S1 New Curriculum Physics

Theme: Mechanics and properties of Matter

Chapter 3 – Pressure in solids and Fluids

Pressure in solids

Pressure is force per unit area. i.e.

Pressure = $\frac{Force\ (N)}{Area\ (m^2)}$ Nm^{-2} or Pascal, Pa

Pressure is thus inversely proportional to the area. For a given amount of force, the smaller the area of contact between two bodies the greater the pressure exerted.

Example 1

A metallic block of mass 50kg exerts a pressure of $20Nm^{-2}$ on a surface. Find the area of contact between the block and the surface.

Pressure = $\frac{Force\ (N)}{Area\ (m^2)}$

Area = $\frac{Force\ (N)}{Pressure} = \frac{50\ x\ 10}{20}$ = $25m^2$

Trial 1

(a) A metallic block of weight 100N rests on a surface. Find the pressure exerted on the surface if the area of contact between the block and the surface is

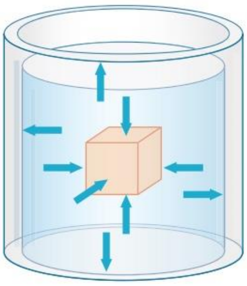
(i) $0.1m^2$ [1000Pa]
(ii) $0.01m^2$ [10,000Pa]

(b) A cuboid of dimensions 4m x 3m x 2m weights 480N. Calculate the maximum and minimum pressures it exerts on a table. [80Pa, 40Pa]

(c) A rectangular block as sides 5.0cm by 10.0cm by 20cm. It is made of material of density 2.5gcm^{-3}. Find the maximum pressure in NM^{-2} it exerts when resting with one of its faces on horizontal surface. [5000N]

Pressure in fluids

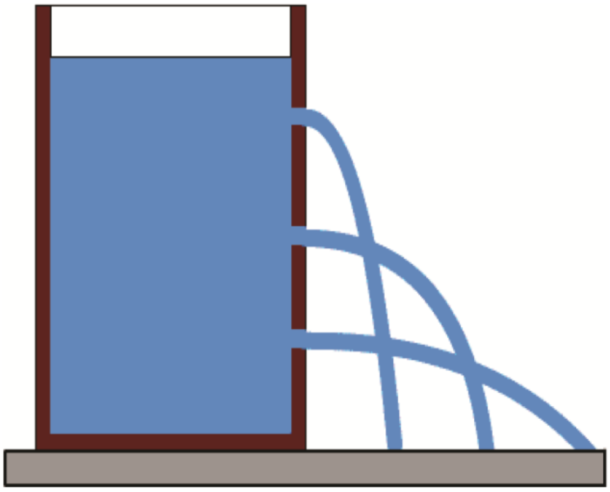
Fluids (liquids and gases) exert pressure on surfaces and objects in contact with them but unlike solids, pressure in fluids acts in all directions as shown below.



Pressure in fluids = hρg

where h = depth, ρ= density of the fluid and g = acceleration due to gravity

Experiment to show that pressure in liquids increases with depth



(i) **Make holes**: Use the nail to carefully poke three holes in a vertical line on the side of the bottle—one near the top, one in the middle, and one near the bottom. Make sure they're the same size and evenly spaced.

(ii) **Seal the holes**: Temporarily cover the holes with tape or your finger.

(iii) **Fill the bottle**: Pour water into the bottle up to the top.

(iv) **Unseal**: Remove all seals at once and observe the water jets.

Observation:

- The top hole releases a short, weak jet of water.

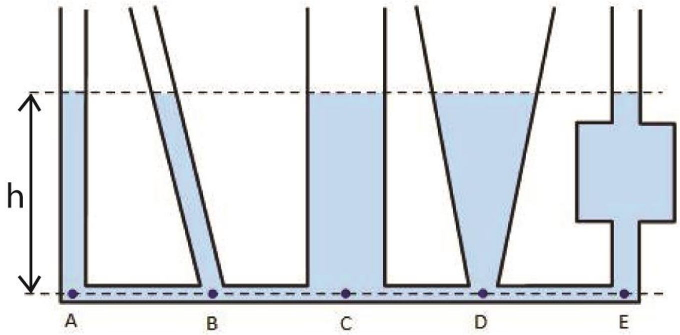
- The middle hole's stream goes farther.
- The bottom hole shoots water the farthest.

Conclusion:

This shows that **liquid pressure increases with depth**. The deeper the hole, the more pressure the water exerts, and the farther it shoots out.

Experiment to show that static fluid pressure does not depend on the shape and cross-section area of the container

Water is filled in differently shaped containers A, B, C, D, E as shown in the diagram below



Observation

A constant height h is maintained for each of the containers indicating that pressure at points A to E is the same and independent of the shape of and cross-section of the containers.

Example 2

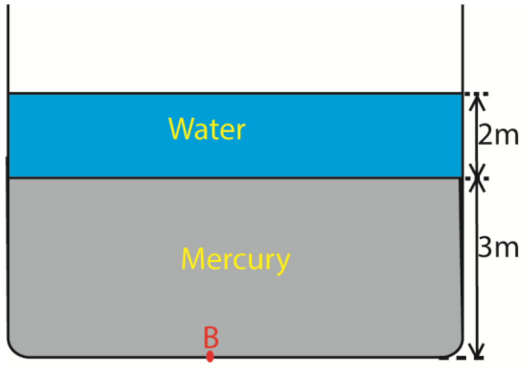
(a) Find the pressure exerted 1,500mbelow the surface of the lake. Given that the density of water is 1000kgm^{-3}.

Pressure in fluids = hρg

= 1500 x 1000 x 10

= 1.5 x 107Nm^{-2}

(b) The tank shown below contains mercury and water. Given that the density of mercury and water are 13600kgm^{-3} and1000kgm^{-3} respectively. Find the pressure at B



Pressure in fluids = hρg

Pressure due to water = 2 x 1000 x 10 = 20,000 Nm^{-2}

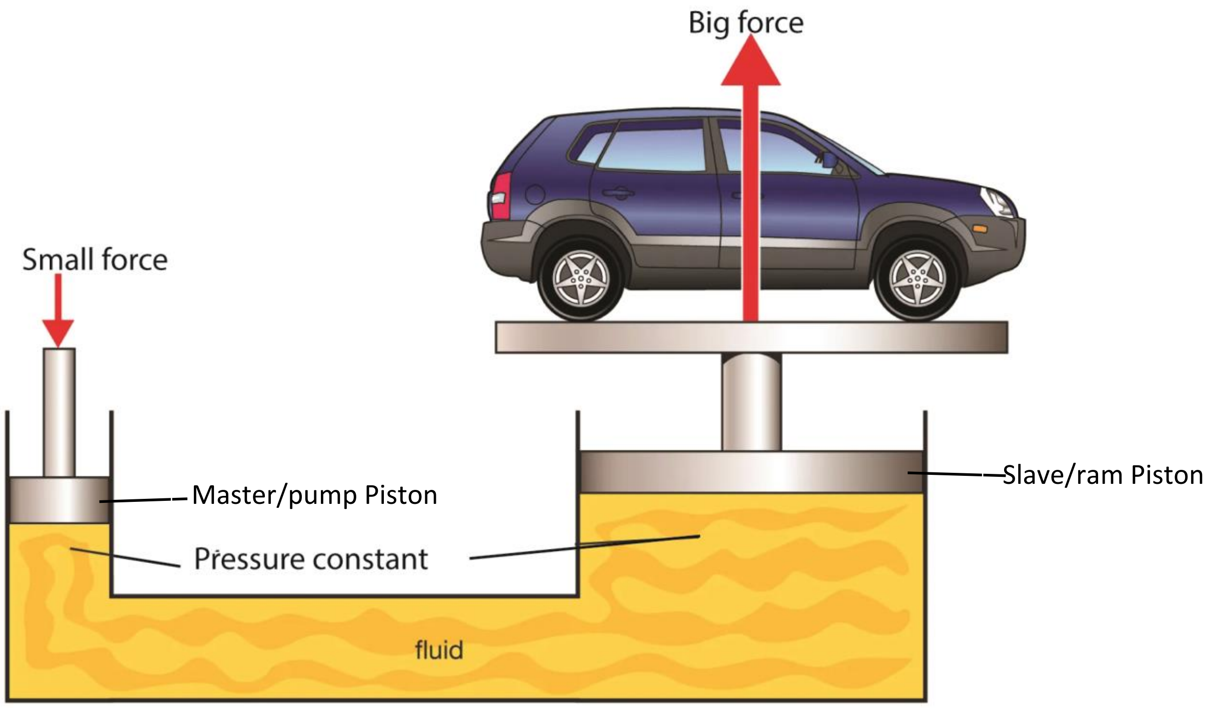
Pressure due to mercury = 3 x 13600 x 10 = 408,000 Nm^{-2}

Total pressure at B = 20,000 + 408,000 = 428,000 Nm^{-2}

Trial 2

The pressure at the bottom of mercury is 106,000Pa. How high is the mercury column? Density of mercury is 13,600kgm^{-3}. [0.78m]

Transmission of pressure in liquids



The **transmission of pressure in liquids** is explained by **Pascal's Principle**, which states:

Pascal's principle states that the pressure applied at a point in an enclosed fluid is transmitted equally to all parts of the fluid

This means that if you apply pressure to a confined liquid, that pressure is passed on uniformly to every part of the liquid and the walls of the container.

Real-Life Applications:

1. **Hydraulic Systems** – Found in car brakes, car jacks, and heavy lifting equipment. A small force applied at one point gets transmitted and magnified to move heavier loads at another.
2. **Dentist Chairs & Barber Seats** – Use hydraulics to smoothly raise or lower the chair with minimal effort.
3. **Hydraulic Presses** – Used in manufacturing to mold, press, or cut materials using transmitted pressure.
4. **Aircraft Landing Gear** – Hydraulic systems transmit pressure to extend and retract landing gear smoothly.

Example 3

(a) The pistons of a hydraulic press have their areas given as A and 10A respectively. If the smaller piston is pushed down with force F, what is the force required to push the larger piston?

Let the force required to push the larger piston be F_2

Pressure = $\frac{Force}{Area}$

Since pressure is constant, then $\frac{F_2}{10A} = \frac{F}{A}$

Hence, $F_2 = 10F$

Trial 3

(a) The pistons of a hydraulic press have their areas given as $3.0 \times 10^{-2} m^3$ and 2.0×10^2 N respectively. If the smaller piston is pushed down with force 120N, what is the force required to push the larger piston? [8.0×10^5N]

(b) A force of 40N applied on the piston pump of area $2cm^2$ to lift a load of 1000N placed on the ram piston. Calculate the

(i) Pressure transmitted [$200,000Nm^{-2}$]

(ii) The area of the ram piston in square centimeters [$50cm^2$]

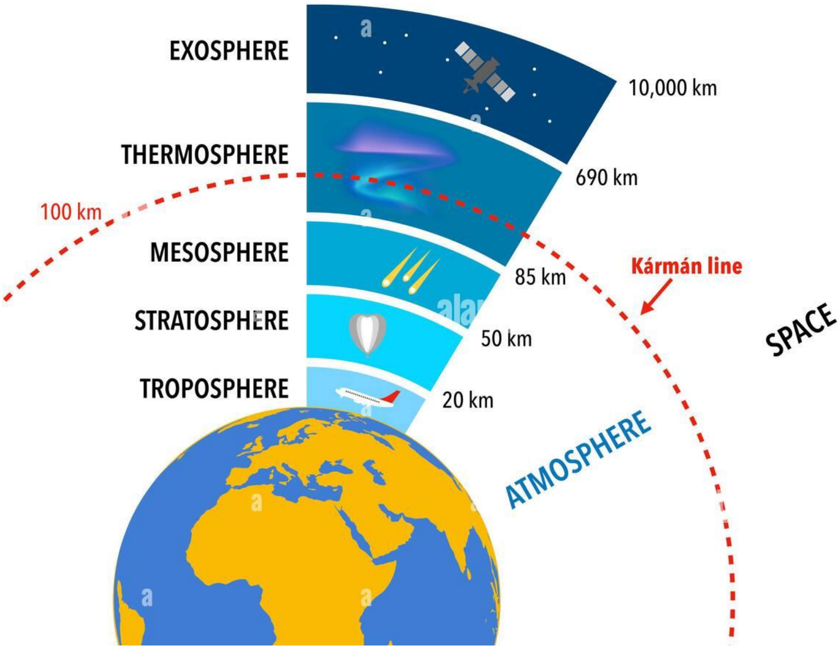
(c) (a) State Pascal's principle.

(b) In a hydraulic press, a force of 200N is applied to master piston of area $25cm^2$. If the hydraulic press is designed to produce a force of 5000N, determine

(i) The area of the slave piston in m^2 [$0.0625m^2$]

(ii) The radius of the slave piston in cm [14.1cm]

Atmosphere



The **atmosphere** is the invisible, protective blanket of gases that surrounds Earth. It is divided into **five main layers**, each with unique characteristics and roles that support life and protect the planet:

1. **Troposphere** occupies space from Surface to ~12 km**.** This is where *all weather* occurs—clouds, rain, storms. It contains about 75% of the atmosphere's mass and most of its water vapor. Temperature decreases with altitude here.
2. **Stratosphere** is the second layer that occurs between 12 km to 50 km. it contains ozone layer, which absorbs harmful ultraviolet (UV) radiation from the sun. Unlike the troposphere, temperature increases with height due to ozone absorption of UV rays. Jet aircraft often cruise here for smoother flights.
3. **Mesosphere** is the third layer occurring between 50 km to 85 km. It's the coldest layer, with temperatures dropping as low as –90°C.
4. **Thermosphere** the fourth layer occurs between 85 km to 600 km. here temperatures soar up to 1500^{0}C due to absorption of high-energy solar radiation.
5. **Exosphere** the fifth layer occurs between 600 km to 10,000 km. it is thin and contains hydrogen and helium. It gradually fades into the vacuum of space and is where many satellites orbit.

Harmful human activities to the atmospheres

Humans have had a profound impact on the atmosphere—some of it beneficial, but much of it harmful. Here are some of the most damaging activities:

1. **Burning Fossil Fuels:** Cars, factories, and power plants release **carbon dioxide (CO_2)** and **methane (CH_4)** into the air. These greenhouse gases trap heat, leading to global warming and climate change.
2. **Deforestation:** Cutting down forests reduces the number of trees that absorb CO_2. It also disrupts ecosystems and contributes to increased atmospheric carbon.
3. **Industrial Emissions:** Factories emit pollutants like **sulfur dioxide**, **nitrogen oxides**, and **particulate matter**, which can cause acid rain and respiratory problems.
4. **Use of CFCs**: Chlorofluorocarbons (CFCs), once common in aerosols and refrigerants, have damaged the **ozone layer**, which protects us from harmful UV radiation. Though largely banned, their effects linger.
5. **Agricultural Practices:** Fertilizers release **nitrous oxide**, another potent greenhouse gas. Livestock farming also produces large amounts of methane.
6. **Urbanization:** Expanding cities increase energy use, vehicle emissions, and heat retention (urban heat islands), all of which strain the atmosphere.

How to mitigate the negative effects of human activities on atmosphere

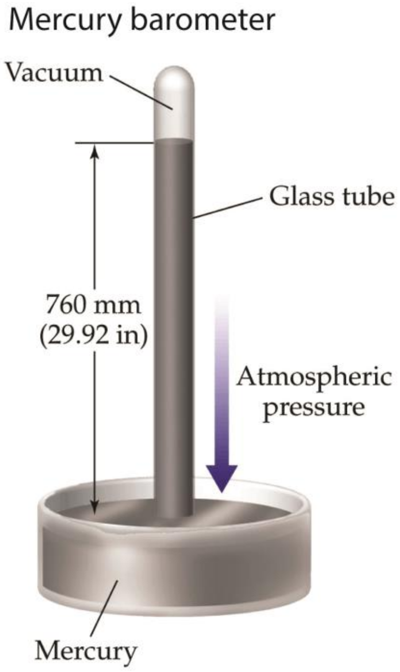
Mitigating the negative effects of human activities on the atmosphere requires both individual action and systemic change. Here are some powerful strategies:

1. **Switch to Clean Energy:** Using renewable sources like solar, wind, and hydroelectric power reduces reliance on fossil fuels, cutting down greenhouse gas emissions.
2. Reforest and Protect Green Spaces: Trees absorb carbon dioxide and release oxygen. Reforestation and preventing deforestation are among the most effective ways to combat climate change.
3. **Adopt Sustainable Transportation:** Walking, biking, using public transit, or switching to electric vehicles can significantly reduce air pollution and carbon emissions.
4. **Reduce, Reuse, Recycle:** Minimizing waste and reusing materials helps lower the energy and emissions involved in production and disposal.
5. Improve Energy Efficiency: Insulating homes, using energy-efficient appliances, and turning off unused electronics can reduce energy consumption and emissions.
6. **Support Climate-Friendly Policies:** Advocating for environmental regulations, clean energy investments, and sustainable urban planning can drive large-scale change.
7. **Educate and Inspire Others:** Spreading awareness and encouraging others to take action multiplies the impact. Collective effort is key to reversing environmental damage.

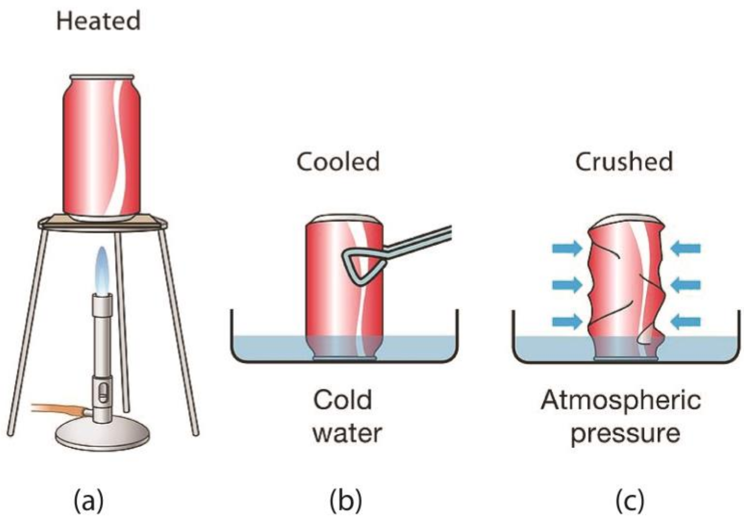
Atmospheric pressure

Atmospheric pressure is the force per unit area exerted on a surface by the weight of the air above it in the Earth's atmosphere. At sea level, atmospheric pressure is about **101,325 Pascals (Pa)**, **1 atmosphere (atm) or760 mmHg**. It decreases with altitude because there's less air above you.

Atmospheric pressure is measured by mercury barometer or aneroid barometer shown below



Experiment to demonstrate atmospheric pressure



(a) Heat a little water in a can until it boil

(b) Close the opening of the hot can and place if in cold water.

(c) Observations: the can collapses.

Explanation

(i) Boiling water fills the can with steam, displacing the air.
(ii) When the can is flipped into cold water, the steam rapidly condenses back into liquid, creating a partial vacuum inside.
(iii) With little to no internal pressure, the **atmospheric pressure outside crushes the can**.

Applications of atmospheric pressure

(i) **Drinking with a Straw:** When you suck air out of a straw, you lower the pressure inside it. The higher atmospheric pressure on the drink's surface pushes the liquid up into your mouth.

(ii) **Syringes and Droppers:** Pulling the plunger or releasing the bulb reduces internal pressure, allowing atmospheric pressure to push liquid into the device.

(iii) **Vacuum Cleaners:** They create a low-pressure zone inside, and atmospheric pressure forces air (and dust) into the machine.

(iv) **Rubber Suckers (Suction Cups)**: Pressing them against a surface expels air, creating a partial vacuum. Atmospheric pressure then holds them firmly in place.

(v) **Lift Pumps:** Used to draw water from wells—atmospheric pressure pushes water up when air is removed from the pump cylinder.

(vi) **Can Crushing Experiment:** Heating and then rapidly cooling a can cause's internal pressure to drop. Atmospheric pressure outside crushes the can—dramatic proof of its strength!

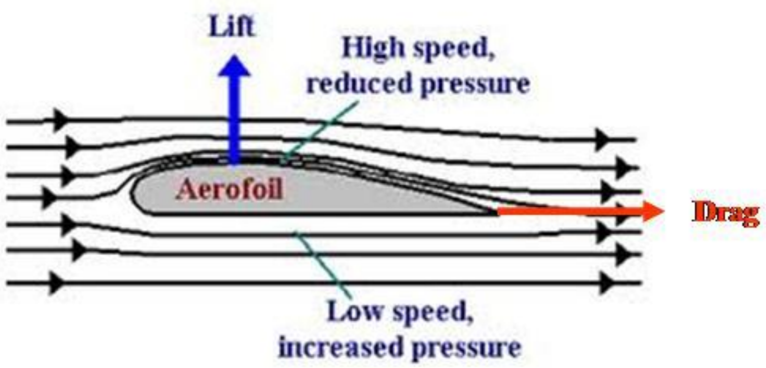
(vii) **Weather Forecasting:** Barometers measure atmospheric pressure to predict weather changes—falling pressure often signals storms.

Bernoulli's effect

The **Bernoulli effect** (or Bernoulli's principle) is a concept in fluid dynamics that explains how **fluid pressure decreases as the fluid's speed increases**.

Application of Bernoulli Effect

(a) **Airplane Wings**: Air moves faster over the curved top of a wing than underneath, creating lower pressure above and lifting the plane.



(b) **Spray Bottles**: Fast-moving air over a tube draws liquid upward due to lower pressure.

(c) **Chimneys**: Wind blowing across the top creates low pressure, helping smoke rise.

Trial 4

Explain the following in relation to Bernoulli's Effect.

(a) It is not advisable to stand close to the railway when a fast moving train is passing.

(b) Rifting of roofs from buildings during high speed wind.

Upthrust

Upthrust, also known as **buoyant force**, is the upward force exerted by a fluid (liquid or gas) on an object that is either fully or partially submerged in it.

Why It Happens:

When an object is placed in a fluid, the pressure at the bottom of the object is greater than the pressure at the top. This difference in pressure creates a net upward force—**upthrust**.

Archimedes' Principle:

Upthrust is equal to the **weight of the fluid displaced** by the object. So:

- If upthrust > object's weight → it floats
- If upthrust < object's weight → it sinks
- If upthrust = object's weight → it hovers or stays suspended

Law of floatation

The **law of floatation** states that: *A floating object displaces its own weight of the fluid in which it floats.*

Everyday Examples:

- A boat floating on water
- A helium balloon rising in air
- You feeling lighter when swimming

Example 4

(a) A boat of mass 150kg floats on water. Find

(i) The upthrust

Upthrust, F = Weight of the boat

= mg

= 150 x 10

= 1500N

(ii) The mass of water displaced

From Archimedes' principle, the weight of water displaced is equal to upthrust.

Mass of water = $\frac{weight\ of\ water}{10} = \frac{1500}{10} = 150kg$

(iii) The maximum mass the boat can load if the volume of the boat at the safety level is $3.0m^3$.

Upthrust, F = weight = mg

mg = ρvg since mass = density, ρ x volume v

= 1000 x 3 x 10 = 30,000N

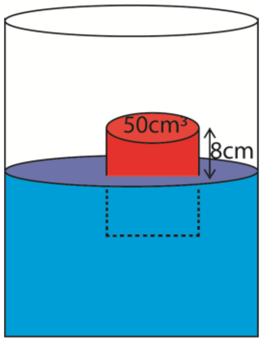
Maximum weight of the load = weight sustained – weight of the boat

= 30,000 – 1500

= 28,500

Maximum mass of the load, m = $\frac{weight\ of\ load}{g} = \frac{28,500}{10} = 2,850kg$

(b) The figure below shows a cylinder immersed in water. If the height of the cylinder is20cm, and the density of water is 1000kgm^{-3}. Find the density of the cylinder in kgm^{-3}.



Volume of water displaced = 50 x 12 = 600cm^3

Mass of water = 600 x 1 = 600g or $\frac{600}{1000} = 0.6kg$

Volume of the cylinder = 20 x 50 = 1000cm^3 or $\frac{1000}{1000000} = 0.001m^3$

Density = $\frac{mass}{volume} = \frac{0.6}{0.001}$ = 600kg/m^3

Trial 5

1. A metal of volume 0.3m^3 is held in water with a string. What is the tension in the string if the density of the metal = 8 x 10^{3}kgm^{-3} and the density of water = 1 x 10^{-3}kgm^3. [14,000N]
2. The density and mass of a metal block are 5000kgm^{-3} and 4.0kg respectively. Find the upthrust which acts on the metal block when it is fully immersed in water. (The density of water = 1000kgm^{-3}) [8N]
3. A steel cable holds 120kg shark tank 3m below the surface of salt water. If the volume of water displaced by the shark is 0.1m^3, what is the tension in the cable? Assume the density of salt water is 1,025kgm^{-3}. [175N]

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Thanks

Dr. Bbosa Science