P_{atm} &= P_{gauge}
\end{align*} \]
\[ P_2 = \rho gh \]
\[ P_2 = 13600 \text{ kg/m}^3 \times (9.80 \text{ m/s}^2) \times h \]
\[ P_2 = 1.33 \times 10^5 \text{ Pa/m} \times h \]

1 atm is 760 mm if we make \( P_2 = 1.013 \times 10^5 \text{ Pa} \)

Changes in weather are often due to change in air pressure. Low pressure = bad weather; high pressure = sunny weather
Let me pressure you into solving these problems

Read 11.7
Think of trying to push a beach ball under water

The water pushes it up

All fluids push things up because the pressure is higher at greater depths

The upward force is **buoyant force**
05-04 ARCHIMEDES’ PRINCIPLE

♦ Do the Buoyancy Lab.

♦ When you are finished DRY the washer before putting them away!!

♦ Make a conclusion about the buoyant force and the weight of water displaced.

The buoyant force = weight of water displaced.
05-04 ARCHIMEDES' PRINCIPLE

- $F_B = P_2A - P_1A$
- $F_B = (P_2 - P_1)A$

- $P_2 = P_1 + \rho gh \Rightarrow P_2 - P_1 = \rho gh$
- $F_B = (\rho gh)A$

- $\rho = \frac{m}{V} \Rightarrow m = \rho V$
- $V = Ah$
- $m = \rho hA$

- $F_B = mg = W_{\text{liquid}}$
05-04 ARCHIMEDES’ PRINCIPLE

Archimedes’ Principle

- Buoyant force = weight of the displaced fluid
  \[ F_B = W_{fl} \]

- If buoyant force ≥ gravity, then it floats
- If buoyant force < gravity, then it sinks
For not solid objects, think of a boat
05-04 ARCHIMEDES’ PRINCIPLE

✨ Specific Gravity

\[ \text{specific gravity} = \frac{\bar{\rho}}{\rho_{fl}} = \text{fraction submerged} \]

-if specific gravity < 1 it floats
-if specific gravity > 1 it sinks
An ice cube is floating in a glass of fresh water. The cube is 3 cm on each side. If the cube is floating so a flat face is facing up, what is the distance between the top of the cube and the water?

$0.25 \text{ cm}$

\[
\frac{\bar{\rho}}{\rho_{fl}} = \text{fraction submerged}
\]

\[
\frac{917 \frac{kg}{m^3}}{1000 \frac{kg}{m^3}} = 0.917
\]

$0.917(3 \text{ cm}) = 2.751 \text{ cm submerged}$

$3 \text{ cm} - 2.751 \text{ cm} = 0.249 \text{ cm above}$
A man tied a bunch of helium balloons to a lawn chair and flew to a great altitude. If a single balloon is estimated as a sphere with a radius of 20 cm and is filled with helium, what is the net force on one balloon?

\[ \sum F = F_B - W_{He} \]

\[ V_{balloon} = \frac{4}{3} \pi (0.2 m)^3 = 0.03351 m^3 \]

\[ F_B = \rho_{air} V_{balloon} g = \left(1.29 \frac{kg}{m^3}\right)(0.03351 m^3) \left(9.8 \frac{m}{s^2}\right) = 0.4236 N \]

\[ W_{He} = \rho_{He} V_{balloon} g = \left(0.179 \frac{kg}{m^3}\right)(0.03351 m^3) \left(9.8 \frac{m}{s^2}\right) = 0.05878 N \]

\[ \sum F = 0.4236 N - 0.05878 N = 0.3648 N \]

\[ \sum F = F_B x - W_{He} x - W_{man} = 0 \]

\[ (0.3648 N)x - (80 kg) \left(9.8 \frac{m}{s^2}\right) = 0 \]

\[ (0.3648 N)x = 784 N \]

\[ x = 2150 \text{ balloons} \]
05-04 HOMEWORK

- Be buoyed up by the thought of the joy derived from solving these problems

- Read 12.1, 12.2
Do the Air Streams Lab

All the motion observed in this lab was caused by differences in pressure.

In all the experiments, which way is the object move: towards or away from the moving air?

An object will move from higher to lower pressure. Where was the pressure the lowest: moving or still air?

Where was the pressure the highest?

Towards
Moving air
Still air
05-05 FLOW RATE AND BERNOULLI’S EQUATION

♦ Flow Rate

\[ Q = \frac{V}{t} \]

- \( Q \) = Flow rate
- \( V \) = Volume of fluid
- \( t \) = time

♦ \[ Q = \frac{V}{t} = \frac{A d}{t} = A \bar{v} \]

- \( A \) = cross-section area
- \( \bar{v} \) = average velocity of fluid
Since flow rate is constant for a given moving fluid

Equation of continuity
\[ \rho_1 A_1 \bar{v}_1 = \rho_2 A_2 \bar{v}_2 \]

If incompressible
\[ A_1 \bar{v}_1 = A_2 \bar{v}_2 \]

If incompressible and several branches
\[ n_1 A_1 \bar{v}_1 = n_2 A_2 \bar{v}_2 \]
B, then C, then A

My old woodstove had 8in round pipe, then entered 10in square chimney. Since the area got bigger, the smoke slowed down. That let the creosote in the smoke build up on the chimney walls more and cause chimney fires.
A garden hose has a diameter of 2 cm and water enters it at 0.5 m/s. You block 90% of the end of the hose with your thumb. How fast does the water exit the hose?

\[ v = 5 \text{ m/s} \]

Incompressible so

\[ A_1 \bar{v}_1 = A_2 \bar{v}_2 \]

\[ (\pi (0.01 \text{ m})^2) \left( 0.5 \frac{m}{s} \right) = 0.1 (\pi (0.01 \text{ m})^2) v \]

\[ v = 5 \frac{m}{s} \]
05-05 FLOW RATE AND BERNOULLI’S EQUATION

- When a fluid goes through narrower channel, it speeds up
- It increases kinetic energy
- \( W_{net} = \frac{1}{2} m v^2 - \frac{1}{2} m v_0^2 \)
- Net work comes from pressure pushing the fluid
05-05 FLOW RATE AND BERNOULLI’S EQUATION

- Derivation
- $W_{net} = E_f - E_0$
- $E = KE + PE$
  \[= \frac{1}{2}mv^2 + mgh\]
- $W_{net} = F \cdot x$
- $P = \frac{F}{A} \rightarrow F = PA \rightarrow Fx = PV$
- $W_{net} = (P_2 - P_1)V$
05-05 FLOW RATE AND BERNOULLI’S EQUATION

\[ W_{\text{net}} = (P_2 - P_1)V = \left( \frac{1}{2} m v_1^2 + m gh_1 \right) - \left( \frac{1}{2} m v_2^2 + m gh_2 \right) \]

- Divide by V and rearrange

\[ \rho = \frac{m}{v} \]

- Bernoulli’s Equation

\[ P_1 + \frac{1}{2} \rho v_1^2 + \rho gh_1 = P_2 + \frac{1}{2} \rho v_2^2 + \rho gh_2 \]

- This is a form of conservation of energy \( E_0 + W_{\text{nc}} = E_f \) where the net work comes from the pressure in the fluid.
Think about driving down a road with something in your car’s trunk. The object is too large to completely shut the trunk lid. While the car is stopped, the lid quietly rests as far down as it can go. As you drive down the road, why does the trunk open?

The air in the trunk is still. The air above the trunk is moving. The air in the trunk is at a higher pressure than above the trunk. So the trunk is pushed open.
The blood speed in a normal segment of a horizontal artery is 0.15 m/s. An abnormal segment of the artery is narrowed down by an arteriosclerotic plaque to one-half the normal cross-sectional area. What is the difference in blood pressures between the normal and constricted segments of the artery?

35.8 Pa

\[
P_1 + \frac{1}{2} \rho v_1^2 + \rho gh_1 = P_2 + \frac{1}{2} \rho v_2^2 + \rho gh_2
\]

\[
P_1 - P_2 = \frac{1}{2} \rho v_2^2 - \frac{1}{2} \rho v_1^2
\]

\[
A_1 v_1 = A_2 v_2
\]

\[
A_1 \cdot 0.15 \frac{m}{s} = \frac{1}{2} A_1 v_2 \rightarrow v_2 = 0.30 \frac{m}{s}
\]

\[
P_1 - P_2 = \frac{1}{2} \left(1060 \frac{kg}{m^3}\right) \left(0.30 \frac{m}{s}\right)^2 - \frac{1}{2} \left(1060 \frac{kg}{m^3}\right) \left(0.15 \frac{m}{s}\right)^2
\]

\[
P_1 - P_2 = 35.8 Pa
\]
Why do all houses need a plumbing vent?

Waste water flows through a sewer line.

Something like a sink is connected to the line, but there is a water trap to keep the sewer gasses from entering the house.

The flowing water in the sewer means the air directly above the flowing water has a lower pressure than the air above the sink.

This pushes the water in the trap down the pipe and sewer gasses enter the house.
05-05 FLOW RATE AND BERNOULLI’S EQUATION

(a) Without vent

(b) With vent

Clothes washer

Sink

Water-filled trap

To sewer

(To outside)

Roof

Vent
How do airplane wings work (even paper airplanes)?

The top of the wing is curved and the bottom is not. The air flows faster over the top of the wing, than the bottom. This pushes the wing up.
Bottom: spin against air flow ➔ slow relative velocity ➔ high pressure
Top: spin with air flow ➔ fast relative velocity ➔ low pressure
05-05 HOMEWORK

- The faster you work, the less pressure you’ll feel?

- Read 12.3
05-06 THE MOST GENERAL APPLICATIONS OF BERNOULLI’S EQUATION

- Previous examples of Bernoulli’s Equation had simplified conditions
- Bernoulli’s Equation work in real world
Water circulates throughout a house in a hot-water heating system. If the water is pumped at a speed of 0.50 m/s through a 4.0-cm-diameter pipe in the basement under a pressure of 3.0 atm, what will be the flow speed and pressure in a 2.6-cm-diameter pipe on the second floor 5.0 m above? Assume the pipes do not divide into branches.

\[ v_2 = 1.2 \frac{m}{s} \]

\[ p_2 = 2.5 \text{ atm} \]

Equation of Continuity

\[ v_1 A_1 = v_2 A_2 \]
\[ (0.50 \frac{m}{s}) (\pi (0.02 m)^2) = v_2 (\pi (0.013 m)^2) \]
\[ v_2 = 1.183 \frac{m}{s} \]

Bernoulli’s Equation

\[ p_1 + \frac{1}{2} \rho v_1^2 + \rho g h_1 = p_2 + \frac{1}{2} \rho v_2^2 + \rho g h_2 \]
\[ (3 (1.01 \times 10^5 \text{ Pa})) + \frac{1}{2} \left( 1000 \frac{kg}{m^3} \right) (0.50 \frac{m}{s})^2 + 0 \]
\[ = p_2 + \frac{1}{2} \left( 1000 \frac{kg}{m^3} \right) (1.183 \frac{m}{s})^2 + \left( 1000 \frac{kg}{m^3} \right) (9.8 \frac{m}{s^2}) (5.0 \text{ m}) \]
\[ 303125 \text{ Pa} = p_2 + 49700 \text{ Pa} \]
\[ p_2 = 253425 \text{ Pa} = 2.5 \text{ atm} \]
The tank is open to the atmosphere at the top. Find an expression for the speed of the liquid leaving the pipe at the bottom.

\[ v_1 = \sqrt{2gh} \]
Since Bernoulli’s Equation is conservation of energy, the water would rise up to the same height as the water in the tank.
**05-06 THE MOST GENERAL APPLICATIONS OF BERNOULLI’S EQUATION**

- Power in Fluid Flow
- Power is rate of work or energy
- Bernoulli’s Equation terms are in energy per volume
- Multiply Bernoulli’s Equation by volume and divide by time
  - Or multiply by flow rate $Q$
- $Power = \left( P + \frac{1}{2} \rho v^2 + \rho gh \right) Q$
05-06 HOMEWORK

- Apply yourself to these applications
- Read 12.4, 12.5
05-07 VISCOSITY, POISEUILLE’S LAW, AND TURBULENCE

- Viscosity
  - Fluid friction

- Laminar Flow
  - Smooth flow in layers that don’t mix

- Turbulent Flow
  - Has eddies and swirls that mix layers of fluid
  - Turbulent flow is slower than laminar flow
How viscosity is measured

Two plates with fluid between

Top plate moved

Friction causes the fluid to move

\[ \eta = \frac{FL}{vA} \]

\( \eta \) is coefficient of viscosity
F is force applied to top plate
L is distance between plates
v is speed that top plate is moved
A is area of plate
Resistance is most effected by radius

Laminar flow in tubes
- Difference in pressure causes fluids to flow

\[ Q = \frac{P_2 - P_1}{R} \]

Where
- \( Q \) is flow rate
- \( P_1 \) and \( P_2 \) are pressures
- \( R \) is resistance

Poiseuille’s law for resistance

\[ R = \frac{8\eta l}{\pi r^4} \]

Where
- \( \eta \) is viscosity
- \( l \) is length of tube
- \( r \) is radius of tube
Since flow rate depends on pressure

Higher pressure difference, higher Q

Higher resistance, higher pressure difference to maintain constant Q

In blood vessels this is a problem with plaque on artery walls
How to tell if laminar or turbulent flow

- Low speed with smooth, streamlined object → laminar
- High speed or rough object → turbulent

Reynolds number
- Below 2000 → laminar
- Above 3000 → turbulent
- Between 2000 and 3000 depends on conditions

\[ N_R = \frac{2 \rho v r}{\eta} \]

- \( N_R \) = Reynolds number
- \( \rho \) = fluid density
- \( v \) = speed of fluid
- \( r \) = radius of tube
- \( \eta \) = viscosity
A hypodermic syringe is filled with a solution whose viscosity is $1.5 \times 10^{-3} \text{ Pa} \cdot \text{s}$. The plunger area of the syringe is $8.0 \times 10^{-5} \text{ m}^2$, and the length of the needle is 0.025 m. The internal radius of the needle is $4.0 \times 10^{-4} \text{ m}$. The gauge pressure in a vein is 1900 Pa (14 mmHg). What force must be applied to the plunger, so that $1.0 \times 10^{-6} \text{ m}^3$ of solution can be injected in 3.0 s?

Is the flow laminar if the density is 1000 kg/m$^3$?

$L_n = 353; \text{ Yes}$

$F = 0.25 \text{ N}$

\[
\begin{align*}
\eta &= 1.5 \times 10^{-3} \text{ Pa} \cdot \text{s}, l = 0.025 \text{ m}, r = 4.0 \times 10^{-4} \text{ m}, P_1 = 1900 \text{ Pa}, V \\
&= 1.0 \times 10^{-6} \text{ m}^3, t = 3.0 \text{ s} \\
Q &= \frac{V}{t} = \frac{1.0 \times 10^{-6} \text{ m}^3}{3.0 \text{ s}} = 3.3 \times 10^{-7} \text{ m}^3/\text{s} \\
R &= \frac{8\eta l}{\pi r^4} = \frac{8(1.5 \times 10^{-3} \text{ Pa} \cdot \text{s})(0.025 \text{ m})}{\pi(4.0 \times 10^{-4} \text{ m})^4} = 3.730 \times 10^9 \text{ Pa} \cdot \text{s}/\text{m}^3 \\
Q &= \frac{P_2 - P_1}{R} \\
3.3 \times 10^{-7} \text{ m}^3/\text{s} &= \frac{P_2 - 1900 \text{ Pa}}{3.730 \times 10^9 \text{ Pa} \cdot \text{s}/\text{m}^3} \\
P_2 - 1900 \text{ Pa} &= 1243 \text{ Pa} \\
P_2 &= 3143 \text{ Pa} \\
P &= \frac{F}{A} \\
3143 \text{ Pa} &= \frac{F}{8.0 \times 10^{-5} \text{ m}^2} \\
F &= 0.25 \text{ N} \\
\text{Laminar?} \\
Q = A v &\Rightarrow \frac{3.33 \times 10^{-7} \text{ m}^3}{\text{s}} = \pi(4 \times 10^{-4} \text{ m})^2 v \Rightarrow v = 0.662 \text{ m/s}
\end{align*}
\]
\[ N_R = \frac{2\rho vr}{\eta} = \frac{2 \left( 1000 \ \frac{\text{kg}}{\text{m}^3} \right) \left( 0.662 \ \frac{\text{m}}{\text{s}} \right) \left( 4.0 \times 10^{-4} \ \text{m} \right)}{1.5 \times 10^{-3} \ \text{Pa} \cdot \text{s}} = 353 \]
05-07 HOMEWORK

💫 Let the answers flow

💫 Read 12.6, 12.7