CHP#05

PRESSURE AND DEFORMATION IN SOLIDS

Q#01: Define elasticity and elastic limit. Give some examples a force may produce changes in size and shape of solids.

Ans:

Elasticity:

The ability of a material to return to its original shape after being stretched or compressed.

Elastic Limit:

The maximum amount of stretch or compression a material can take and still return to its original shape.

Examples of How a Force Changes Size and Shape of Solids:

Stretching a Rubber Band:

1. **Original State**: The rubber band is at its normal length.
2. **Apply Force:** You pull on the ends of the rubber band.
3. **Change in Size:** The rubber band gets longer.
4. **Release Force:** The rubber band returns to its original length if you didn't stretch it too much (within its elastic limit).

Compressing a Spring:

1. **Original State:** The spring is at its normal length.
2. **Apply Force:** You press down on the spring.
3. **Change in Size:** The spring gets shorter.
4. **Release Force:** The spring returns to its original length if you didn't compress it too much (within its elastic limit).

Bending a Metal Rod:

1. **Original State:** The metal rod is straight.
2. **Apply Force:** You push on one end of the rod.
3. **Change in Shape:** The rod bends.
4. **Release Force:** The rod goes back to being straight if you didn't bend it too much (within its elastic limit).

Q#02: What is Hook's law? Illustrate its application.

Ans:

Hooke's law:

Hooke's Law states that the force (F) exerted by a spring is directly proportional to the displacement (x) of the spring from its equilibrium position.

Mathematically;

$$F \propto -x$$

$$F = -kx$$

where:

(F) is the restoring force exerted by the spring,

(k) is the spring constant (a measure of the stiffness of the spring),

(x) is the displacement of the spring from its equilibrium position.

The negative sign indicates that the force exerted by the spring is in the opposite direction of the displacement.

Application of Hooke's Law:

Spring-based Shock Absorbers: Shock absorbers are one of the suspension systems of automobiles where Hooke's Law is most frequently applied. To absorb shocks and vibrations from the road surface, coil springs are employed. The springs compress and store potential energy when the vehicle hits an uneven surface.

Mechanical Watches and Clocks: The mechanism which is used in Watches and Clocks uses Hooke's law. The balance wheel is fitted with a balance spring, also known as a hairspring, which is usually composed of a highly elastic material like steel. According to Hooke's Law, the spring stretches and contracts as the balance wheel oscillates back and forth, applying a restoring force. This ensures that the timekeeping mechanism moves precisely and on schedule.

Real Life Experiments using Hooke's Law:

Measurement of the spring constant:

Materials: spring, weights, hook, and ruler

Method:

- Position the spring vertically and attach a weight to its base.
- With a ruler, measure the spring's extension.
- With different weights, repeat the procedure and note the extensions.
- Plotting a force versus extension graph will allow you to calculate the spring constant, which, in accordance with Hooke's Law, indicates how stiff the spring is.

Hooke's Law Verification Using a Rubber Band:

Materials: Weights, rubber bands, and rulers.

Method:

- Tie one end of the rubber band securely, then fasten weights to the other.
- For every additional weight, measure how far the rubber band extends.
- Draw a force vs. extension graph.
- The force-extension linear relationship validates the Hooke's law.

Q#03: Draw and explain force extension graph for elastic solids.

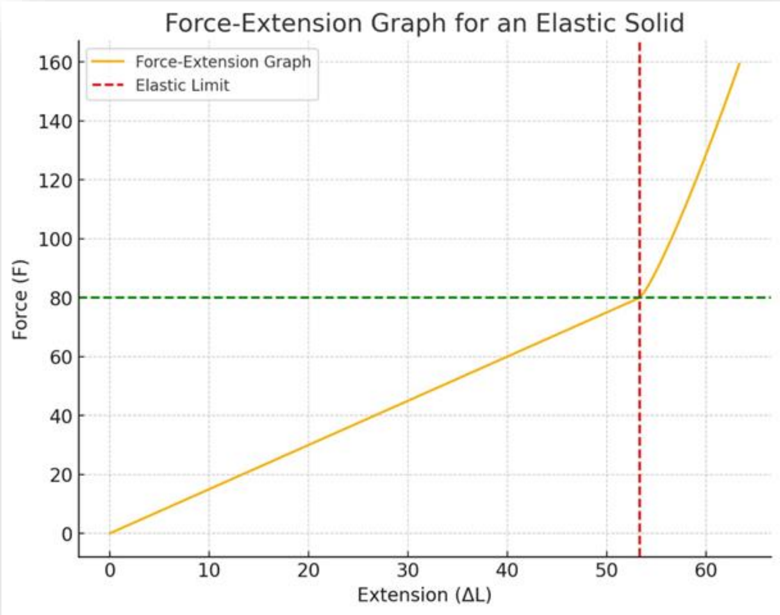
Ans: A force-extension graph for elastic solids shows how a material stretches when a force is applied. Here's a simple explanation with a description of the graph:

1. **Axes:** The horizontal axis (x-axis) represents the extension (stretch) of the material, and the vertical axis (y-axis) represents the applied force.
2. **linear Region:** At the start, the graph is a straight line, showing that the extension is directly proportional to the force. This region follows Hooke's law.

3. **Elastic Limit:** This is the point where the material stops behaving perfectly elastically. Beyond this point, permanent deformation might occur.
4. **Curve:** If the material is stretched beyond its elastic limit, the graph curves and eventually flattens, indicating that more force results in less additional extension.

In summary, the force-extension graph starts as a straight line for elastic deformation and curves beyond the elastic limit. This demonstrates the material's transition from elastic behavior to plastic deformation.

Q#04: Define and explain pressure. What is effect of area on pressure acting on surface?



Ans:

<u>Pressure</u>:

Pressure is defined as the force exerted per unit area on the surface of an object.

Mathematically:

$$P = \frac{F}{A}$$

where

(P) is the pressure.

(F) is the force applied.

(A) is the area over which the force is distributed.

Explanation of Pressure: Pressure describes how concentrated a force is over a particular area. It is a scalar quantity and is measured in pascals (Pa) in the International System of Units (SI). One pascal is equivalent to one newton per square meter(N/m^2).

Effect of Area on Pressure: The area over which a force is applied has a significant impact on the pressure exerted on a surface.

Inverse Relationship: There is an inverse relationship between pressure and the area over which a force is applied. This means that if the same force is applied over a larger area, the pressure decreases. Conversely, if the same force is applied over a smaller area, the pressure increases. From the formula, it is clear that if area increases while force remains constant, pressure will decrease. Similarly, if area decreases, pressure will increase.

Examples:

High Heels vs. Flat Shoes: High heels exert more pressure on the ground than flat shoes because the force (body weight) is concentrated over a smaller area (the heel tips). This can cause damage to floors and discomfort on the wearer's feet.

Knife Cutting: A sharp knife cuts better than a dull one because the same force applied by the hand is concentrated over a smaller area (the sharp edge), creating a higher pressure that allows the knife to penetrate materials more easily.

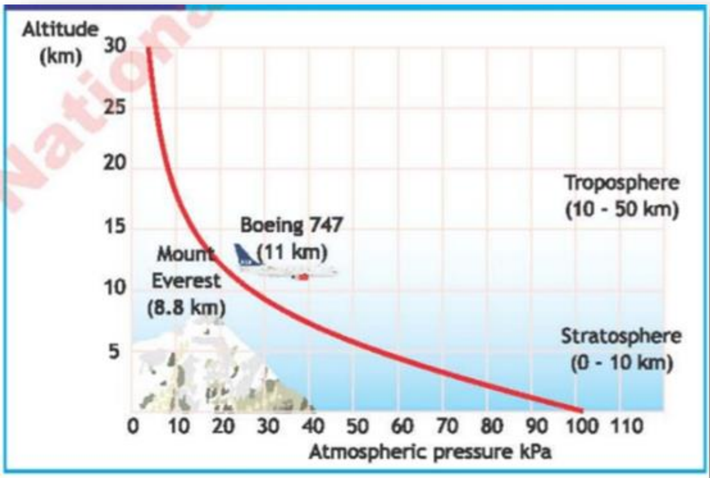
Q#05: Explain the term atmospheric pressure along with its unit. Why atmospheric pressure decreases with altitude?

Ans:

<u>Atmospheric pressure</u>:

The pressure that atmospheric particles exert on the surface and all over the surface of objects on the earth is called atmospheric pressure.

The pressure of the air at a given place varies slightly according to the weather and height from sea level. At sea level, the pressure of atmosphere on average is 1.013×10^5 Nm^2. (or 1.013×10^5 pa). The standard unit for measuring barometric pressure is called an atmosphere (atm).



1 atm = 1.013×10^5 pa.

Another unit of pressure is the bar which is defined as

1 bar = 1.000×10^5 pa.

Atmospheric pressure decreases with altitude:
Atmospheric pressure decreases with altitude because the higher you go, the less air there is above you pushing down. At lower altitudes, the air is packed more tightly because it's being pressed down by all the air above it. As you go higher, there's less air above to push down, so the air becomes less dense and the pressure drops.

Example: Imagine climbing a tall mountain. At the bottom, the air is thick, and you feel the full weight of the atmosphere. As you climb higher, there's less and less air above you, so the pressure decreases. That's why climbers often find it harder to breathe at high altitudes—there's less air pressure and less oxygen available.

Q#06: How atmospheric pressure is measured with liquid barometer? Explain its construction and applications.

Ans:

<u>Measuring Atmospheric Pressure with a Liquid Barometer</u>:

Construction:

Glass Tube: A long, narrow, and closed-at-one-end glass tube.

Mercury: A column of mercury is used as the working fluid due to its high density.

Mercury Reservoir: An open container holding a supply of mercury.

Vacuum: The space above the mercury column inside the glass tube is a vacuum, known as the Torricellian vacuum.

Measures atmospheric pressure:

Atmospheric Pressure Acting on Mercury Surface: Atmospheric pressure exerts a force on the surface of the mercury in the reservoir

Mercury Column Height: This pressure supports the column of mercury in the glass tube. The height of the mercury column is directly proportional to the atmospheric pressure.

Reading the Barometer: The height of the mercury column, typically measured in millimeters (mm) or inches, gives the atmospheric pressure. Standard atmospheric pressure at sea level supports a mercury column of about 760 mm (29.92 inches).

Applications:

Meteorology:

Weather Prediction: Pressure changes indicate weather patterns.

Weather Mapping: Data from multiple barometers help create weather maps.

Altitude Measurement:

Altitude Estimation: Used in aviation and mountaineering due to pressure-altitude correlation.

Scientific Research:

Experiments: Provides accurate pressure readings for lab experiments.

Calibration: Serves as a reference for calibrating other instruments.

Q#07: How does atmospheric pressure influence weather patterns? Write some applications of atmospheric pressure.

Ans:

High Pressure Systems (Anticyclones):

Weather Characteristics: High pressure systems are generally associated with clear skies, light winds, and stable weather conditions. This is because the descending air in high-pressure areas suppresses cloud formation.

Movement: These systems can bring extended periods of settled weather and are often responsible for heatwaves in summer or cold spells in winter.

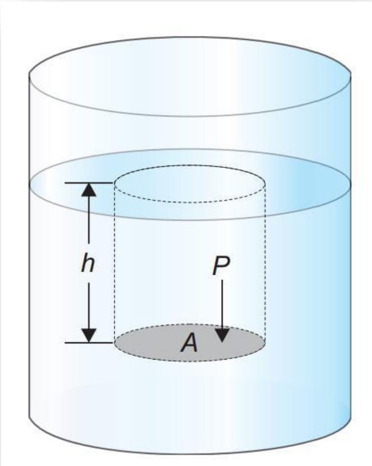
Low Pressure Systems (Cyclones):

Weather Characteristics: Low pressure systems are characterized by rising air, which cools and condenses to form clouds and precipitation. This results in cloudy, wet, and often windy conditions.

Movement: These systems are associated with storms, including thunderstorms, hurricanes, and extratropical cyclones. They can lead to significant weather events such as heavy rain, snow, and strong winds.

Pressure Gradients:

Wind Generation: The difference in atmospheric pressure between high- and low-pressure areas creates pressure gradients. Air moves from high to low pressure, generating winds. The greater the pressure difference, the stronger the wind.



Weather Fronts: Pressure gradients are also responsible for the formation of weather fronts, which are boundaries between air masses of different temperatures and humidities. Fronts can lead to sudden changes in weather, including temperature drops and precipitation.

Applications of atmospheric pressure:

Weather Prediction: We measure atmospheric pressure to help predict if it will be sunny or rainy.

Flying: Pilots use tools that measure air pressure to know how high the plane is flying.

Breathing: The air pressure affects how much oxygen we get when we breathe. At high places like mountains, the air pressure is lower, making it harder to breathe.

Food Storage: Vacuum sealing food involves removing air to keep it fresh longer, as the lower pressure inside the package stops bacteria from growing.

Drinking with Straws: When you suck on a straw, the pressure difference helps pull the drink up into your mouth.

Q#08: Show that liquid in a container exerts pressure equal to P = ρgh. Why pressure in a liquid increase with depth.

Ans: Liquids exert pressure. The pressure of a liquid acts in all directions. Consider a surface of area A in a liquid at a depth has shown by shaded region. The length of the cylinder of liquid over this surface will be h. The force acting on this surface will be the weight w of the liquid above this surface. If ρ is the density of the liquid and m is mass of liquid above the surface, then

Mass of cylinder m = volume × density

$$= (A \times h) \times \rho$$

Force acting on area A

$$F = w = mg$$

as we know

$$m = Ah\rho$$

$$F = A\,h\,\rho\,g$$

as pressure

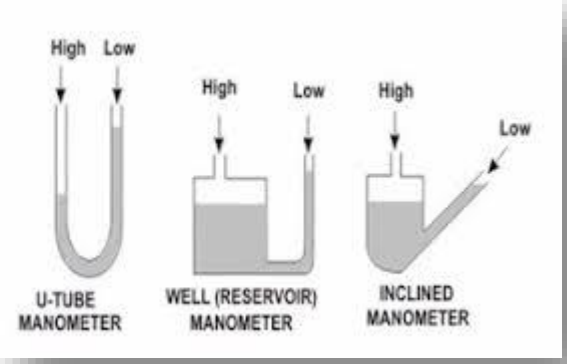
$$P = F / A$$

$$P = \frac{A\,h\,\rho\,g}{A}$$

Liquid pressure at depth h = P = ρ g h

Pressure in a liquid increase with depth: Pressure in a liquid increase with depth because the deeper you go, the more liquid is above you, pushing down due to its weight. This weight causes greater pressure the further down you go.

Q#09: What is a manometer and how does it function in measuring pressure? Write some applications of manometer.



Ans:

<u>Manometer</u>:

A manometer is a tool that measures the pressure of gases or liquids. It usually consists of a U-shaped tube filled with liquid, like water or mercury.

Two Ends: One end of the U-tube is connected to the pressure source (like a gas tank), and the other end is open to the air or connected to another pressure source.

Liquid Levels: The pressure pushes the liquid up one side of the U-tube and down the other side.

Measurement: By looking at how much higher the liquid is on one side compared to the other, you can tell how strong the pressure is.

Essentially, the manometer shows you the pressure by balancing the pressure against the weight of the liquid in the tube.

<u>Types of manometer</u>:

U-Tube Manometer: Consists of a U-shaped tube filled with a liquid (usually mercury or water). The difference in liquid levels in the two arms indicates the pressure.

Well Reservoir Manometer: A well-type (or well reservoir) manometer measures pressure using a large liquid-filled reservoir and a connected narrow tube. The pressure is indicated by the difference in liquid levels between the reservoir and the tube. This type of manometer is accurate, simple, and provides direct readings, making it useful for laboratory measurements and calibrating other devices.

Inclined Manometer: Similar to the U-tube but with one arm inclined at an angle. This design allows for more precise measurement of small pressure differences.

Applications:

- It is to measure the pressure of the fluids using mechanical properties of fluids.
- It is also used to measure vacuum.
- It is also used to measure the flow of the fluid.
- It is used to measure the filter pressure drop of the fluids.
- It is also used used for meter calibrations.
- It is used to measure leak testing.
- It is also used to measure the liquid level present in a tank.

Q#10: Differentiate between Manometer and Barometer.

Ans:

Manometer	Barometer
Measures pressure of liquids and gases.	Measures atmospheric pressure
Used in industrial processes and labs.	Typically used for forecast weather.
Types include U-tube, inclined, and digital manometers.	Types include U-tube, inclined, and digital manometers.
Measure pressure difference	Indicated changes in weather condition.

Q#11: State Pascal's law? Describe working principle of hydraulic lift using Pascal's law? Also describe working of hydraulic car brake system.

Ans:

Pascal's Law:

Pascal's Law states that a change in pressure applied to an enclosed fluid is transmitted undiminished to all portions of the fluid and to the walls of its container. In simpler terms, when pressure is applied to a fluid in a closed system, the pressure change is transmitted equally and instantly throughout the entire fluid.

Hydraulic lift: A hydraulic lift operates based on Pascal's law, which states that pressure exerted anywhere in a confined incompressible fluid is transmitted equally in all directions throughout the fluid.

Pascal's principle at work in hydraulic lift, which is shown figure. Here we see two cylinders, one of cross-sectional area A_1 and the other of cross-sectional area A_2 (such that $A_2 > A_1$). The cylinders, each of which is fitted with a piston, are connected by a tube and filled with a Hydraulic fluid. Initially the pistons are at the same level and exposed to the atmosphere. Now, suppose we push down on piston 1 with the force F_1. The pressure P_1 exerted by this piston is:

$$P_1 = \frac{F_1}{A_1} \qquad (1)$$

Similarly, the pressure on the piston lifting vehicle is P_2

$$P_2 = \frac{F_2}{A_2} \qquad (2)$$

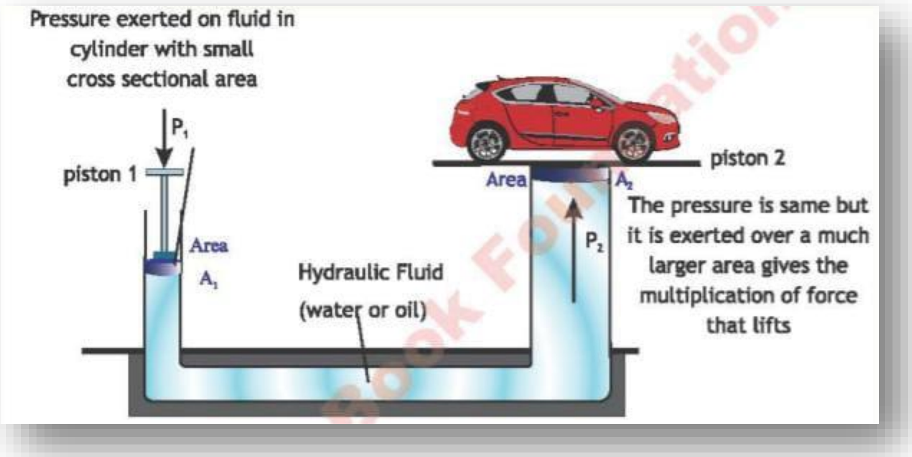
By pascal's principle

$$P_2 = P_1 \qquad (3)$$

Putting values from equation 1 and equation 2 in equation 3, we get

$$\frac{F_2}{A_2} = \frac{F_1}{A_1}$$

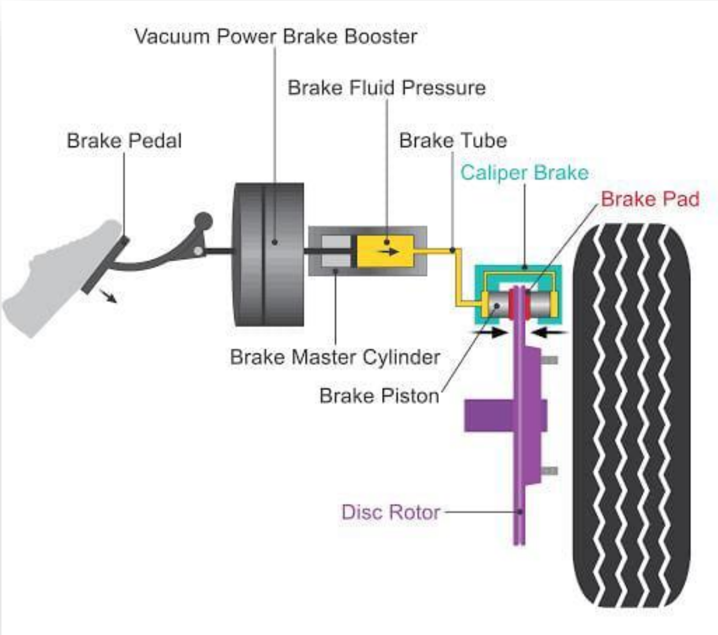
And rearranging for F_2



$$F_2 = \frac{A_2}{A_1} F_1$$

From above equation shows that depending on the ratio A_2 / A_1, the force F_2 can be large as possible. For example, A_1 is 100 times greater than A_2. Then by pushing down on piston 1 with a force F_1 we push upward piston 2 with a force of $F_2 = 100 F_1$.

Hydraulic car brake system:



Purpose: To slow down or stop the car by converting mechanical force into hydraulic pressure.

Components:

Brake pedal: Controlled by the driver to initiate braking.

Master cylinder: Converts the force from the brake pedal into hydraulic pressure.

Brake lines: Carry hydraulic fluid (brake fluid) to the wheels.

Calipers: Located at each wheel, these hold the brake pads and apply pressure to the rotors to slow or stop the wheels.

Brake pads: These squeeze against the brake rotor to create friction and stop the wheel.

Operation:

- When the brake pedal is pressed, it pushes a piston in the master cylinder, pressurizing the brake fluid.
- The pressurized fluid travels through the brake lines to the calipers at each wheel.
- The calipers squeeze the brake pads against the rotors, causing friction and slowing down the wheels.

Conceptual Questions

Q#01: While walking on a trampoline. Do you feel more pressure when you stand still or jump up and down? Why does pressure change with movement?

Ans: You feel more pressure when jumping on a trampoline because the forces from acceleration and deceleration during jumping are greater than the force when standing still, leading to higher dynamic impact and reaction forces.

Q#02: How does the shape of a thumb pin help it penetrate surfaces easily?

Ans: The shape of a thumb pin, with its sharp pointed end and wide head, allows it to penetrate surfaces easily. The pointed tip concentrates force on a small area to reduce resistance, while the wide head provides a large surface for applying pressure, making it easier to push the pin in with minimal effort.

Q#03: If you blow up a balloon and then tie it closed, why does it stay inflated even though you stop blowing? How does pressure play a role here?

Ans: The pressure inside an inflated balloon is greater than the pressure outside it. The balloon is stable because the expanding force due to the pressure difference is balanced by the contracting force exerted by the surface tension of the rubber.

Q#04: Why an inner airtight layer of a space suit is designed to maintain a constant pressure around the astronaut?

Ans: The inner airtight layer of a space suit maintains a constant pressure around astronauts to protect them from the vacuum of space. This pressure prevents bodily fluids from boiling and allows astronauts to breathe comfortably, ensuring their safety and ability to perform tasks during spacewalks.

Q#05: If a liquid has density twice the density of mercury, what will be height of liquid column barometer?

Ans: Consider a liquid used is twice dense as compared to mercury. Thus, the height of the column of liquid is half the height of the mercury column.

Q#06: Why we wouldn't be able to sip water with a straw on the moon?

Ans: On the moon, there's no atmosphere to create the pressure difference that allows straws to work on Earth. Therefore, you wouldn't be able to sip water through a straw on the moon.

Q#07: How are we able to break a metal wire by bending it repeatedly?

Ans: When you bend a metal wire repeatedly, it develops tiny cracks due to stress. These cracks grow with more bending until the wire breaks.

Q#08: A spring, having spring constant k when loaded with mass 'm', is cut into two equal parts. One of the pars is loaded with the same mass m again. What will be its spring constant now?

Ans:

$$\text{Spring constant (k)} \propto \frac{1}{Length\ of\ the\ spring(L)}$$

As length become half, k becomes twice is 2k.

Q#09: Why do static fluids exert a force always perpendicular to the surface?

Ans: A force exerted by a static fluid on a surface is always perpendicular to the surface because the hydrostatic pressure in the fluid acts equally in all directions. This pressure results in a net force acting perpendicular to the surface, ensuring that the fluid remains at rest (in equilibrium) within the fluid.

Q#10: How can a small car lifter lifts load heavier than itself?

Ans: A small car lifter can lift loads heavier than itself due to its hydraulic system and mechanical advantage. The hydraulic system uses fluid under pressure to exert force, which is transmitted through a piston mechanism. Pascal's Principle ensures that the pressure applied to the fluid is distributed equally, but because the lifter has pistons of different sizes, the force applied to the smaller piston (connected to the lifting arm) is greater than the force applied to the larger piston. This difference in force, amplified by the mechanical advantage of the lifter's design, allows it to lift heavy loads effectively despite its small size.

Q#11: What Happens to the Human Body Under Extreme Atmospheric Pressures?

Ans: In scenarios such as diving, deep-sea divers are exposed to high pressures that can increase the risk of nitrogen narcosis which is a condition that impairs cognitive and motor functions and decompression sickness (DCS). DCS is where nitrogen bubbles form in the bloodstream during rapid ascents, causing joint pain, dizziness, and other serious symptoms.

Q#12: It is easy to remove air from a balloon but it is very difficult to remove air from glass bottle. Why?

Ans: Filling air into a balloon is straightforward, but removing air from a glass bottle is challenging because the air pressure inside the bottle is lower than the atmospheric pressure outside. This pressure difference creates suction, making it difficult to extract air from the bottle once it's sealed.

Q#13: What makes a suction cup pressed on a smooth wall sticks to it?

Ans: When we press a suction cup onto a smooth surface, it displaces some of the air between the cup and the surface. This absence of air causes the external atmospheric pressure to push against both the surface and the cup, maintaining the suction that keeps the cup attached to the surface.

Assignment Questions

1. A spring with a spring constant of 150 N/m is stretched by a force. If the spring extends by 0.04 m, calculate the magnitude of the force applied to the spring. What would be the extension if the force applied was doubled? **(6 N, 0.08 m)**

2. A spring has a spring constant of 200 N/m. Two forces are applied to the spring in separate experiments. The first force extends the spring by 0.05 m, and the second force extends the spring by 0.08 m. Calculate the magnitudes of both forces. Also compare the two forces. **(10N, 16N, $\frac{F_1}{F_2} = \frac{10}{16}$)**

3. A spring stretches 0.02 meters when a force of 5 Newtons is applied. Find the spring constant. If the same spring stretches by an amount of 0.06 m, determine the force to produce this extension. Additionally, explain whether this scenario would likely fall within the elastic limit of the spring, and justify your reasoning based on the concept of the limit of proportionality. (-1 250 Nm, 15 N, elastic limit doesn't exceed)

4. A load-extension experiment on a wire resulted in the following data:

   (a) Load (N): 0, 5, 10, 15, 20, 15

   (b) Extension (cm): 0, 1, 2, 3, 5, 8

   (c) Plot these points on a graph. Identify the limit of proportionality and calculate the spring constant up to this limit. **(500 N/m)**.

5. A woman with a mass of 60 kg is standing on one foot. If the area of her foot is 0.03 square meters, calculate the pressure exerted on the ground. **(19.6 kPa)**

6. Two books are placed on a table. One book covers an area of 0.15 square meters and exerts a force of 15 Newtons, and the other covers an area of 0.30 square meters with a force of 30 newtons. Which book exerts more pressure on the table? **(100 Pa, same pressure)**

7. If a force of 500 newtons is applied to the piston of a hydraulic press and the piston has an area of 0.5 square meters, calculate the pressure transmitted to the hydraulic fluid. **(1 kPa)**

8. The weight of the atmosphere above 1 square meter of Earth's surface is about 10,000 kg. Calculate the atmospheric pressure in Pascals (Pa) exerted on this area. **(98 kPa)**

9. If the atmospheric pressure at sea level is 101,325 Pa (101.325 kPa), calculate the expected atmospheric pressure at an altitude of 5,000 meters, assuming a pressure decrease of 12 kPa for every 1,000 meters of ascent. **(41.325 kPa)**

10. A barometer shows a drop in atmospheric pressure from 101.3 kPa to 99.8 kPa within 24 hours. Calculate the percentage decrease in atmospheric pressure. **(1.48%)**

11. If the atmospheric pressure can support a column of mercury 760 mm high, calculate the pressure in pascals. (Density of mercury = 13,600 kg/m³, acceleration due to gravity = 9.81 m/s²). **(101.325 kPa)**

12. A diver reaches a depth where the water pressure (excluding atmospheric pressure) is 200,000 Pa. If the density of sea water is 1025 kg/m³, calculate the depth the diver has reached. **(19.94 m)**

13. Different differential manometer connected to a gas pipe shows a mercury level ce of 120 mm between the two arms. Calculate the pressure di ence between the pipe and the atmosphere. (Density of mercury = 13,600ffer kg/m³). **(16 kPa)**

14. A hydraulic system has a master cylinder with a diameter of 2 cm and a slave cylinder with a diameter of 10 cm. If a force of 100 Newtons is applied to the master cylinder, calculate the force exerted by the slave cylinder. **(2,500 N)**

15. An elephant weighing 6000 kg stands on one foot with an area of 0.2 square meters and then lies down, spreading its weight over an area of 2 square meters. Calculate the pressure exerted by the elephant in both cases and explain the difference in terms of pressure distribution.

(294 kPa, 29.4 kPa)

16. Given the atmospheric pressure at sea level is 101.3 kPa, explain how this pressure would affect a sealed bag of chips taken to the top of a 3000-meter mountain, where the pressure is approximately 0 kPa. Calculate the difference in pressure inside and outside the bag at the top of the mountain. **(31.3 kPa)**

17. Calculate the force required to press a hydraulic jack's small piston with an area of 0.01 square meters to lift a car weighing 1500 kg using a large piston with an area of 0.5 square meters. Discuss the implications of Pascal's Law on the operation of the hydraulic jack. **(294 N)**

18. A scuba diver descends to a depth of 30 meters in the ocean, where the density of saltwater is 1025 kg/m^3. Calculate the pressure experienced by the diver at this depth and discuss how this pressure would affect the volume of air in the diver's lungs compared to the surface. **(402.675 kPa)**

19. If a manometer connected to a gas tank shows a liquid rise of 0.1 meters and the liquid is mercury with a density of 13546 kg/m^3, calculate the pressure of the gas in the tank. Discuss the safety implications if the pressure exceeds the tank's design limit. **(13.28 kPa)**