According to new syllabus of all intermediate boards of Sindh.

Prof. Rawala's ....

PHYSICS

HELPING BOOK

For
Class XI
(All science students)

UNIT -7

Fluid dynamics.

CONTENTS

Thoroughly revised and updated 2026 – 2027

- ***Detailed notes.***
- ***Multiple Choice Questions (M.C.Q's).***
- ***Solution of text book numericals.***
- ***MCQs and solution of numericals from Karachi board past papers.***

Prof.**(r) **Mohammed Hussain Rawala.
B.Sc. (Hons.), M.Sc.(Physics)
Former head of physics department.
Saint Patrick's college, Karachi.

Unit. 7**.....** ✍

Fluid dynamics

Fluids:

Q.No.1: What is a fluid?

Ans: There are three states of matter. States of matter that can flow are called ***fluids***. Since liquids and gasses can flow therefore, broadly speaking they are called **fluids**.

Q.No.2: What is fluid dynamics (or Aerodynamics related with water)?

Ans: **Fluid dynamics** is a branch of physics in which we study properties of a flowing fluid.

Fluid friction or viscosity:

Q.No.3: What is viscosity of a fluid?

Ans: Imagin a number of layers of a flowing liquid. The lowest layer of a flowing liquid which is in contact with a solid surface will be at ***rest***, It retards the flow of layer immediately above it, which in turn retards the flow of next layer above it, in this manner each layer opposes the motion of layer immediately above it. Hence there is an internal force of friction between adjacent layers of a liquid, this force of friction acts parallel to the surface of layers and is known as ***fluid friction*** or ***viscous force*** and this property of fluids is called ***VISCOSITY***.

- ❖ Liquids have higher viscosity than gasses.
- ❖ Viscosity slows down the flow of a fluid.

Since honey has a **very high viscosity** as compared with water, therefore, honey flows **slowly** whereas water can flow **quickly**.

Similarly, a gas can flow **easily** as compared a liquid because gasses have **low viscosity**.

- ❖ Honey, syrup, motor oil, cooking oil, paints etc. are liquids of high viscosity, hence they flow slowly. Whereas water, sprit, kerosene oil etc. are liquids of low viscosity, therefore they can flow quickly. In general gasses have even **lower viscosity** as compared to liquids.

Derivation:

Viscous force "F" between layers of a liquid is directly proportional to the rate of change of velocity of liquid layers with respect to distance "$\Delta v/l$" perpendicular to the direction of flow of layers. Viscous force is also directly proportional to area "A" of contact of layers.

Hence:
$$F \propto -A\frac{\Delta v}{l}$$

OR
$$F = -\eta A\frac{\Delta v}{l}$$

Where "η" is the constant of proportionality known as ***"coefficient of viscosity"***.

❖ Highly viscous fluids have high value of coefficient of viscosity "η". ***In other words,*** "η" is a measure of viscosity of a fluid. Negative sign is used just to show that the viscous force opposes internally the relative motion between different layers. Hence if there is velocity gradient between different layers of a fluid there will be viscous force between them due to which it will have some viscosity.

For Honey the value of "η" is high and for water the value of "η" is low, which shows that honey is a highly viscous and water is less viscous, as a result of which honey flows slowly and water flows quickly.

Viscosity of a fluid also depends upon its ***temperature***. As the temperature of a liquid rises its viscosity ***decreases***. But viscosity of a gas ***increases*** with a rise in its temperature.

- S.I unit of η is **N . s/m²** = **Pa . s** (N/m^2 = Pascal Pa)
- C.G.S unit of η is **dyne . s/cm²**.

But C.G.S unit of η is commonly known as "Poise" (i.e. **dyne . s/cm² = poise**)

$$1 \text{ N . s/m}^2 = 10 \text{ poise.}$$

Velocity gradient:

***Q.No.4*: What is velocity gradient?**

***Ans*:** Velocity gradient may be defined as:

"***The rate of change of velocity with respect to distance normal (perpendicular) to the direction of flow of liquid layers"***.

Higher the value of velocity gradient more viscous is a fluid i.e. the fluid will offer more force to resist the liquid flow or to the motion of a body through it.

Terminal velocity:

***Q.No.5*: What is terminal velocity?**

Ans*:** When a small spherical body of radius "r" is dropped slowly in a viscous fluid of coefficient of viscosity "η" then at first it falls under its weight and has some acceleration. As soon as it enters the fluid the fluid exerts a force opposite to its weight. This force exerted by the fluid because of Its viscosity is called "Drag force***". As soon as the drag force balances weight of the spherical body, net force acting on the falling body will be zero, hence acceleration of the body also becomes **zero**. It then on moves down with a **uniform velocity**. This constant velocity with which the spherical body moves through the fluid is called its ***"terminal velocity***."

Derivation:

Viscous or drag force exerted by a fluid on a body moving through it depends upon viscosity of the fluid, size, shape and terminal velocity of the body.

According to Stocke's law viscous or drag force "F" acting on a small **spherical** body of radius "r" moving with a uniform velocity "v" through a viscous fluid of coefficient of viscosity "η" is given by:

$$F = 6 \pi \eta r v$$

Note that this formula is valid only for a **spherical body** moving with a uniform velocity through a viscous fluid. Formula for drag force for any other shape will be different.

When a spherical body moves with a constant terminal velocity through a viscous medium, its weight is balanced by viscous drag force, hence:

$$6 \pi \eta r v = m g$$

If "ρ" is the density of the viscous medium and $(4/3) \pi r^3$ is volume of the spherical body, then its mass "m" is given by:

$$m = \rho \times (4/3) \pi r^3$$

$$\therefore \quad 6 \pi \eta r v = \rho \times (4/3) \pi r^3 g$$

$$\therefore \quad v = \frac{\rho \times (4/3) \pi r^3 g}{6 \pi \eta r}$$

Simplifying this equation we get:

$$\boxed{v = \frac{2 r^2 \rho g}{9 \eta}}$$

This formula gives us terminal velocity "v" of a spherical body of density "ρ" moving through a viscous medium of coefficient of viscosity "η" at a given location (constant g). It shows that at a given location, at a given temperature and in a given liquid the terminal velocity "v" of a spherical body is directly proportional to square of its radius (r^2).

Types of fluid flow:

Liquid flow is basically of two types **steady** and **unsteady** flow.

Steady (Streamline or Laminar) flow:

Q.No.6: What is steady (or stream line) flow?

Ans: In steady flow of a fluid properties of the fluid **do not change with time**.

For example, velocity "v" of particles of the fluid, viscosity of the fluid "η" and pressure "P" of the fluid etc. **do not change** with time.

It means that speed "v" of particles of the flowing fluid will be the same everywhere and in the same direction at different instants. **In other words,** particles of the fluid will travel **parallel** to each other with the same velocity at different instants, and will **not cross** each other's path.

- **Streamline** is a line which shows path of a particle in a flowing fluid, such that a tangent to the line at any particular instant shows the direction of velocity of a particle at that instant.

In steady or streamline or laminar flow of a fluid, streamlines showing the path of moving particles of the fluid are **parallel** to each other, ***in other words*** all the particles of the fluid move in the **same direction** with the **same speed**.

- ❖ Steady, streamline or laminar flow of fluids is usually observed when a fluid of high viscosity is flowing slowly.

Unsteady (irregular or turbulent) flow:

Q.No.7: What is unsteady (or turbulent) flow?

Ans: In unsteady flow of a flowing fluid, properties of the fluid **change with time**.

For example, velocity "v" of particles of the fluid, viscosity of the fluid "η" and pressure "P" of the fluid etc. **change** with time.

It means that velocity "v" of particles of the fluid will be different everywhere. **In other words,** particles of the fluid will travel with different speeds in different directions, and will **cross** each other's path.

In unsteady, irregular or turbulent flow of a fluid streamlines showing the path of moving particles of the fluid are **not parallel** to each other, in other words particles of the fluid move in **different directions** with **different velocities**, different streamlines cross each other.

Incompressible flow:

Q.No.8: What is incompressible flow?

Ans: Incompressible flow of a fluid is that in which during the flow density **does not change**, although pressure may change. Mostly **liquids are incompressible** whereas, **gasses are compressible**.

(In other words, under normal conditions liquids **may be considered incompressible**, whether they are **at rest** or **in motion**)

Non-viscous flow:

Q.No.9: What is non-viscous flow?

Ans: It is the flow of an incompressible and non-viscous fluid in which a fluid can flow without any dissipation of energy for doing work against viscous force.

All real fluids have some viscosity; some have **low** and some have **high** viscosity. Hence depending upon their viscosity there is some dissipation of energy during their flow. **It means that** a totally incompressible fluid having zero viscosity will be an **ideal fluid**.

Raynold number:

***Q.No.10*: What is Raynold number?**

Ans: Raynold number is ***the ratio of inertial force to the viscous force.***
Since it is the ratio of two similar quantities therefore, it is a ***dimensionless*** quantity.

Raynold number is given by:

$$\text{Raynold number} = \frac{\text{fluid velocity} \times \text{internal diameter}}{\text{Kinetic viscosity}}$$

Where

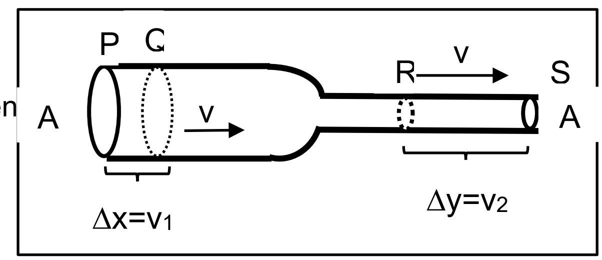
$$\text{Kinetic viscosity} = \frac{\text{Dynamic viscosity}}{\text{Fluid density}}$$

- If Raynold number "R_e" is less than 2300 ($R_e < 2300$) then the flow of fluid is Laminar or regular.
- If Raynold number is greater than 2300 but less than 4000 ($2300 > R_e < 4000$) then the flow of fluid is transient, this type of flow of a fluid occurs just before the turbulent conditions.
- If Raynold number is greater than 4000 ($R_e > 4000$) then the flow of fluid is turbulent.

Equation of continuity:

***Q.No.11*: Derive equation of continuity.**

Ans: For an incompressible fluid the mass flow rate $\Delta m/\Delta t$ (rate of flow of its mass) at different points through the fluid is constant. This is in accordance with **law of conservation of mass**.



Let a liquid flow from point P to Q in time Δt with velocity v_1 through wider section of a pipe of area A_1, then the volume of liquid flowing from P and Q will be "$A_1 \Delta x$". But velocity "v_1" with which liquid is flowing is given by: velocity $v_1 = \frac{\text{Distance covered } \Delta x}{\text{time taken } \Delta t}$ OR $\Delta x = v_1 \Delta t$

$\therefore$ volume of liquid flowing from P to Q will be "$A_1 v_1 \Delta t$".

$$\text{Density of liquid } \rho = \frac{\text{mass of liquid } \Delta m}{\text{Volume of liquid}}$$

$$\rho = \frac{\Delta m}{A_1 v_1 \Delta t}$$

OR

$$\frac{\Delta m}{\Delta t} = \rho A_1 v_1 \text{ .... } (i)$$

This equation gives us **mass flow rate** of the liquid between P and Q.
Similarly mass flow rate of the liquid between R and S is given by:

$$\frac{\Delta m}{\Delta t} = \rho A_2 v_2 \text{ .... } (ii)$$

Mass flow rate $\Delta m/\Delta t$ (rate of flow of mass of liquid) at different points in a flowing liquid is constant. Hence left hand side of both equations will be equal.

$$\rho A_1 v_1 = \rho A_2 v_2$$

Since the liquid is **incompressible** therefore, its density "ρ" throughout the pipe will be the same.

$$\therefore \qquad \boxed{A_1 v_1 = A_2 v_2}$$

This equation is known as **equation of continuity**.
From this equation we can see that when a liquid flows through wide pipe of area of cross section "A_1" its velocity "v_1" will be **small** i.e. the liquid will flow **slowly** whereas while flowing through

narrow section of the pipe of **small** area of cross-section "A_2" its velocity "v_1" will be **high** i.e. the liquid will flow **with high speed.** In other words, **large** "A_1" **small** "v_1" and **small** "A_2" **large**"v_2". This shows that speed of a fluid changes with diameter of the pipe.

The product "A v" gives us "**volume rate of flow**".

Its S.I unit is m^3/s.

Bernoulli's principle:

***Q.No.12*: State and derive Bernoulli's principle.**

***Ans*:** Bernoulli's principle (or Bernoulli's theorem or Bernoulli's equation) is based upon law of conservation of energy. It states that:

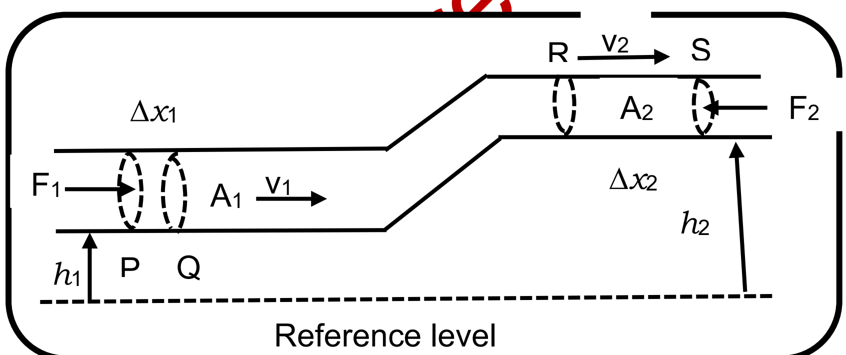
$$\boxed{P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}}$$

Derivation:

Consider an incompressible fluid (such as water) flowing with velocity "v_1" through a pipe of area of cross- section "A_1". Force "F_1" is exerted from left side moves the liquid through "Δx_1". This force will do some **work "$F_1 \Delta x_1$"on** the liquid, where Δx_1 is the distance through which the liquid moves from P to Q. Similarly force "F_2" exerted to oppos its Flow, this force acts over distance "Δx_2" . Hence **work done by** this force will be " $F_2 \Delta x_2$". Net **work done on** the liquid Is given by:

Net work done **on** = $F_1 \Delta x_1 - F_2 \Delta x_2$

This work done on the liquid will change Its kinetic and potential energies, as the liquid flows with different velocities "v_1" and "v_2" between points P Q and R S.



at the same time, it is lifted from height "h_1" to "h_2" ("h_1" and "h_2" are measured from some reference level). Hence:

Change in kinetic energy = $\frac{1}{2} m_1 v_1^2 - \frac{1}{2} m_2 v_2^2$

Change in potential energy = $m_1 g h_1 - m_2 g h_2$

Net **work done on** the liquid must be equal to the sum of change in Kinetic and potential energies, Hence

$$F_1 \Delta x_1 - F_2 \Delta x_2 = \left(\frac{1}{2} m_1 v_1^2 - \frac{1}{2} m_2 v_2^2\right) + (m_1 g h_1 - m_2 g h_2)$$

OR $$F_1 \Delta x_1 + \frac{1}{2} m_1 v_1^2 + m_1 g h_1 = F_2 \Delta x_2 + \frac{1}{2} m_2 v_2^2 + m_2 g h_2$$

For incompressible liquid mass "m_1" flowing from P to Q will be equal to "m_2" flowing from R to S,

$\therefore$ $m_1 = m_2 = m$

$\therefore$ $F_1 \Delta x_1 + \frac{1}{2} m v_1^2 + m g h_1 = F_2 \Delta x_2 + \frac{1}{2} m v_2^2 + m g h_2$

But $F_1 = P_1 A_1$ (P_1 is the pressure of fluid at the left-hand side),

and $F_2 = P_2 A_2$ (P_2 Is the pressure of fluid at the right hand side)

$\therefore$ $P_1 A_1 \Delta x_1 + \frac{1}{2} m v_1^2 + m g h_1 = P_2 A_2 \Delta x_2 + \frac{1}{2} m v_2^2 + m g h_2$

But $A_1 \Delta x_1 = V_1$ (V_1 = volume of liquid between P and Q)

and $A_2 \Delta x_2 = V_2$ (V_2 = volume of liquid between R and S)

$\therefore$ $P_1 V_1 + \frac{1}{2} m v_1^2 + m g h_1 = P_2 V_2 + \frac{1}{2} m v_2^2 + m g h_2$

Since the liquid is incompressible (cannot be compressed) its volume "V_1" flowing from P to Q will be equal to its volume "V_2" flowing during the same time from R to S, i.e. $V_1 = V_2 = V$

$$\therefore \quad P_1 V + \tfrac{1}{2} m v_1^2 + mgh_1 = P_2 V + \tfrac{1}{2} m v_2^2 + mgh_2$$

Dividing this equation throughout by "V" we get:

$$\therefore \quad P_1 + \tfrac{1}{2} \frac{m}{V} v_1^2 + \frac{m}{V} gh_1 = P_2 + \tfrac{1}{2} \frac{m}{V} v_2^2 + \frac{m}{V} gh_2$$

But density $\rho = \frac{\text{mass m}}{\text{Volume V}}$ (ρ is the density of fluid, which is constant everywhere for an incompressible fluid)

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

In other words: $\mathbf{P + \tfrac{1}{2} \rho v^2 + \rho g h = Constant}$

This is Bernoulli's equation.

Note that while flowing through a pipe of variable area of cross section, in wider section of the pipe **pressure** of the liquid is **high,** but **speed** of flow is **low**, whereas, in narrow section of the pipe **pressure** is **low** but **speed** of flow is **high**. These observations are in accordance with Bernoulli's theorem, equation of continuity is also satisfied.

***Applications of Bernoulli's principle*:**

There are many devices, machines etc. whose working is based upon Bernoulli's principle. For example working of "***Venturi meter***" which is used to measure rate of flow of a fluid through a pipe, just by measuring the pressure difference at two points of different area of cross section, "***Bunsen burner***" (used for heating purpose in laboratory), ordinary spray pump, also called an "***Atomizer***" (used for spraying insecticide, mosquito sprayer), shape of wings of airplane acts as "***an airfoil***" that moves through air with such a speed that a pressure difference above and below the airplane is produced. This difference in pressure provides lift to the airplane. This pressure difference takes place in accordance with "Bernoulli's principle".

Section–A Multiple-Choice Questions MCQs:

Q.No.1: For an incompressible fluid the flow rate is:
(A) equal for all surfaces.
(B) constant throughout the pipe.
(C) greater for the larger parts of the pipe
(D) None of the above.

Q.No.2: Bernoulli's principle states that for horizontal flow of a fluid through a tube, the sum of pressure and energy of motion per unit volume is:
(A) increasing with time.
(B) decreasing with time.
(C) constant. (D) varying with time.

Q.No.3: Which of the following is associated with the law of conservation of energy in fluids?
(A) Archimede's principle. (B) Bernoulli's principle.
(C) Pascal's principle. (D) Equation of continuity

Q.No.4: As the speed of a moving fluid increases, the pressure in the fluid:
(A) increases. (B) remains constant.
(C) decreases,
(D) may increase or decrease, depending on the viscosity.

Q.No.5: If the cross- sectional area of a pipe decreases, what happens to the fluid viscosity?
(A) Increases. (B) decrease.
(C) remains the same.
(D) depends on the fluid density

Q.No.6: A sky diver falls through the air at terminal velocity. The force of air resistance on him is:
(A) half his weight. (B) equal to his weight.
(C) twice his weight.
(D) cannot be determined from the information given.

Q.No.7: Wind speeding up as it blows over the top of a hill:
(A) Increases atmospheric pressure.
(B) decrease atmospheric pressure.
(C) Doesn't affect atmospheric pressure there.
(D) equal's atmospheric pressure.

Q.No.8: A fluid is undergoing "incompressible" flow. This means that:
(A) the pressure at a given point cannot change with time.
(B) The velocity at a given point cannot change with time.
(C) The velocity must be the same everywhere.
(D) The pressure must be the same everywhere.
(E) the density cannot change with time or location.

Q.No.9: A fluid is undergoing steady flow. Therefore:
(A) the velocity of any given molecule of fluid does not change.
(B) the pressure does not vary from point to point.
(C) the velocity of any given point does not vary with time.
(D) the density does not vary from point to point.

Q.No.10: The equation of continuity for fluid flow can be derived from the conservation of:
(A) energy. (B) mass.
(C) volume. (D) pressure.

Q.No.11: This is associated with law of conservation of energy in fluids:
(***2025 Karachi Board***)
(A) Archimede's principle.
(B) Pascal's principle.
(C) Bernoulli's principle.
(D) Equation of continuity.

Q.No.12: A fluid is flowing through a pipe of variable cross-sectional area. The decrease in cross-sectional area of the pipe results in:
(***2026 Karachi Board***)
(A) Decrease in velocity.
(B) Increase in velocity.
(C) No change in velocity.
(D) Random variation in velocity.

***Answers*:**

(1) (B) constant throughout the pipe.
(2) (C) constant.
(3) (B) Bernoulli's principle.
(4) (C) decreases,
(5) (C) remains the same.
(6) (B) equal to his weight.
(7) (B) decrease atmospheric pressure.
(8) (E) the density cannot change with time or location.
(9) (D) the density does not vary from point to point.
(10) (B) mass.
(11) (C) Bernoulli's principle.
(12) (B) Increase in velocity.

Numericals:

Q.No.1: **Two spherical raindrops of equal size are falling through air at a velocity of 0.08 m/s. if the drops join together forming a large spherical drop, what will be the new terminal velocity?**

Data:

Initial terminal velocity of rain drops (**before** combining) $v_1 = 0.08$ m/s

New terminal velocity of rain drop (**after** combining) $v_2 = ?$

Solution:

Let "r" be the radius of each drop **before** combining and "R" be the radius of lager drop **after** combining. Then since terminal velocity of a spherical body moving through a viscous liquid is directly proportional to square of its radius, therefore:

$v_1 \propto r^2$ and $v_2 \propto R^2$

$\dfrac{v_1}{v_2} = \dfrac{r^2}{R^2}$ OR $\dfrac{0.08}{v_2} = \dfrac{r^2}{R^2}$

$v_2 = \dfrac{0.08}{(r/R)^2}$ ………………..(i)

But volume of drops before and after are given by: $\dfrac{4}{3}\pi r^3$ $\dfrac{4}{3}\pi R^3$

But volume of combined drop will be **twice** the volume of each combining drop.

$\dfrac{4}{3}\pi R^3 = 2\left(\dfrac{4}{3}\pi r^3\right)$

$R^3 = 2r^3$

$\therefore \dfrac{r^3}{R^3} = \dfrac{1}{2}$

Taking cube root of both sides we get:

$\dfrac{r}{R} = \sqrt[3]{\left(\tfrac{1}{2}\right)} = 0.7937$

Put this value of (r/R) in equation (i).

$v_2 = \dfrac{0.08}{(r/R)^2}$ ………(i)

$v_2 = \dfrac{0.08}{(0.7937)^2} = \underline{\mathbf{0.127\ m/s.}}$

New terminal velocity is **<u>0.127 m/s</u>.**

Q.No.2: **Calculate the viscous drag on a drop of oil of 0.1 mm radius falling through air at its terminal velocity.**

(Viscosity of air = 1.8×10^{-5} Pa-s.
Density of oil = 850 kg/m^3.)

Data:

Viscous drag $F = ?$

Radius of oil drop $r = 0.1$ mm $= 1\times10^{-4}$ m

Viscosity of air $\eta = 1.8\times10^{-5}$ Pa-s.

Density of oil $\rho = 850$ kg/m^3.

Solution:

According to Stocke's law viscous or drag force on a small **<u>spherical</u>** body is given by:

$F = 6\pi\eta r v$

But (first we will have to find terminal velocity) terminal velocity of the spherical oil drop is given by: $v = \dfrac{2 r^2 \rho g}{9\eta}$

$v = \dfrac{2\times(1\times10^{-4})^2\times850\times9.8}{9\times1.8\times10^{-5}}$

$v = $ **1.028 m/s.**

Drag force $F = 6\pi\eta r v$

$F = 6\pi\times1.8\times10^{-5}\times1\times10^{-4}\times1.028$

$\mathbf{F = 3.4879\times10^{-8}\ N.}$

Drag force on the oil drop is **<u>3.4879 ×10⁻⁸ N</u>.**

Q.No.3: **What area must a heating duct have if air moving 3.0 m/s along it can replenish the air every 15 minutes in a room of volume 300 m^3. Assume air density remains constant.**

Data:

Velocity $v = 3.0$ m/s

Time taken $t = 15$ min. $= 15\times60$ s. $= 900$ s

Volume of the room $V = 300$ m^3.

Area of heating duct $A = ?$

Solution:

Volume of a fluid passing a given point per second, called **volume rate of flow** is given by: $\dfrac{V}{t} = A v$

$\therefore \dfrac{300}{900} = A\times3$

$$A = \frac{300}{900\times 3} = \mathbf{0.111\ m^2}.$$

Area of heating duct must be **$\underline{0.111\ m^2}$**.

***Q.No.4*: Water circulates throughout a house in a hot -water heating system. If 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.

***Data*:**

Speed of water in the basement v_1 = 0.5 m/s

Diameter of pipe in the basement r = 4 cm=0.04 m

Radius of pipe in the basement r_1 = 0.02 m.

Pressure in the basement

P_1 = 3 atm.=3 ×1.01×10^5 N/m^2=3.03×10^5 N/m^2

Flow speed at second floor v_2 =?

Pressure at second floor P_2 =?

Diameter of second floor pipe d=2.6 cm

Radius of second floor pipe r_2 = 0.013m

Height of second floor h_2 = 5 m.

Density of water ρ = 1000 kg./m^3

Basement is taken as reference hence, h_1 = 0

***Solution*:**

Since $A_1v_1 = A_2 v_2$

$$v_2 = \frac{A_1 v_1}{A_2} = \frac{\pi r_1^2 v_1}{\pi r_2^2} = \frac{\cancel{\pi}(0.02)^2 \times 0.5}{\cancel{\pi}(0.013)^2}$$

v_2 = **1.183 m/s.**

According to Bernoulli's theorem:

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

$$3.03\times10^5 + \tfrac{1}{2}\,1000\times(0.5)^2 + 0$$
$$= P^2 + \tfrac{1}{2}\times1000\times(1.183)^2 + 1000\times9.8\times5$$

$$P_2 = 3.03\times10^5 + \tfrac{1}{2}\,1000\times(0.5)^2 - \tfrac{1}{2}\times1000\times(1.183)^2 - 1000\times9.8\times5$$

$$P_2 = 3.03\times10^5 + 125 - 699.745 - 49000$$

$$P_2 = 253425.255\ N/m^2 = \frac{253425.255}{1.01\times10^5}$$

P_2 = **2.51 atm.**

Flow speed on the second floor is **<u>1.183 m/s</u>** and pressure is **<u>2.51 atm</u>.**

***Q.No.5*: What is the volume rate of flow of water from a 1.85 cm diameter faucet if the pressure head is 12 m?**

***Data*:**

Volume rate of flow $\frac{V}{t}$ =?

Diameter of faucet d =1.85 cm.
= 0.0185 m.

Radius of faucet r = d/2 = 0.0185/ 2 m
r = 0.00925 m

Height of pressure head h = 12 m.

***Solution*:**

According to law of conservation of energy:

P.E lost while falling down = K.E gained

$$mgh = \tfrac{1}{2} m v^2$$

$$v^2 = 2 g h \qquad v = \sqrt{2 g h}$$

$$v = \sqrt{2\times9.8\times12} = \mathbf{15.336\ m/s}$$

("v" is the velocity with which water flows from the faucet).

According to equation of continuity:

$VA = A v$ But $A = \pi r^2$

$\therefore$ $A = \pi r^2 = \pi (0.00925)^2 = \mathbf{2.688\times10^{-4}\ m^2}$

$A v = \frac{V}{t}$ = volume rate of flow of water

$\therefore$ $A v = 2.688\times10^{-4}\times15.336$

$A v = \frac{V}{t} = \mathbf{4.122\times10^{-3}\ m^3/s.}$

Volume rate of flow of water will be **<u>4.122 ×10⁻³ m³/s</u>.**

***Q.No.6*: The stream of water emerging from a faucet 'neck down' as it falls. The cross-sectional area is 1.2 cm² and 0.35 cm². The two levels are separated by a vertical distance of 45 mm as shown in figure. At what rate does water flow from the tape.**

***Data*:**

Cross sectional area at upper level
A_1 = 1.2 cm^2

Cross sectional area at lower level
A_2 = 0.35 cm^2

Vertical distance h = 45 mm = 4.5 cm

Rate of flow v/t = ?

***Solution*:**

According to equation of continuity:

Rate of flow of water at upper level v/t = A_1v_1

Rate of flow of water at lower level v/t = A_2v_2

Hence: $A_1v_1 = A_2v_2$ Squaring both sides

$A_1^2\, v_1^2 = A_2^2\, v_2^2$ .... (*i*)

Acceleration with which water falls is "g": hence applying equation of motion,

$v_2^2 - v_1^2 = 2\,g\,h$ We get:

$v_2^2 = v_1^2 + 2\,g\,h$

Putting this value of v_2^2 in equation (*i*) we get

$$A_1^2\, v_1^2 = A_2^2\,(v_1^2 + 2\,g\,h)$$

$$A_1^2\, v_1^2 = A_2^2 v_1^2 + 2\,A_2^2 g\,h$$

$$A_1^2\, v_1^2 - A_2^2 v_1^2 = 2\,A_2^2 g\,h$$

$$(A_1^2 - A_2^2)\, v_1^2 = 2\,A_2^2 g\,h$$

$$v_1^2 = \frac{2\,A_2^2 g\,h}{(A_1^2 - A_2^2)}$$

Substituting the values of known quantities we get: (**Note that** in this numerical all quantities are in C.G.S units.)

$$v_1^2 = \frac{2 \times (0.35)^2 \times 980 \times 4.5}{(1.2)^2 - (0.35)^2}$$

$$v_1^2 = \frac{1080.45}{1.44 - 0.1225} = \frac{1080.45}{1.3175} = 820.076$$

$$v_1 = \sqrt{820.076} = \mathbf{28.637\ m/s.}$$

Rate of flow of water at upper level = $A_1 v_1$

Rate of flow of water at upper level

$= 1.2 \times 28.637 = \underline{\mathbf{34.36\ m^3/s}}$.

Rate of flow of water at upper level is **34.36 m³/s**.

***Q.No.7*: Water leaves the jet of a horizontal hose at 10 m/s. If velocity of water within the hose is 0.40 m/s. Calculate the pressure within the hose. Density of water is 1000 kg/m³ and the atmospheric pressure is 100000 Pa.**

***Data*:**

Velocity of water inside the hose $v_1 = 0.4$ m/s

Pressure within the hose $P_1 = ?$

Velocity of water at the hose $v_2 = 10$ m/s.

Atmospheric pressure $P_2 = 100000$ Pa.

Density of water $\rho = 1000$ kg/m³

***Solution*:**

According to Bernoulli's theorem:

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

Since the hose is horizontal, therefore, $h_1 = h_2$ (which means that there is no change in P.E)

$$P_1 + \tfrac{1}{2}\rho v_1^2 = P_2 + \tfrac{1}{2}\rho v_2^2$$

$$P_1 + \tfrac{1}{2}\times 1000(0.4)^2 = 100000 + \tfrac{1}{2}\times 1000(10)^2$$

$$P_1 + 80 = 100000 + 50000$$

$$P_1 = \mathbf{149920\ Pa} = \mathbf{1.499\times 10^5\ Pa.}$$

Pressure of water with the hose is **1.499×10⁵ Pa**.

***Q.No.8*: What is the maximum weight of an aircraft with a wing area of 50 m² flying horizontally. Velocity of air over the upper surface of the wing is 150 m/s and that at lower surface is 140 m/s. density of air is 1.29 kg/m³.**

***Data*:**

Maximum weight an aircraft $W = ?$

Wing area $A = 50$ m².

Velocity of air over the upper surface of the wing $v_2 = 150$ m/s.

Velocity of air over lower surface $V_1 = 140$ m/s.

Density of air $\rho = 1.29$ kg/m³.

***Solution*:**

According to Bernaulli's equation:

$$P_1 + \tfrac{1}{2}\rho v_1^2 = P_2 + \tfrac{1}{2}\rho v_2^2$$

(Since the plane if flying horizontally therefore there is no change in potential energy involved $\therefore \rho g h_1 = \rho g h_2$)

$$P_1 - P_2 = \tfrac{1}{2}\rho v_2^2 - \tfrac{1}{2}\rho v_1^2$$

$$P = \tfrac{1}{2}\times 1.29 \times (150)^2 - \tfrac{1}{2}\times 1.29 \times (140)^2$$

$$P = 14512.5 - 12642 = 1870.5\ \text{N/m}$$

But $P = F/A$

$F = W = P\,A = 1870.5 \times 50 = \mathbf{93525\ N.}$

Maximum weight of the aircraft is **93525 N**.

***Q.No.9*: A liquid flows through a pipe with a diameter of 0.50 m at a speed of 4.20 m/s. What is the rate of flow in L/min.?**

***Data*:**

Diameter of pipe $d = 0.50$ m.

Radius of pipe $r = 0.50/2$ m $= 0.25$ m

Speed of liquid $v = 4.20$ m/s.

Rate of flow in L/min. $V/t = ?$

***Solution*:**

Rate of flow of a liquid $V/t = A\,v = \pi r^2 v$

Rate of flow $= \pi\,(0.25)^2 \times 4.20 = \mathbf{0.824668\ m^3/s.}$

1 liter = 10^3 m³ and 1 min. = 60 s

$$\therefore \text{Rate of flow of a liquid} = \frac{0.824668\times 60}{10^3}\ \text{L/min}$$

$\therefore$ Rate of flow of a liquid = **49480 L/min.**

Rate of flow of a liquid through the pipe is **49480 L/min.**

Q.No.10: **A liquid flows through a pipe of diameter 0.50 m at a speed of 4.20 m/s.**
What is the rate of flow?
(*2026 Karachi Board*)

Data:

Diameter of pipe $d = 0.50$ m.
Radius of pipe $r = 0.50/2$ m $= 0.25$ m
Speed of liquid $v = 4.20$ m/s.
Rate of flow $= ?$

Solution:

Rate of flow of a liquid $V/t = A\,v = \pi\, r^2\, v$
Rate of flow $= \pi\,(0.25)^2 \times 4.20 =$ $\mathbf{0.824668\ m^3/s}$.
🗣Rate of flow of liquid through the pipe is **0.824668 m^3/s**.

Effects polarization of water molecule.

As we know that water molecule is highly polarized, because of high electronegativity, oxygen atom causes shifting of shared electrons towards itself, due to which a partial negative charge "– 2δ" appears on oxygen and a partial positive charge "+δ" appears on each hydrogen end of the molecule. Due to repulsion between positively charged H-atoms the angle between H-atoms increases to about 104.5°.

- Highly polarized water molecule each having bond angle of 104.5° and the weak bonds between different water molecules are responsible for special properties of water. It is also responsible for the existence of all forms of life on our beautiful little planet EARTH.

Some of the special properties of water are:

- Density of ice (solid form of water) is less than water (liquid form), that's why ice floats on water. Density of other substances in solid state is more than their density in liquid state, that's why they sink in their liquid state.
- Water has high specific heat of about 4200 J/kg. °C.
  It means that about 4200 Joules of heat are needed to raise the temperature of I kg. water through 1°C. Specific heat of most of the other substances is far less. Hence water will take long time to heat up or cool down, as a result of which temperature in areas around large water masses (lakes, rivers etc.) remains moderate.
  High specific heat of water slows down escape of heat from water to atmosphere during sever winters. As a result of which water always remains in liquid form at the bottom and at the surface it freezes to ice whose thickness keeps on growing with falling atmospheric temperature (ice floats on the surface because of its lower density).
  Water in liquid form is vital for the survival of various forms of water-based life.
- Water has high surface tension, due to which capillary action takes place. As result of capillary action water reaches the highest point of tallest trees from their roots.