FORCE AND PRESSURE

K-TET Category III | Physical Science | Part A Physics | Unit 3

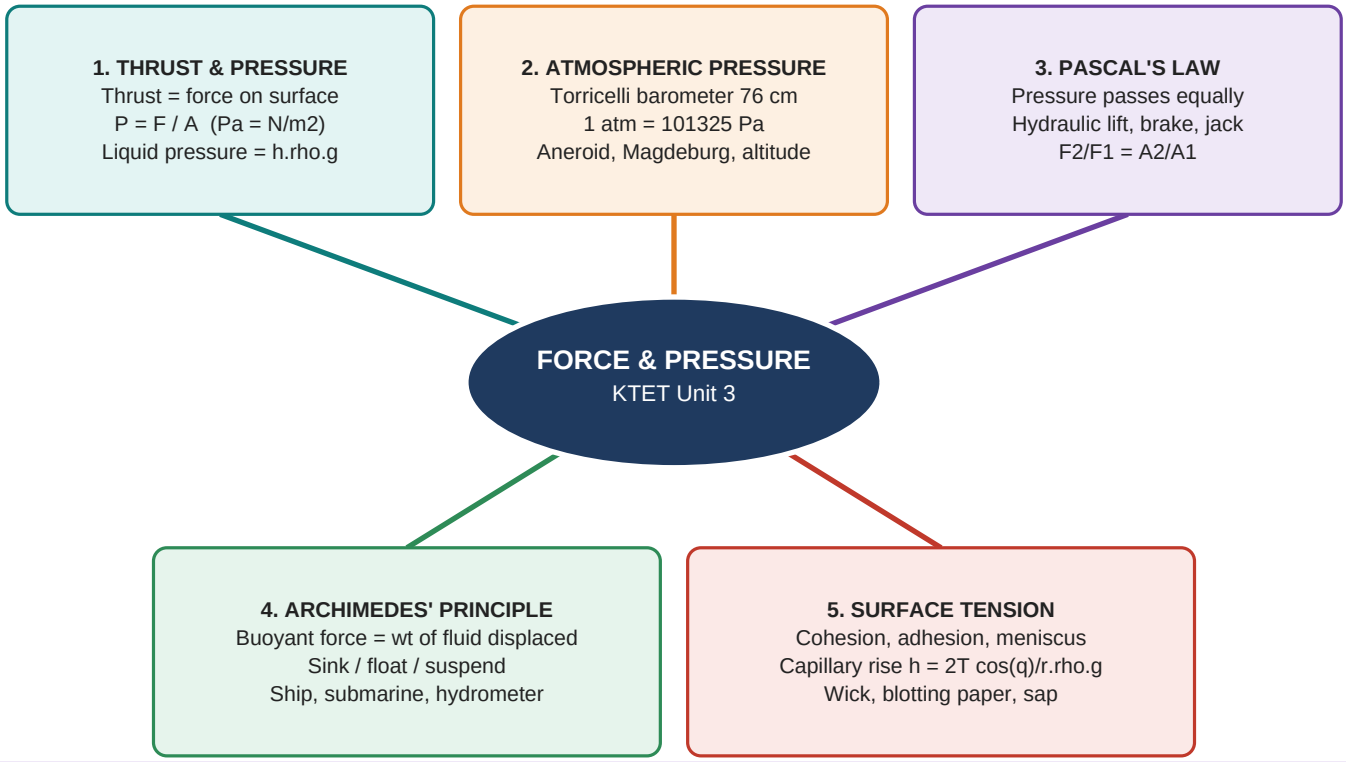
Thrust • Atmospheric Pressure • Pascal's Law • Archimedes' Principle • Surface Tension & Capillarity

Syllabus (K-TET 2012, Category III) - Unit 3. Force and pressure

- Thrust, atmospheric pressure, Pascal's law, Archimedes principle, surface tension and capillarity.

Exam weight: Physics carries 25 of 80 questions; questions on this unit are typically direct concept, unit, daily-life application and simple numerical types.

Mind Map - the whole unit at a glance



Memory key: "TAPAS"

- **T**hrust **A**tmospheric pressure **P**ascal's law **A**rchimedes **S**urface tension - the five syllabus topics in order.

1 THRUST AND PRESSURE

Force is a push or a pull (SI unit newton, N; a vector). When a force acts **perpendicular (normal)** to a surface, it is called **thrust**. The same thrust can have very different effects depending on the **area** over which it acts - that effect is measured by **pressure**.

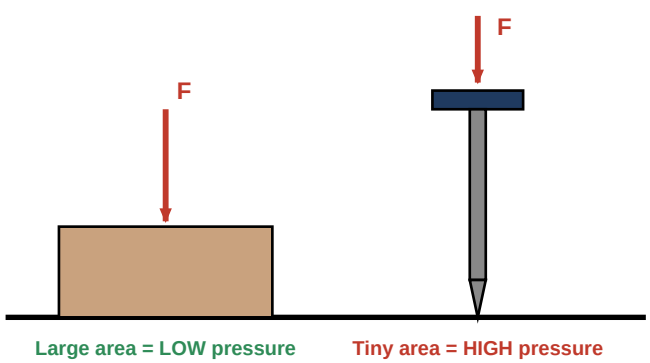


Fig 1. Same force, different area: different pressure

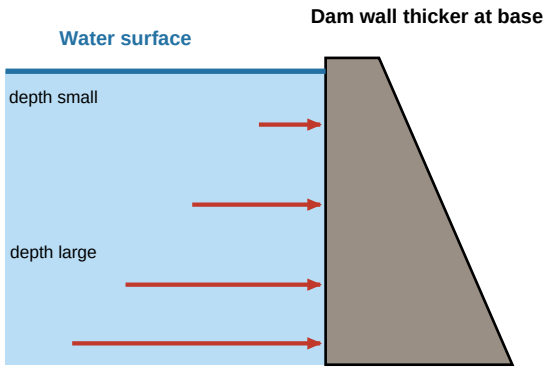


Fig 2. Liquid pressure increases with depth

Point	Thrust	Pressure
Definition	Force acting normally on a surface	Thrust acting per unit area
Formula	F (= weight, for a resting body)	P = F / A
SI unit	newton (N)	pascal (Pa) = N/m^2
Nature	Vector	Scalar
Depends on	Applied force only	Thrust (directly) and area (inversely)
Daily life	Weight of a person on the floor	Sharp knife cuts easily; broad bag strap hurts less

Increase pressure - REDUCE area	Decrease pressure - INCREASE area
Knife edge, needle, nail, drawing pin, axe, chisel, spike shoes, sharpened pencil	Wide school-bag straps, tractor and bulldozer tyres, camel's broad feet, snow skis, railway sleepers, building foundations, many wheels of a heavy truck

Units of pressure (very frequently asked)

Unit	Value	Note
1 pascal (Pa)	1 N/m^2	SI unit, named after Blaise Pascal
1 bar	10^5 Pa	1 millibar = 100 Pa (used in weather reports)
1 atmosphere (atm)	101325 Pa = 1.013 x 10^5 Pa	= 76 cm (760 mm) of mercury; about 14.7 psi
1 torr	1 mm of Hg = about 133.3 Pa	Named after Torricelli

Pressure inside a liquid

Pressure at depth **h** in a liquid of density ρ: **P = h ρ g** (gauge pressure). Total (absolute) pressure = P_{atm} + h ρ g.

- Increases with depth; at the same level it is the same in all directions (liquid pressure acts sideways, up and down).
- Does **not** depend on the shape or the cross-section of the container (Pascal's vases / hydrostatic paradox), only on depth, density and g.
- Applications: dam walls are thicker at the bottom (Fig 2); deep-sea divers need pressure-resistant suits; water tanks are placed on rooftops to get pressure in taps; blood pressure is higher at the feet than the head when standing.

Solved numericals (take g = 10 m/s^2)

- **Q1.** A thrust of 600 N acts on 0.2 m^2. Pressure = F/A = 600/0.2 = **3000 Pa**.
- **Q2.** A boy of 40 kg stands on both feet, total contact area 0.04 m^2. F = 400 N, P = 400/0.04 = **10000 Pa**. On one foot the area halves, so pressure **doubles** to 20000 Pa.
- **Q3.** Pressure at 10 m depth in water (ρ = 1000 kg/m^3): hρg = 10 x 1000 x 10 = **1 x 10^5 Pa** (about one atmosphere extra). Absolute pressure is about 2 atm.

2 ATMOSPHERIC PRESSURE

The earth is surrounded by a blanket of air (atmosphere) extending to several hundred kilometres. The weight of this air column exerts pressure on everything - **atmospheric pressure**. At sea level it is about **101325 Pa**, which equals about 10 tonnes on every square metre! We do not get crushed because the pressure inside our body balances it.

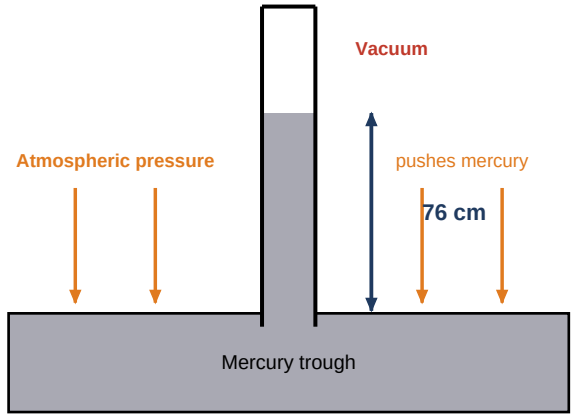


Fig 3. Torricelli's mercury barometer

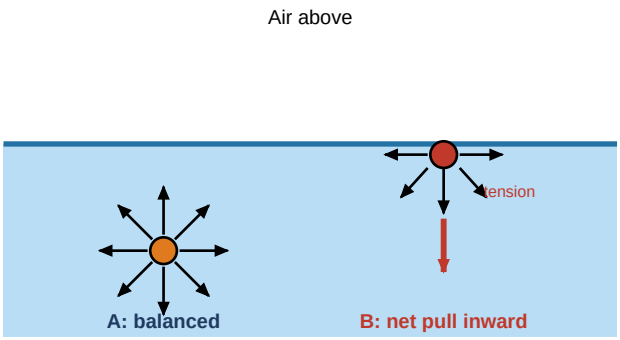


Fig 4. Origin of surface tension (see Topic 5)

Torricelli's experiment (1643) - the mercury barometer

- A glass tube about 1 m long, closed at one end, is filled with mercury and inverted into a mercury trough. The column falls and stops at **76 cm (760 mm)** above the trough level at sea level; the space above is a **Torricellian vacuum**.
- The mercury column is held up by atmospheric pressure, so P_{atm} = 76 cm Hg = hρg = 0.76 x 13600 x 9.8 = about 1.01 x 10^5 Pa.
- The height does **not** change if the tube is tilted, widened or narrowed - only the vertical height matters. It changes only with altitude and weather.
- **Why mercury?** Very high density (13600 kg/m^3) so a short column is enough, negligible vapour pressure, does not wet glass, opaque and shiny so easy to read. With water the column would be **about 10.3 m** tall.

Instrument	Measures	Remarks
Mercury barometer (Fortin type)	Atmospheric pressure	Accurate, laboratory use; fragile and not portable
Aneroid barometer	Atmospheric pressure	No liquid; metal box with flexible lid; portable; with a scale in height it becomes an altimeter
Manometer (U-tube)	Pressure of a gas relative to atmosphere	Gauge pressure; liquid levels differ in the two arms
Sphygmomanometer	Blood pressure	Normal about 120/80 mm Hg (systolic / diastolic)

Effects and proofs of atmospheric pressure

Phenomenon	Explanation
Magdeburg hemispheres (Otto von Guericke, 1654)	Two copper hemispheres joined and air pumped out; teams of horses could not pull them apart - outside air pressure pushes them together
Drinking through a straw	Sucking lowers pressure inside the straw; the outside atmospheric pressure pushes the liquid up
Dropper, syringe, pen filler, vacuum cleaner	Reduced pressure inside; atmosphere pushes the liquid or dust in
Water does not fall from an inverted full glass covered with card	Atmospheric pressure upward is greater than the weight of the water
Pressure cooker	Raised pressure raises the boiling point above 100 °C, so food cooks faster
Cooking is slow on high mountains	Low atmospheric pressure there lowers the boiling point of water
Nose bleeds and breathing trouble at altitude; astronauts wear pressurised suits	Outside pressure drops so much that body pressure becomes relatively high
Storm / cyclone forecast	A sudden fall in barometer reading signals a low-pressure area and bad weather; a steady high reading signals clear weather

Key facts to remember

- Atmospheric pressure **decreases** with altitude (about 1/3 of sea-level value near the summit of Mount Everest); it is not uniform because air density falls with height.
- The barometer reading is **lower** on a hill station than at sea level, and slightly **higher** deep inside a mine.
- A mercury barometer carried to the Moon would read zero (no atmosphere).

3 PASCAL'S LAW

Statement (Blaise Pascal, 1653)

- **Pressure applied to an enclosed fluid is transmitted undiminished and equally to every part of the fluid and to the walls of the container.**

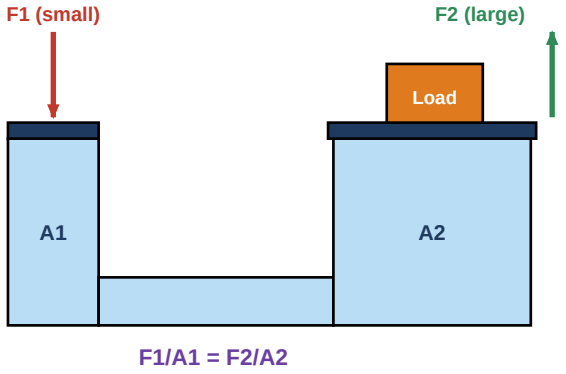


Fig 5. Hydraulic lift (Pascal's law)

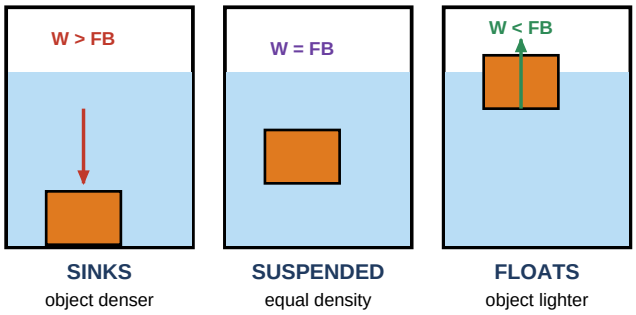


Fig 6. Sinking, suspension, floating (Topic 4)

Hydraulic machine - working

A small force F_1 on a small piston (area A_1) produces pressure $P = F_1/A_1$. By Pascal's law the **same pressure** acts on the large piston (A_2), giving $F_2 = P \times A_2$. Therefore $\mathbf{F_2/F_1 = A_2/A_1}$ - a **force multiplier**. Energy is not created: the small piston moves a larger distance, so work in = work out ($F_1 d_1 = F_2 d_2$).

Application	How Pascal's law helps
Hydraulic lift / car service jack	Small effort lifts a car or a heavy load
Hydraulic brakes (cars, buses)	Pedal force travels equally through brake fluid to all four wheels
Hydraulic press, excavator, JCB, dentist and barber chairs	Large force from a small input through liquid
Hydraulic door closer, aircraft landing gear	Controlled force transmission through oil

Solved numerical

- In a hydraulic lift $A_1 = 10\ cm^2$, $A_2 = 500\ cm^2$, $F_1 = 100$ N. $F_2 = F_1 \times A_2/A_1 = 100 \times 500/10 =$ **5000 N** (mechanical advantage 50).
- **Why liquids, not gases?** Liquids are almost incompressible, so pressure is transmitted fully; a gas would compress and absorb the effort. **Air bubbles in brake fluid** make brakes "spongy" for this very reason.

4 ARCHIMEDES' PRINCIPLE

Statement

- **When a body is wholly or partly immersed in a fluid, it experiences an upward force (buoyant force or upthrust) equal to the weight of the fluid displaced by it.**
- Buoyant force $F_B = V_{displaced} \times \rho_{fluid} \times g$ | Apparent weight = weight in air - buoyant force

Story: Archimedes of Syracuse (about 250 BC) was asked by King Hiero to check whether a crown was pure gold. Stepping into a full bath and seeing water overflow, he realised the volume of displaced water equals the volume of the immersed body and shouted **"Eureka!"**. Cause of buoyancy: pressure increases with depth, so the upward push on the bottom face is greater than the downward push on the top face.

Condition	Result	Everyday example
Weight > buoyant force ($\rho_{object} > \rho_{fluid}$)	Body **sinks**	Stone, iron nail in water
Weight = buoyant force ($\rho_{object} = \rho_{fluid}$)	Body **suspended** at any depth	Submarine under water, fish with swim bladder
Weight < buoyant force ($\rho_{object} < \rho_{fluid}$)	Body **floats**; submerged volume x fluid density = weight	Wood, ice, cork, iron ship, iron nail on mercury

Law of flotation

A floating body displaces fluid whose **weight equals the body's own weight**. So a floating body is in equilibrium, and the fraction submerged = density of body / density of fluid. An **iceberg floats with about 9/10 of its volume under water** because ice is slightly less dense than water.

Application	Explanation
Ship (steel)	Hollow shape displaces a huge volume of water, so the **average density is less than water** and it floats
Plimsoll line (load line) on ships	Marks safe loading depth; different marks for fresh water (less dense, ship sinks deeper) and salt water
Submarine	Ballast tanks are filled with water to sink, and emptied with compressed air to rise
Hydrometer / lactometer	Floats higher or lower according to liquid density; hydrometer measures density of liquids, lactometer checks purity of milk
Hot-air balloon, weather balloon, airship	Air is also a fluid; a balloon filled with hot air, hydrogen or helium has lower average density than surrounding air and rises
Swimming is easier in the Dead Sea / sea than a river	Higher density of salt water gives greater buoyant force
A stone feels lighter in water; a bucket in a well feels lighter while under water	Apparent weight decreases by the buoyant force

Solved numericals

- A metal piece weighs 10 N in air and 6 N in water. Buoyant force = 10 - 6 = **4 N**. Volume = 4/(1000 x 10) = 4 x 10^{-4} m^3. Relative density = weight in air / loss of weight = 10/4 = **2.5**.
- **Ice in water:** when floating ice melts, the water level in the glass **stays the same** because the ice displaced exactly its own weight of water.
- **Iron floats on mercury** (density 7.8 vs 13.6 g/cm^3) but sinks in water.

Density	Relative density (specific gravity)
Mass per unit volume; unit kg/m^3	Density of substance / density of water at 4 °C; no unit
Water = 1000 kg/m^3	Water = 1; mercury = 13.6; iron = 7.8; ice = 0.92
Measured with a measuring jar and balance	Measured with a hydrometer or by Archimedes' principle

5 SURFACE TENSION AND CAPILLARITY

Molecules attract one another by **cohesive force**. A molecule in the bulk (A in Fig 4) is pulled equally in all directions - net force zero. A molecule at the surface (B) has liquid below but air above, so a **net inward pull** acts on it. The surface therefore behaves like a **stretched elastic skin** that tries to have the **smallest possible area**.

Surface tension (T)

- The force acting per unit length on an imaginary line drawn on the liquid surface, perpendicular to it: **T = F / L**. SI unit **N/m** (also J/m^2); a scalar.
- Water about 0.072 N/m at 20 °C; mercury about 0.465 N/m (very high); soap solution much lower than water.

Effects and examples

Observation	Reason
Rain drops, mercury drops, soap bubbles are spherical	Minimum surface area for a given volume is a sphere
Insects (water strider) walk on water; a needle or razor blade floats carefully placed	Surface film supports a light weight
Brush hair clings together when wet but spreads in the air	Surface tension of water film pulls hairs together
Camphor piece dances on water	Camphor lowers surface tension unevenly, so the surface pulls the camphor
Hot water cleans better; soap and detergent clean oil	Both lower surface tension, so the liquid spreads and wets the fabric

Factors affecting surface tension

- **Temperature:** surface tension **decreases** when temperature rises (zero at the critical temperature).
- **Impurities:** soluble substances like soap, detergent and alcohol **decrease** it; highly soluble salts like sodium chloride slightly increase it.
- Contamination by oil or dust decreases it. Surface tension is independent of the surface area.
- **Excess pressure:** inside a liquid drop 2T/R; inside a soap bubble (two surfaces) **4T/R**. Hence a smaller bubble has higher internal pressure.

Cohesion, adhesion, angle of contact and meniscus

Cohesion	Adhesion
Attraction between molecules of the **same** substance	Attraction between molecules of **different** substances
Why mercury forms drops	Why water wets glass, and ink sticks to paper
Cause of surface tension	Cause of wetting and capillary rise

Point	Water in glass	Mercury in glass
Stronger force	Adhesion > cohesion	Cohesion > adhesion
Meniscus	Concave (curves upward at the walls)	Convex (curves downward at the walls)
Angle of contact θ	Acute, less than 90° (about 0° for pure water)	Obtuse, about 140°
Wets the glass?	Yes	No
In a capillary tube	Liquid **rises**	Liquid is **depressed**

Capillarity

The rise or fall of a liquid in a tube of very fine (hair-like) bore is called **capillarity**. **Jurin's law:** $h = 2T\cos\theta / (r \rho g)$. So the height is **inversely proportional to the radius** - narrower tube, greater rise (Fig 7) - and directly proportional to surface tension.

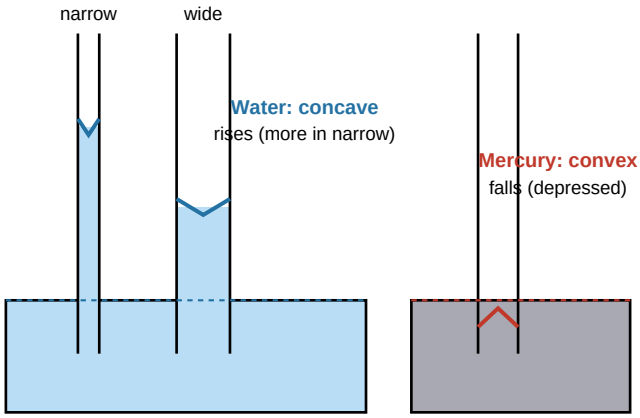


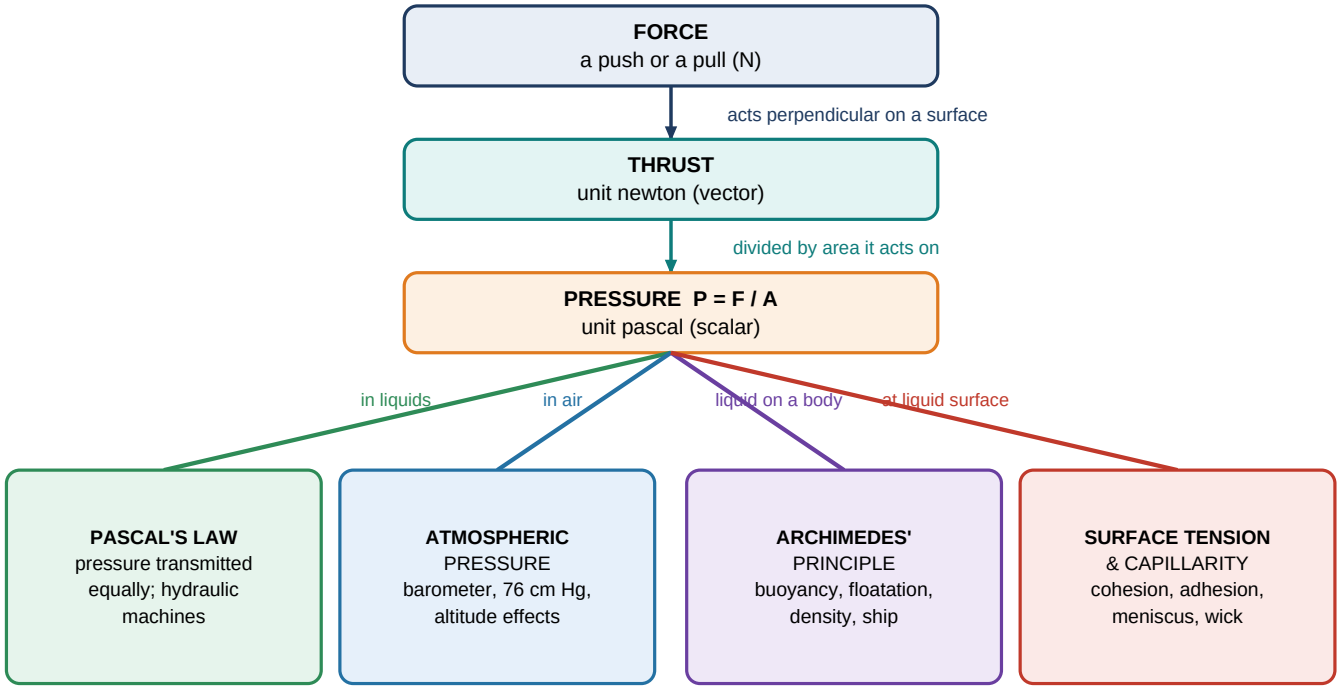
Fig 7. Capillary rise of water and fall of mercury

Capillary action in daily life	Capillary action to be prevented
Oil rising in a lamp wick; ink in a blotting paper, chalk or sponge; towel absorbing water; sap rising in plants and trees; water moving through soil to roots; kerosene in a stove wick	Ploughing and hoeing break the soil capillaries, stopping moisture from rising and evaporating; damp-proof course in house walls; water-proofing of tents

Solved numerical

- Rise of water ($T = 0.072$ N/m, $\theta = 0$) in a tube of radius 0.5 mm: $h = 2T/(r\rho g) = (2 \times 0.072)/(0.0005 \times 1000 \times 9.8)$ = **about 2.9 cm**. In a tube of half the radius the rise doubles to about 5.9 cm.

6 CONCEPT MAP, DIFFERENTIATION AND RECHARGE TIPS



	Pascal's law	Archimedes' principle
Deals with	Transmission of pressure in an enclosed fluid	Upward force on a body immersed in a fluid
Key idea	Pressure same everywhere; F2/F1 = A2/A1	Buoyant force = weight of fluid displaced
Applications	Hydraulic lift, brakes, press, jack	Ship, submarine, balloon, hydrometer

Mercury barometer	Aneroid barometer	Manometer
Uses mercury and a glass tube	No liquid; flexible metal box	U-tube with liquid
Measures atmospheric pressure accurately	Portable; can be used as altimeter	Measures gas pressure against atmosphere

Formula sheet

- Pressure $P = F/A$ | Liquid pressure $P = h\rho g$ | Absolute pressure = $P_{atm} + h\rho g$
- Pascal: $F_1/A_1 = F_2/A_2$ | Buoyant force = $V\rho_{fluid}g$ | Relative density = weight in air / loss of weight in water
- Surface tension $T = F/L$ | Capillary rise $h = 2T\cos\theta/(r\rho g)$ | Drop $2T/R$, soap bubble $4T/R$
- 1 atm = 101325 Pa = 76 cm Hg = 10.3 m of water

Recharge tips and mnemonics

- **Pressure triangle:** draw a triangle with P on top, F and A below, and cover the unknown; F/A reads on the bottom row.
- **Sharp = High pressure** (small area). **Broad = Low pressure** (large area).
- **Water Wets, Mercury Mopes:** water - adhesion wins - concave - rises; mercury - cohesion wins - convex - falls.
- **Sink if Denser:** object denser than fluid sinks; lighter floats; equal is suspended.
- Think "**ST goes down when heat goes up**": surface tension falls on heating or adding soap.
- Hydraulic brake fails when air enters: gases compress, liquids do not.

7 PREVIOUS YEAR QUESTIONS WITH ANSWERS

No.	Question	Answer
1	SI unit of pressure is	pascal (N/m^2)
2	Thrust is a	Vector (force acting normally on a surface)
3	Standard atmospheric pressure equals	101325 Pa = 76 cm of mercury = 1.013 bar
4	Who invented the mercury barometer?	Evangelista Torricelli
5	Why is mercury preferred in a barometer?	High density, so a short column is enough; low vapour pressure
6	Height of the water barometer column at sea level	About 10.3 m
7	Height of mercury column in the barometer when the tube is tilted	Vertical height remains 76 cm
8	On a mountain top the barometer reading is	Lower than at sea level
9	Why does food cook slowly at high altitude?	Lower atmospheric pressure lowers the boiling point of water
10	A pressure cooker cooks faster because	Increased pressure raises the boiling point
11	Magdeburg hemispheres demonstrate	Atmospheric pressure
12	Instrument used for measuring gas pressure	Manometer
13	Pascal's law is applied in	Hydraulic brake, lift and press
14	Liquid pressure at a point depends on	Depth, density of liquid and g - not on the shape of the vessel
15	Why is the dam wall thicker at the base?	Liquid pressure increases with depth
16	A sharp knife cuts better than a blunt one because	Smaller area gives greater pressure
17	Archimedes' principle: buoyant force equals	Weight of the fluid displaced
18	Hydrometer is used to measure	Density of liquids (law of flotation)
19	Lactometer is used to test	Purity of milk
20	Plimsoll line on a ship shows	Safe loading limit for different waters
21	Fraction of an iceberg below the water surface	About 9/10
22	When ice floating in water melts, the water level	Remains the same
23	SI unit of surface tension	N/m
24	Effect of detergent and heating on surface tension	Decreases
25	Shape of a free liquid drop in space	Spherical (minimum surface area)
26	Shape of the mercury meniscus in glass	Convex; angle of contact obtuse
27	Rise of oil in a lamp wick is due to	Capillarity
28	Capillary rise is ____ proportional to tube radius	Inversely
29	Excess pressure inside a soap bubble of radius R	4T/R
30	Why is ploughing done after rain?	To break soil capillaries and retain moisture

Last-minute checklist

- Know the units: Pa, N/m^2, bar, atm, torr and their conversions.
- Draw the Torricelli diagram and hydraulic-lift diagram; practise F2/F1 = A2/A1 sums.
- Remember sink / float / suspend conditions and the examples: ship, submarine, hydrometer, balloon.
- Memorise the water-versus-mercury meniscus table and Jurin's law.
- Revise two daily-life examples for each topic - KTET loves application questions.

ONE-SHEET MEMORY REVISION | FORCE AND PRESSURE

1. THRUST AND PRESSURE

- Thrust = force normal to surface (N, vector)
- P = F/A; unit Pa = N/m^2 (scalar)
- Sharp = small area = HIGH pressure
- Liquid: P = hρg; rises with depth, same at one level, shape does not matter
- 1 bar = 10^5 Pa; 1 torr = 1 mm Hg

2. ATMOSPHERIC PRESSURE

- Torricelli: 76 cm Hg = 760 mm = 101325 Pa = 1 atm
- Water barometer about 10.3 m; mercury: dense, no wetting
- Tilting tube: vertical height stays 76 cm
- Falls with altitude; pressure cooker raises boiling point
- Magdeburg hemispheres; aneroid = altimeter; manometer = gas pressure

3. PASCAL'S LAW

- Pressure on enclosed fluid goes undiminished in all directions
- $F_2/F_1 = A_2/A_1$ (force multiplier, work same)
- Hydraulic lift, brake, jack, press, dentist chair
- Liquids used because incompressible; air bubble = spongy brakes

4. ARCHIMEDES' PRINCIPLE

- Buoyant force = weight of fluid displaced
- F_B = Vρg; apparent weight = W - F_B
- Denser sinks, equal suspends, lighter floats
- Ship: hollow, low average density; Plimsoll line
- Hydrometer (liquid density), lactometer (milk)
- Iceberg 9/10 under water; melting floating ice: level same

5. SURFACE TENSION

- T = F/L; unit N/m; cause: cohesion at surface
- Falls with heat, soap, detergent; drops and bubbles are spherical
- Insects on water, camphor dance, needle floats
- Excess pressure: drop 2T/R, soap bubble 4T/R

CAPILLARITY

- h = 2T cosθ/(rρg); h inversely proportional to r
- Water: adhesion > cohesion, concave, acute angle, rises
- Mercury: cohesion > adhesion, convex, obtuse angle, falls
- Wick, blotting paper, sap, soil moisture; ploughing breaks capillaries

Memory hooks and key numbers

- **TAPAS** = Thrust, Atmospheric pressure, Pascal, Archimedes, Surface tension.
- **Numbers:** 101325 Pa | 76 cm Hg | 10.3 m water | water T = 0.072 N/m | ice about 9/10 submerged | mercury relative density 13.6.
- **Water Wets, Mercury Mopes | Sink if Denser | Sharp = High pressure | ST goes down when heat goes up**.
- **Scientists:** Torricelli (1643, barometer), Pascal (1653, law), Von Guericke (1654, Magdeburg), Archimedes (about 250 BC, Eureka).

Compare	Quick difference
Thrust vs Pressure	Thrust = total force (N, vector); pressure = force per unit area (Pa, scalar)
Mercury vs Aneroid barometer	Liquid column, accurate, fragile vs metal box, portable, altimeter
Pascal vs Archimedes	Pressure transmission in enclosed fluid vs upward force on immersed body
Cohesion vs Adhesion	Same-substance attraction vs different-substance attraction
Density vs Relative density	kg/m^3 vs ratio to water, no unit