Chapter 4 – Mass, Weight and Density

Subject content

Content
- Mass and weight
- Gravitational field and field strength
- Density

Learning outcomes
(a) state that mass is a measure of the amount of substance in a body
(b) state that mass of a body resists a change in the state of rest or motion of the body (inertia)
(c) state that a gravitational field is a region in which a mass experiences a force due to gravitational attraction
(d) define gravitational field strength, g, as gravitational force per unit mass
(e) recall and apply the relationship weight = mass × gravitational field strength to new situations or to solve related problems
(f) distinguish between mass and weight
(g) recall and apply relationship density = mass / volume to new situations or to solve related problems

Definitions

Term	Definition	SI unit
Mass	Amount of matter in a body	kg
Weight	Gravitational force exerted by Earth on object	N
Gravitational field	Region where mass experiences force due to gravitational attraction	
Gravitational field strength (g)	Gravitational force acting per unit mass	N/kg
Inertia	Reluctance of object to change its state of rest or motion	
Density	Mass per unit volume	kg/m^3

Formulae

Weight	Density
$W = mg$	$\rho = \frac{m}{V}$

4.1 Mass and Weight

Differences between mass and weight

Aspects	**Mass**	**Weight**
Definition	amount of matter	gravitational force
Quantity	scalar	vector
SI unit	kilogram (kg)	newton (N)
Gravitational field strength (g)	independent (constant throughout)	dependent (not constant at all locations)
Measurement	• Beam balance • Calibrated electronic balance	• Spring balance • Force-meter

Quantities

<table>
<tr><th>Quantity</th><th>Explanation</th><th>SI unit</th></tr>
<tr><td>Mass</td><td>• Does not change with location, shape
• Depends on number and composition of atoms / molecules that make up the body</td><td>kg</td></tr>
<tr><td>Weight</td><td>• Direction of weight is downward, towards centre of Earth
• Depends on gravitational field strength</td><td>N</td></tr>
<tr><td>Gravitational field</td><td>• Any object near Earth experiences gravitational force
• Gravitational force experienced
<table>
<tr><th>Distance</th><th>Gravitational force</th></tr>
<tr><td>Near</td><td>Strong</td></tr>
<tr><td>Far</td><td>Weak</td></tr>
</table></td><td></td></tr>
<tr><td>Gravitational field strength (g)</td><td>• Weight depends on strength of gravitational force acting on it
• Same value as acceleration due to gravity
• Earth = 10 N/kg
Moon = 1.6 N/kg</td><td>N/kg</td></tr>
</table>

Weight

$$\boxed{W = mg}$$

where W = weight (in N)
m = mass (in kg)
g = gravitational field strength (in N/kg)

4.2 Inertia

Inertia

- Greater **mass** → greater inertia
- Larger mass of object, harder for object to change its state of motion
  - (a) start moving
  - (b) slow down
  - (c) move faster
  - (d) change direction
- **Law of inertia**: consistent with Newton's first law of motion

Applications of inertia

<table>
<tr><th>Examples</th><th>Explanation</th></tr>
<tr><td>1. Wear seat belt</td><td>Driver suddenly applies brakes
• Continue to move forward due to inertia
• Without seat belt holding back → crash into windscreen
• Seat belt: provide necessary <u>opposing force</u> that stops him</td></tr>
<tr><td>2. Escape charging elephant</td><td>Run in zigzag manner
• Elephant has larger mass → greater inertia
• Harder for elephant to chase in zigzag manner → trip & fall</td></tr>
<tr><td>3. Train</td><td>Movement of train<table><tr><th>Train</th><th>Body</th><th>Explanation</th></tr><tr><td>move</td><td>jerk backward</td><td>body reluctant to change its current state of rest</td></tr><tr><td>stop</td><td>jerk forward</td><td>body reluctant to change its current state of horizontal velocity</td></tr></table></td></tr>
</table>

4.3 Density

Density

$$\rho = \frac{m}{V}$$

Densities of common substances

State	Substance	Density (g/cm^3)
Liquid	(a) Turpentine	0.87
	(b) Oil	0.92
	(c) Water (pure)	1
	(d) Sea water	1.025
	(e) Mercury	13.6
Solid	(a) Polystyrene	0.016
	(b) Cork	0.24
	(c) Pine wood	0.5
	(d) Ice	0.917
	(e) Glass	2.5
	(f) Iron	7.874
	(g) Gold	19.3

Unit conversion:
1 g/cm^3 = 1000 kg/m^3

Applications of density

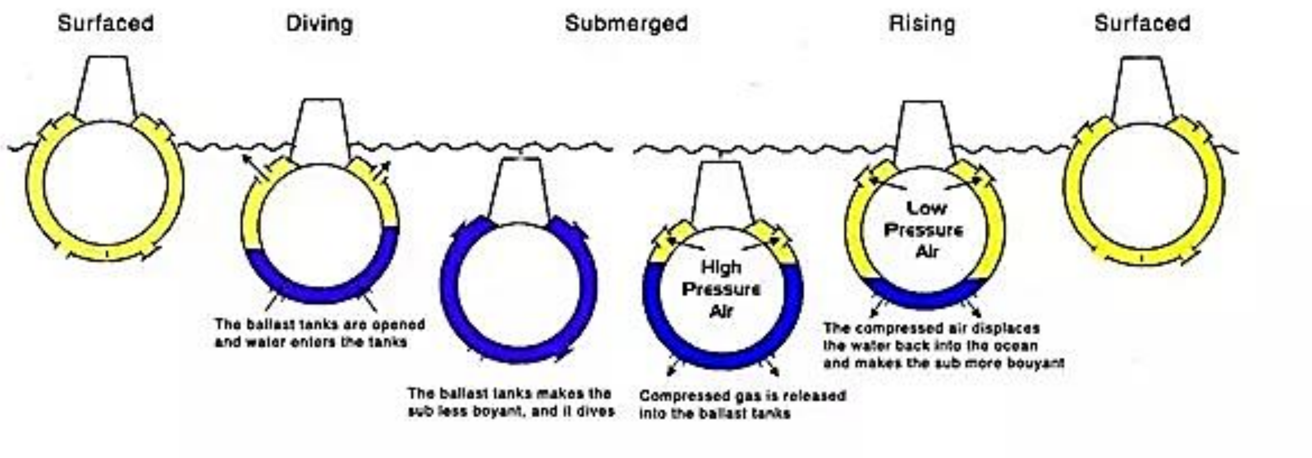
Application	Explanation
1. **Determine purity**	Example: gold chain → compare measured density to that of pure gold (19.3 g/cm^3)
2. **Floatation**	When object floats in various liquids, the denser the liquid, the higher the object will float in liquid <table><tr><th>ρ_{object}</th><th>Object</th></tr><tr><td>$< \rho_{\text{liquid}}$</td><td>Float on liquid</td></tr><tr><td>$= \rho_{\text{liquid}}$</td><td>Suspended anywhere throughout liquid</td></tr><tr><td>$> \rho_{\text{liquid}}$</td><td>Sink in liquid</td></tr></table>

Average density = $\dfrac{\text{total mass}}{\text{total volume}}$

Large and heavy ship floats
- made up of more than one material (steel + air in various rooms and cabins)
- average density less than density of sea water

Submarine (ballast tank) – control buoyancy force

Submarine	Ballast tank	$\rho_{\text{submarine}}$
float	water released through vent, filled with air	$< \rho_{\text{water}}$
sink	air released through vent, filled with water	$> \rho_{\text{water}}$



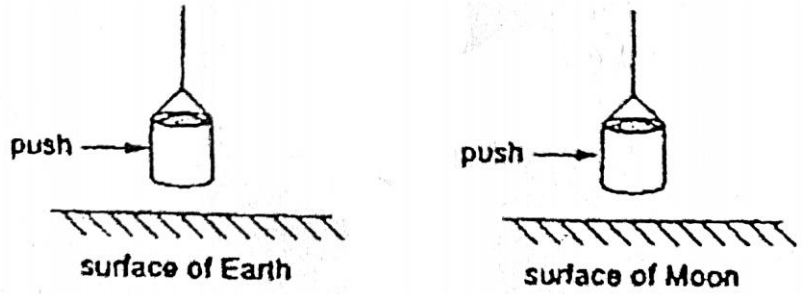
Volume of regular objects

Solids	Formula
Cuboid	$V = \boldsymbol{l} \times \boldsymbol{b} \times \boldsymbol{h}$
Cylinder	$V = \boldsymbol{\pi r^2} \times \boldsymbol{h}$
Cone	$V = \frac{1}{3} \boldsymbol{\pi r^2} \times \boldsymbol{h}$
Sphere	$V = \frac{4}{3} \boldsymbol{\pi r^3}$

<u>Typical questions</u>

Multiple choice questions

1. A can filled with sand, is hung on a long string close to the surface of the Earth. An identical can is hung in the same way close to the surface of the Moon. The cans are given a slight push with the same force.



Compared with the can hanging close to Earth, the can close to the Moon starts to move

A more easily as it has less mass

B more easily as it has less weight

C with the same ease, as it has the same mass

D with the same ease, as it has the same weight

Explanation:
Since same applied force is exerted on the cans horizontally, the cans undergo horizontal motion, which is not dependent on g. In this case, inertia depends on the mass. Since both cans have the same mass, thus they move with same ease as they have the same inertia. If the cans undergo vertical motion, then the can on the Moon moves more easily as the gravitational field strength *g* on the Moon is smaller than that on Earth, thus the gravitational force exerted on the can on the Moon is smaller.

2. Which property of a block of metal remains constant when the metal is heated? (2012 P1 Q9)

A density

B mass

C surface area

D volume

3. The mass of a body resists changes to its motion.
Which property of the body is responsible for this resistance? (2013 P1 Q7)

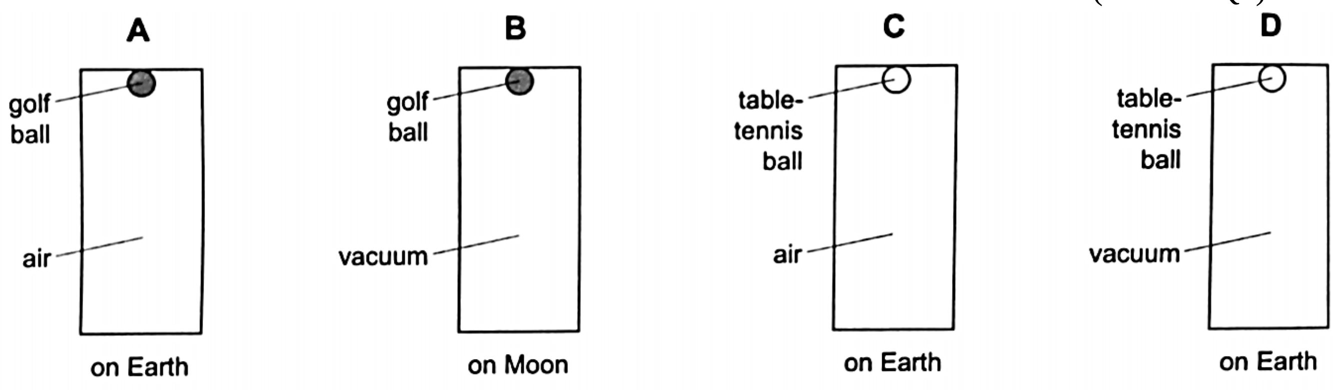
A density

B gravitational potential energy

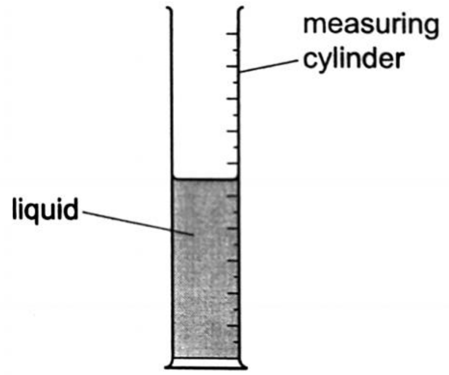
C inertia

D kinetic energy

4. The diagrams show four experiments in which a ball falls from the top to the bottom of identical sealed glass tubes.
In which experiment does the ball take the shortest time to reach the bottom of the tube?
(2013 P1 Q8)



5. The diagram shows liquid in a measuring cylinder.



Using the measuring cylinder and knowing only the density of the liquid, what can be determined?
(2014 P1 Q1)

A the cross-sectional area of the measuring cylinder
B the height of liquid in the measuring cylinder
C the mass of liquid in the measuring cylinder
D the pressure on the base of the measuring cylinder

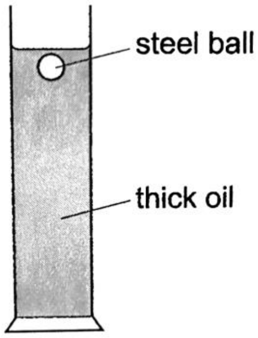
6. An astronaut in a space station orbits the Earth.
When he places his camera at eye level and lets go of it, it stays at his eye level.
At the height at which he orbits, the Earth's gravitational field strength is 5.0 N/kg.
Which statement correctly describes the situation? (2016 P1 Q5)

A The camera has both mass and weight.
B The camera has mass but no weight.
C The camera has no weight and no mass.
D The camera has weight but no mass.

7. Paper is sold in packets labelled 80 g/m2. A sheet of this paper of area 10000 cm2 has a mass of 80g.
The thickness of each sheet is 0.11 mm.
What is the density of the paper? (2016 P1 Q7)

A 0.073 g/cm^3
B 0.088 g/cm^3
C 0.73 g/cm^3
D 0.88 g/cm^3

8. A steel ball is released from rest just below the surface of thick oil in a cylinder.



What happens to the weight of the ball and the resultant force on the ball as it approaches terminal velocity? (2018 P1 Q8)

	weight	resultant force
A	increases	decreases
B	increases	increases
C	stays the same	decreases
D	stays the same	increases

9. A spacecraft travels from the Earth to the Moon. At a certain point in the journey, it has zero weight. Why is the weight zero at this point? (2018 P1 Q9)
   A The gravitational fields of the Earth and of the Moon cancel each other.
   B The spacecraft leaves the Earth's atmosphere.
   C The spacecraft stops moving.
   D There is no air resistance on the spacecraft.

10. Which statement concerning the mass of a body is not correct? (2019 P1 Q9)
   A The body experiences a force in a gravitational field because of its mass.
   B The mass is a measure of the amount of matter in the body.
   C The mass changes when the strength of a gravitational field changes.
   D The mass resists a change in the state of rest or motion of the body.

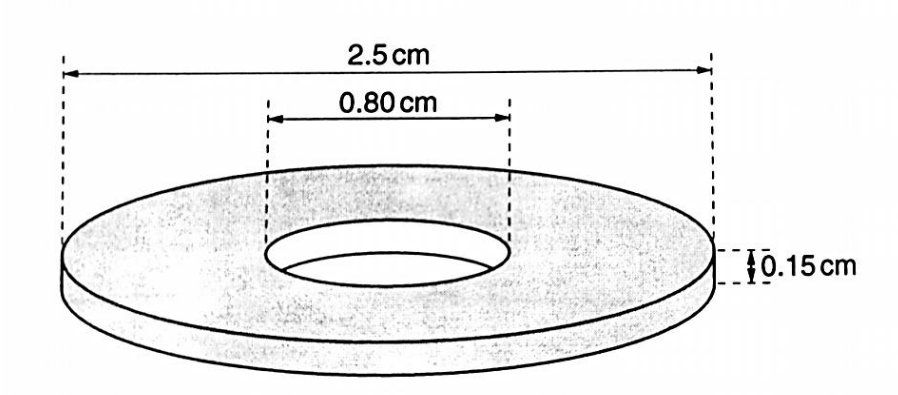
Structured questions

1. Two rubber balls of the same size are both dropped on the Earth and on the Moon. One ball is solid and one is hollow. The approximate gravitational field strength on the Earth is 10 N/kg and on the Moon is 1.7 N/kg.
   Which ball has the greater force acting on it, and where does this occur? Explain why.
   Solid rubber ball has greater force acting on it, on the Earth.
   The ball has greater mass and has greater gravitational field strength on Earth.

2. A driver applies the brakes to stop his car. He is wearing a seatbelt and slows down in his seat. A bad on the seat next to him slides forward, across the seat towards the front of the car.
   Using ideas about forces acting, explain why the drivers slows down but the bag slides forwards.
   Driver slows down because there is a resultant backwards force on driver by seatbelt.
   Bag continues to move forward in a straight line at constant speed due to its inertia, because there is no backward force acting on it.

3. Describe how you can measure the density of a substance.
   1 Determine the mass m of the substance using a beam balance or electronic balance.
   2 Determine the volume V of the substance. If the substance is a liquid, use a measuring cylinder. If the substance is an irregular-shaped solid, use the displacement method. If the substance is a regular-shaped solid, use the appropriate mathematical formula.
   3 Find the density of the substance using the formula density $\rho = \frac{m}{V}$.

4. The figure below shows a large metal washer.
   The washer is 0.15 cm thick and the internal and external diameters are marked on the figure.



(a) A student uses a ruler to measure the internal diameter of the washer.

(i) Describe one practical problem in taking this measurement. [1]

It is not possible for the ruler to measure the length to a precision of 0.80 cm, as the smallest unit of measurement of the ruler is 0.1 cm.

(ii) State of the name of a measuring instrument that is used to take this measurement more accurately. [1]

Vernier calipers

(b) The mass of the metal washer is 5.2 g.

(i) Calculate the volume of metal in the washer. [2]

Volume of metal

$= \left[\pi\left(\frac{2.5}{2}\right)^2 - \pi\left(\frac{0.80}{2}\right)^2\right] \times 0.15$

$= 0.661\ \text{cm}^3$ (3 s.f.)

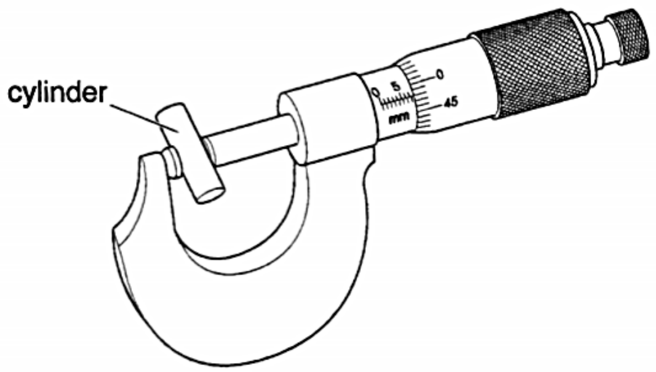
(ii) Calculate the density of the metal. [2]

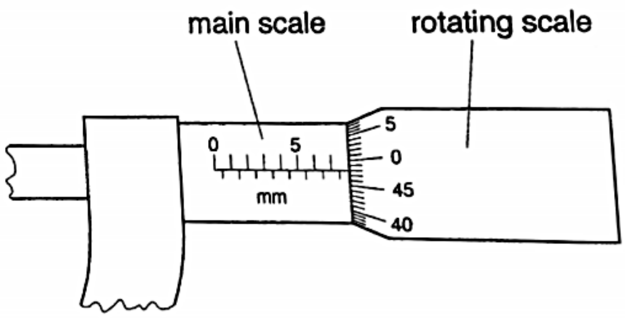
$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$

$= \frac{5.2}{0.661}$

$= 7.87\ \text{g/cm}^3$

5. A micrometer is used to measure the diameter of a small cylinder.
The left figure below shows the micrometer and the right figure below shows the main scale and the rotating scale of the micrometer in detail.





The length of the cylinder is 2.6 cm and its mass is 3.5 g.
Calculate the density of the cylinder.

Diameter of cylinder = 7.98 mm
= 0.798 cm

Volume of cylinder = $\pi r^2 h$
$= \pi \left(\frac{0.798}{2}\right)^2 \times 2.6$ cm^3

Density = $\frac{\text{Mass}}{\text{Volume}}$
$= \dfrac{3.5}{\pi \left(\frac{0.798}{2}\right)^2 \times 2.6}$
= 2.69 g/cm^3 (3 s.f.)