Boğaziçi University

Introductory Phys Labs

THE RATIO OF HEAT CAPACITIES OF AIR, $\gamma = C_P/C_V$

PHYL102

THEORY

HEAT CAPACITY

The heat capacity of a gas is the amount of energy needed to increase its temperature by 1°C.

$$Q = C\,\Delta T$$

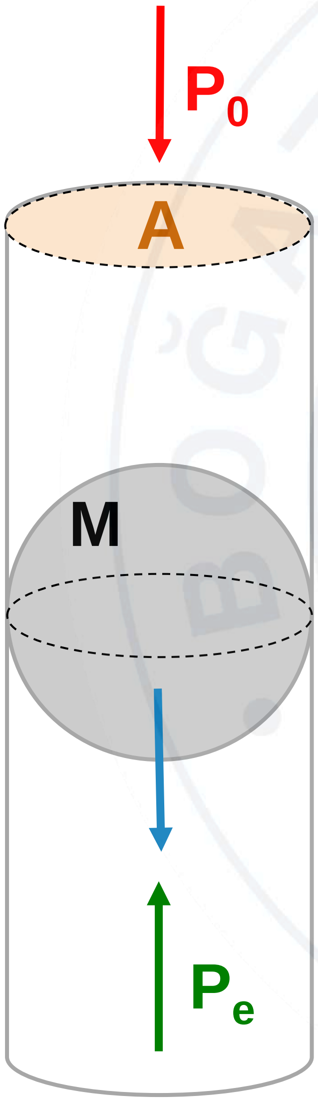
- C_P is the heat capacity at constant pressure (isobaric process).
- C_V is the heat capacity at constant volume (isovolumetric process).
- The ratio of these heat capacities is represented by the Greek letter γ (gamma) and defined as

$$\gamma = C_P/C_V$$

THE RATIO OF HEAT CAPACITIES OF AIR, γ=C_P/C_V

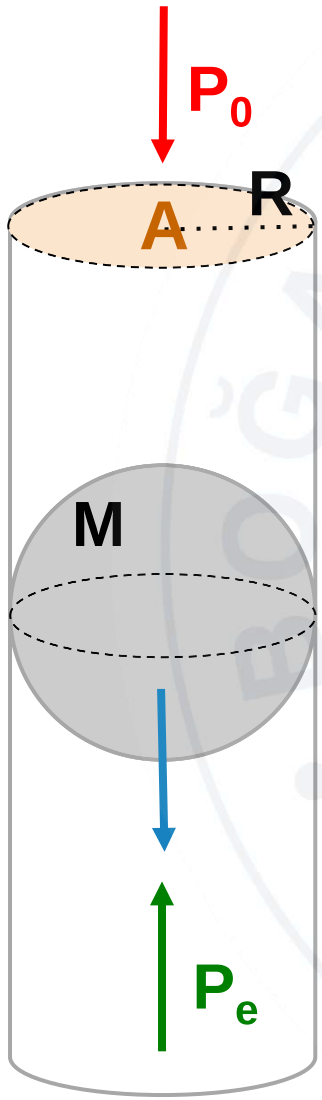
The ratio of heat capacities of air is a thermodynamic quantity but it can be determined by observing
a totally mechanical process: oscillation of a steel ball.

OSCILLATION OF THE BALL



If a ball with mass M is in equilibrium inside a tube with cross-sectional area A, the air pressure inside the tube is equal to atmospheric pressure + pressure exerted by the ball.

$$P_e = P_0 + \frac{Mg}{A}$$



$$P_e = P_0 + \frac{Mg}{A}$$

- **Atmospheric Pressure P_0**

$$P_0 = \rho g h$$

★ **P_0 is measured with barometer**

(ρ: density of Mercury)

(h: height of Mercury in the barometer)

- **Cross-Sectional Area A**

$$A = \pi R^2$$

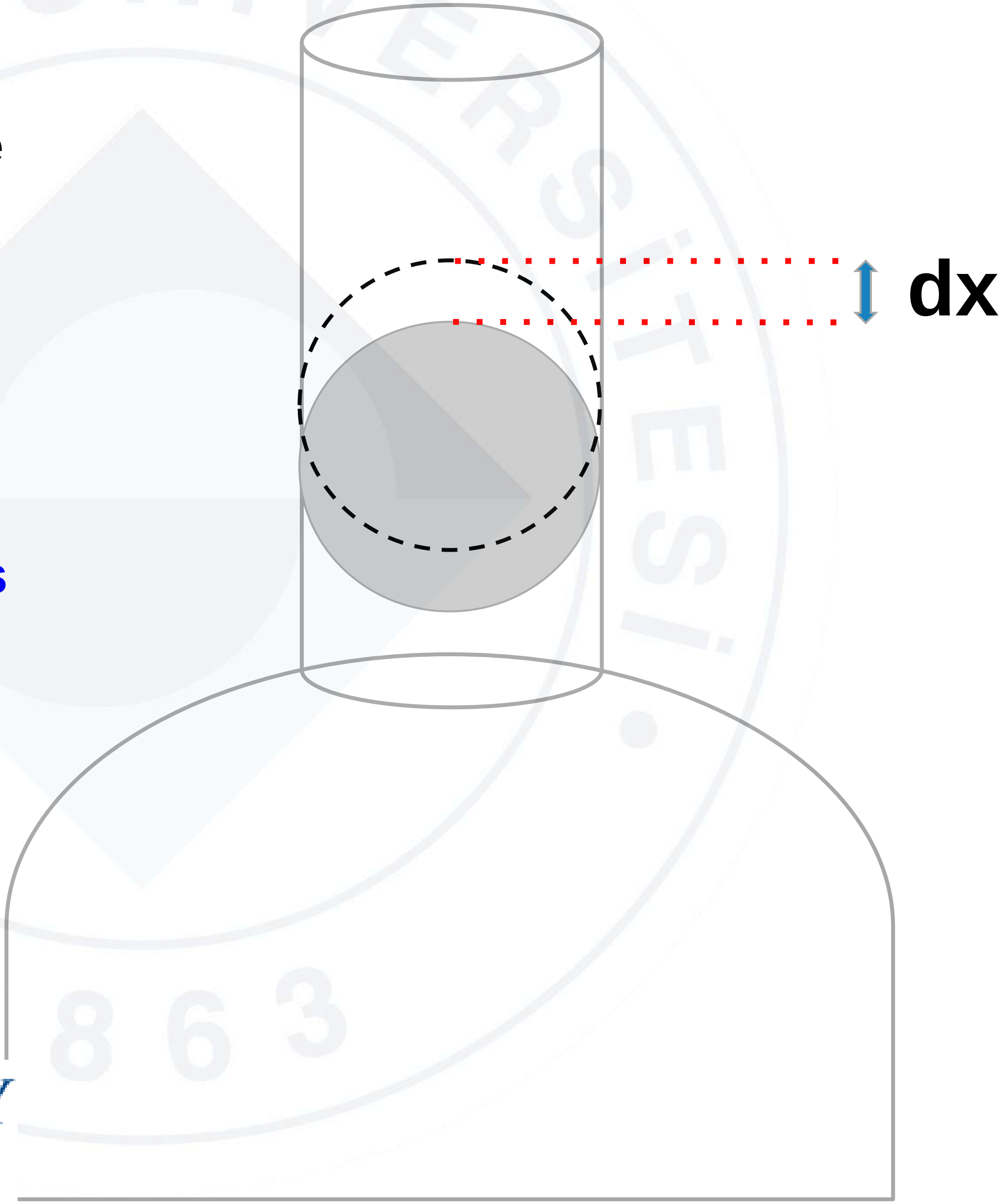
THE RATIO OF HEAT CAPACITIES OF AIR, $\gamma=C_P/C_V$

A small deviation dx of the ball from the equilibrium position makes the air inside the tube expand and compress.

The expansion/compression causes a change ΔP in the pressure.

The pressure change applies a net force on the ball and makes it accelerate.

$$A\,\Delta P = M\frac{d^2x}{dt^2}$$



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THE RATIO OF HEAT CAPACITIES OF AIR, $\gamma = C_P/C_V$

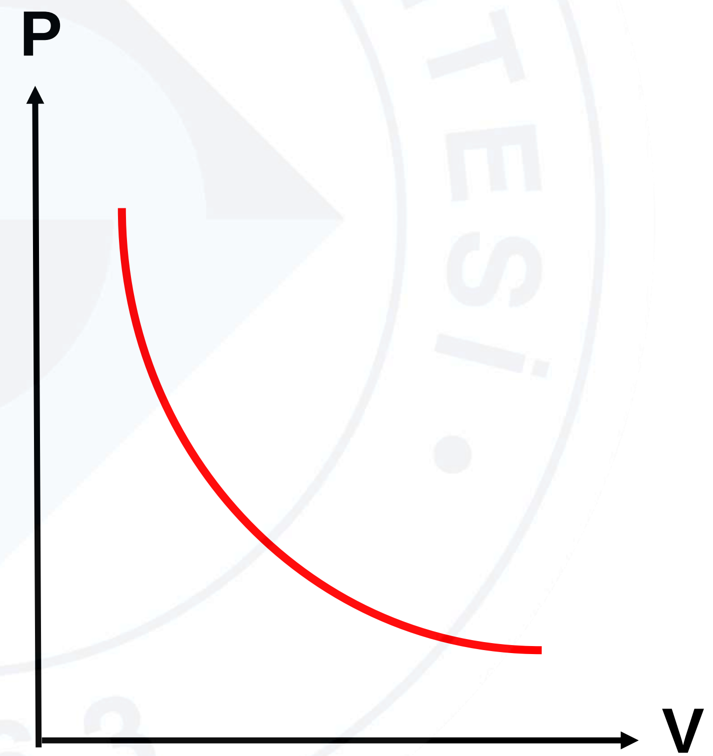
The expansion/compression of the air is an adiabatic process since there is no heat exchange.

In an adiabatic process, the pressure and volume obeys the following relation

$$P V^{\gamma} = \text{constant}$$

where

$$\gamma = C_P / C_V$$



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Taking the variation of this expression,

$$\Delta P\, V^{\gamma} + P\, \gamma\, V^{\gamma-1} \Delta V = 0$$

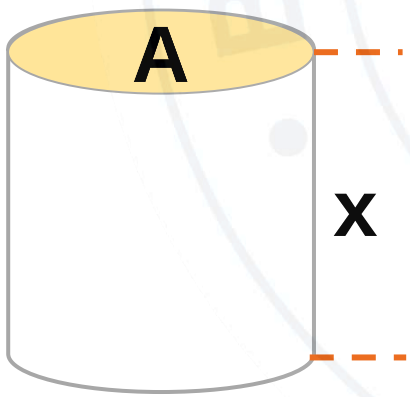
we can calculate the pressure change ΔP,

$$\Delta P = -\frac{P\, \gamma\, \Delta V}{V}$$

and substitute it into the acceleration equation:

Now, the equation of motion of the ball is

$$\frac{d^2x}{dt^2} + \frac{\gamma\, PA\, \Delta V}{MV} = 0$$



ΔV is the volume traced by the ball when it moves up and down inside the tube.

$$\Delta V = Ax$$

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Finally, the acceleration equation of the ball becomes

$$\frac{d^2x}{dt^2} + \frac{\gamma PA^2}{MV}x = 0$$

$$\frac{d^2x}{dt^2} + \omega^2 x = 0$$

$$T = \frac{2\pi}{\omega}$$

Since the equation of simple harmonic motion is the period of the oscillation is given by

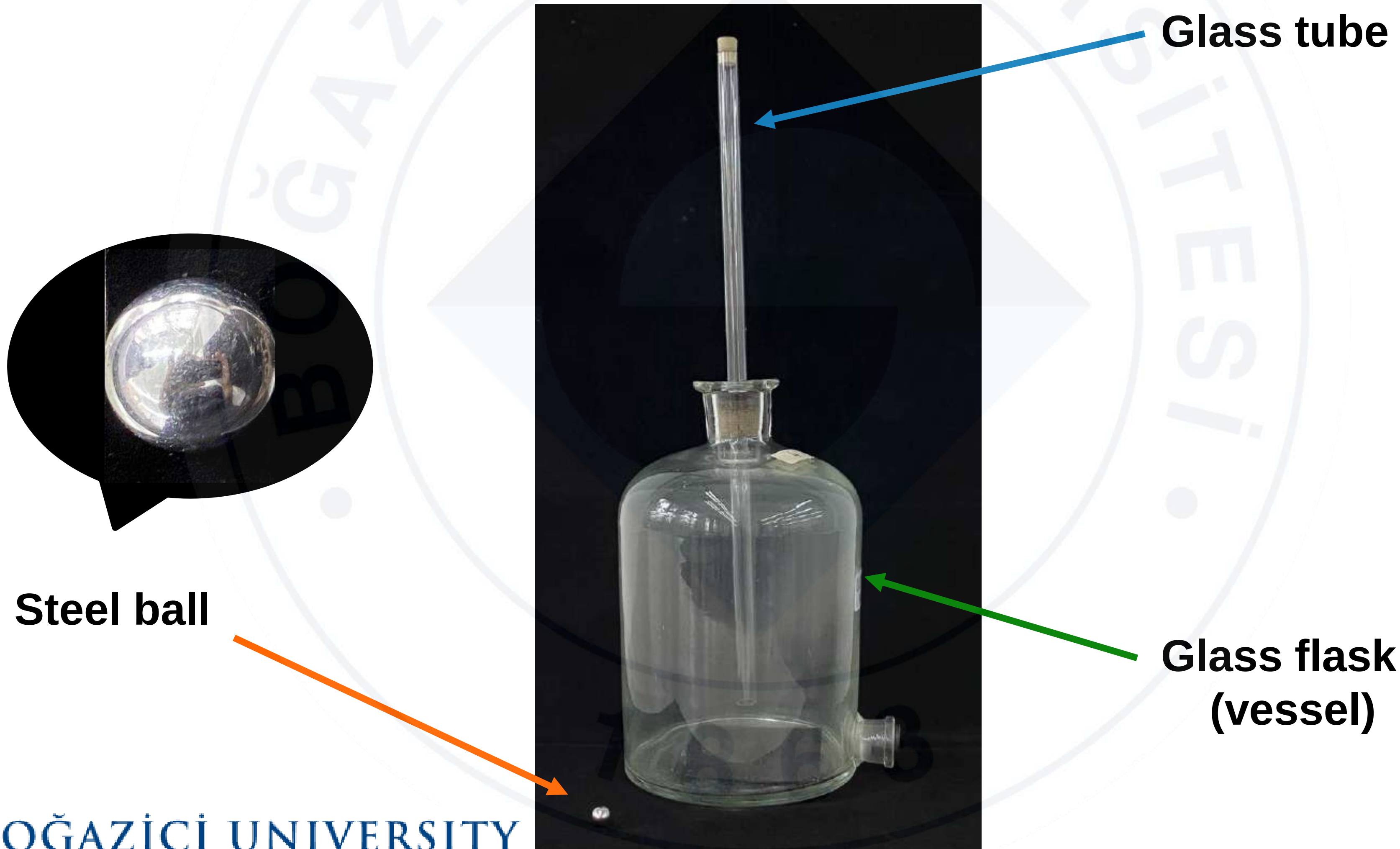
$$T = 2\pi\sqrt{\frac{MV}{\gamma PA^2}}$$

where $P = P_e$

APPARATUS

THE RATIO OF HEAT CAPACITIES OF AIR, $\gamma = C_P/C_V$

Apparatus: **Glass Flask (Vessel), Glass Tube, Steel Ball, Stopwatch, Vernier Calipers**



THE RATIO OF HEAT CAPACITIES OF AIR, $\gamma = C_P/C_V$

Glass flask in details

Flask number

Glass tube

Steel ball

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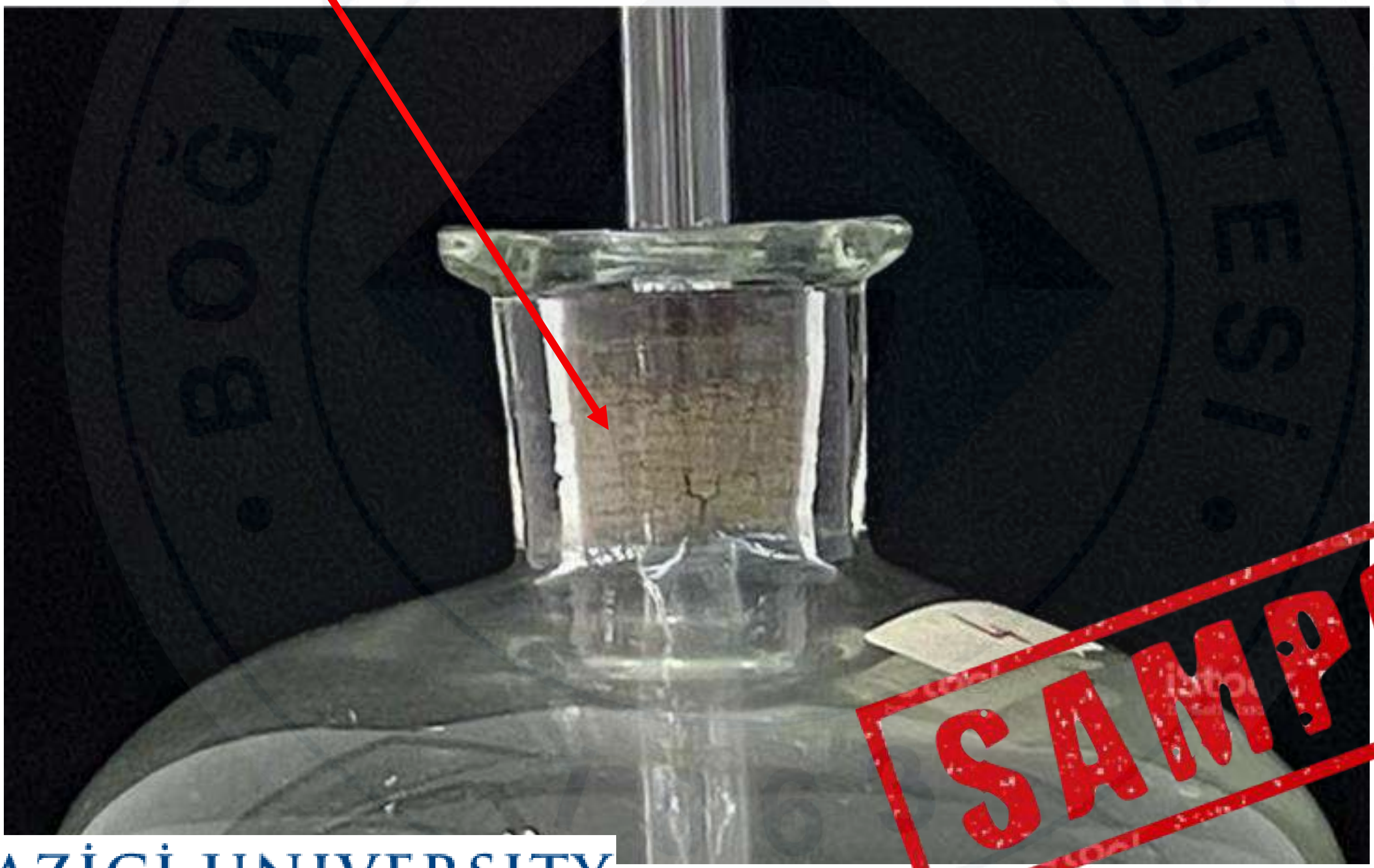
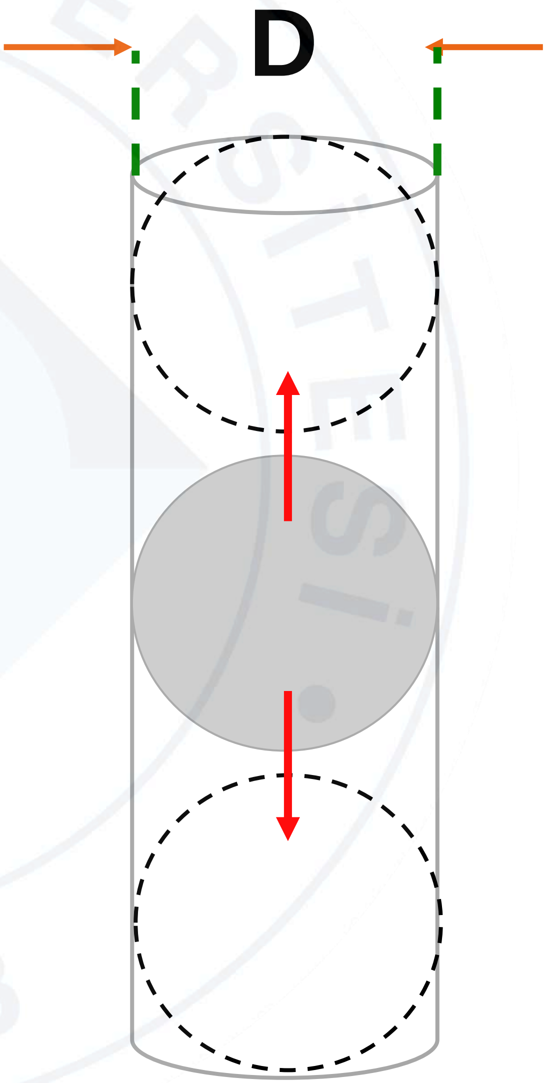
The glass tube is attached to the top of the glass vessel thanks to a cork which prevents the air inside the vessel from leaking when the ball released through the tube.



THE RATIO OF HEAT CAPACITIES OF AIR, $\gamma = C_P/C_V$

- The steel ball fits to the diameter of the tube but can move up and down easily.

- Cross-sectional areas of ball and tube are equal.



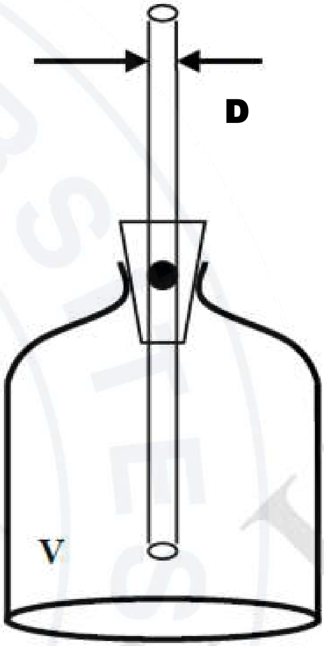
EXPERIMENT

THE RATIO OF HEAT CAPACITIES OF AIR, $\gamma = C_P/C_V$

What to measure : Height of the barometer (h), mass and diameter of the ball (M,D), time for n oscillations (t)

What to calculate : Period of oscillation (T), cross-sectional area (A), atmospheric pressure (P_0), equilibrium pressure (P_e)

Experimental findings : Ratio of heat capacities of air (γ_{air})



Volume V of the flask can be read from the list according to the flask number. The list and your flask number are in Classroom.

Be aware that volume is in unit of liter but you work in CGS units.

PROCEDURE:

The ball is dropped into the tube. The oscillation of the ball is observed.

- **The time for n oscillations (at least 5) is measured using a stopwatch.**
- **This procedure is repeated for 5 trials.**

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(fill in the Table)

# of Trials	# of Oscillations *(n)*	Time for n Oscillations *t* ( )	Time for One Oscillation (Period) *T* ( )
1			
2			
3			
4			
5			

By using the data taken, calculate:

Radius of the ball $R=$ . . . .

Cross sectional Area
of the precision tube $A=$ . . . .

Atmospheric Pressure $P_o = \rho g h =$ . . . .

(fill in the page)

. . . .

Pressure inside the bottle
at Equilibrium Position
of the Ball $P_e = P_o + \frac{mg}{A} =$ . . . .

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(fill in the page)

Average Period T_{average} = ...

. . . .

Ratio of Heat Capacities $\gamma = C_p / C_v$ = ...

. . . .

Show the Dimensional Analysis of γ clearly