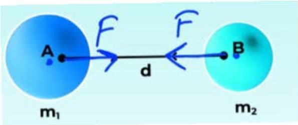
GRAVITATION

Universal Law of Gravitation :-

"Every object in the universe attracts every other object, with a force which is proportional to the product of their masses and inversely proportional to the square of distance between them. The force acts along the line joining the centre of two objects"



m_1 = mass of A (in kg)
m_2 = mass of B (in kg)
d = distance between centre of two objects (in m)
F = force of attraction between two objects (in N)
G = Universal Gravitational constant

$$F = \frac{G m_1 m_2}{d^2}$$

$$F \propto m_1 \times m_2$$
$$F \propto \frac{1}{d^2}$$

$$G = 6.67 \times 10^{-11} \frac{Nm^2}{kg^2}$$

Note :- $F \propto \frac{1}{d^2}$ (inverse square) ⇒ ulta kar, square kar

(i) distance doubled — 2 times ⇒ $\left(\frac{1}{2}\right)^2 = \frac{1}{4}$ → force → $\frac{1}{4}$th
(ii) distance tripled — 3 times ⇒ $\left(\frac{1}{3}\right)^2 = \left(\frac{1}{9}\right)$ → force → $\frac{1}{9}$th
(iii) distance halved — $\frac{1}{2}$ times ⇒ $(2^2) =$ 4 times → force

Importance of the Universal law of Gravitation :-

1) The motion of the moon around Earth.
2) The motion of planets around the sun.
3) The force that binds us to the Earth (Weight).
4) The tides due to the moon and the sun.

Motion of the Moon around the Earth

- Any object moving in a circular path needs a force → centripetal Force.
- This force changes direction of motion (direction of velocity).
- This force always acts towards the centre of circle.
- This force can be provided by any force.
- In the absence of this force, the object will fly off along a straight line (tangent to circle)

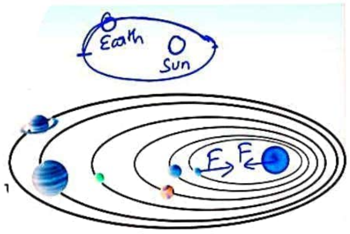
- The motion of moon around Earth is due to centripetal force.
- The centripetal force is provided by the gravitational force of attraction.
- If there was no such force, moon will move in a straight line with the same speed (Uniform straight line motion)
- At each point of its orbit, the moon is pulled towards Earth, instead of going in a straight line.

Motion of planets Around the sun :-

(1) Planets move around the sun due to gravitational force between sun and the planet.

(2) The path of planets around the sun is not exactly circular. [Elliptical path → kepler's law → Not in syllabus]

(3) Planets also attract sun with equal and opposite force (Newton's third law) But sun does not move towards planet as its mass is very large. a↓



$F = ma$ $\quad a = \frac{F}{m}$ $\quad m\uparrow\uparrow, \; a\downarrow\downarrow$

Weight (W)

Weight - The force with which earth attracts an object towards itself (its centre).

$W = mg$ → force (N)

$g = 9.8 m/s^2$
$g = 10 m/s^2$
$W = 60 \times 10$
$= 600 N$

Note - Sometimes g = 10 is given for ease of calculation

W = Weight (in Newton N)
m = mass (in kg)
g = acceleration due to gravity
g = $9.8 m/s^2$ (Approximately near the surface of earth)

Calculate the value of 'g'

Weight (W) = The force with which Earth attracts
(Gravitational Force)

$$\cancel{m}g = \frac{GM\cancel{m}}{R^2}$$

$$g = \frac{GM}{R^2}$$ → G, M, R values put

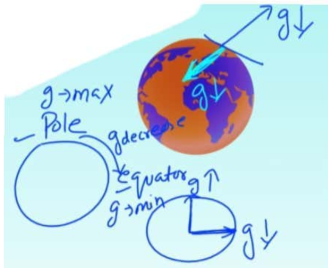
$$g \simeq 9.8\ m/s^2$$

We get, $g = 9.8\ m/s^2$
Acceleration due to gravity near the surface of earth.

Variation in Value of g

$$g = \frac{GM}{R^2}$$

(1) g decreases with height above Earth's surface.
(2) g decreases with depth under Earth's surface.
(3) g is maximum at poles and minimum at equator.
(Earth is Not a perfect sphere)

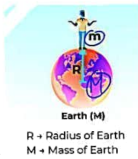


(4) Weight W = mg ; is maximum at poles and minimum at equator.

Weight of an object on the Moon

Weight on earth (WE) = The force with which Earth attract.

$$W_E = \frac{GmM}{R^2}$$

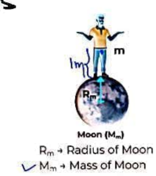


Weight on Moon (Wm) = The force with which Moon attracts

$$W_m = \frac{GM_m m}{R_m^2}$$

calculations

$$W_m = \frac{1}{6} W_E$$



Conclusions

- Weight on Moon = $\frac{1}{6}$ Weight on Earth
- Gravitational Force on Moon surface = $\frac{1}{6}$ gravitational force on Earth's surface
- g at moon = $\frac{1}{6}$ g at Earth

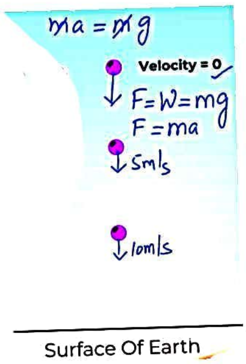
Mass remains same everywhere in universe

Mass	Weight
Mass is the amount of matter present in a body.	Weight is the force with which Earth (or any planet) attracts the body.
It is a scalar quantity.	It is a vector quantity.
Measured in kilogram (kg).	Measured in newton (N).
Remains constant everywhere in the universe.	Changes with place (depends on value of g).
Measured using a beam balance.	Measured using a spring balance.
Formula: Mass = Quantity of matter.	Formula: Weight = Mass × g (W = m × g).

G	g
G is a Universal Gravitation Constant	g is acceleration due to gravity
Value of G is same everywhere in universe	• Value of 'g' varies from Pole to Equator on Earth. Also it varies with height from Earth. Also it is different for different planets • eg: $g_{Moon} = 1/6\ g_{Earth}$
$G=6.67\times10^{-11}\ Nm^2/kg^2$	$g \approx 9.8\ m/s^2$ on or near surface of Earth

Free fall :-

- When an object is dropped from some height above earth's surface, it falls downward due to the gravitational force of attraction of earth (gravity). When object falls towards the Earth under this force alone (no other force acts on it), we say the object is in free fall.
- When an object is dropped from some height above Earth's surface, it falls downward with increasing velocity.
  Any change in velocity involves acceleration.
  This acceleration is due to Earth's gravitational force or gravity.
  This acceleration is called acceleration due to gravity.



- SI Unit of g is m/s^2 $g = 9.8\ m/s^2$

Motion of objects Under Gravity (Gravitational Force of the Earth) :-

Use equations of motion under uniform acceleration.

$a = g = 9.8 m/s^2$

(I) $v = u + at$
(ii) $v^2 = u^2 + 2as$
(iii) $s = ut + \frac{1}{2}at^2$

} learn
s=h

u = initial velocity (m/s)
v = final velocity (m/s)
t = time (s)
s = Displacement/Distance/height (m)
a = acceleration due to gravity
$a = g = 9.8\ m/s^2$

Note

for upward motion, $g = -9.8\ m/s^2$
for downward motion, $g = +9.8\ m/s^2$
(Not completely correct, but for class 9th → Good)

a=g ↑ g=-ve ↓ g=+ve

Importants Points :-

- if there are no external forces (like air resistance), then all objects of any shape, size, mass dropped from the same height will reach the ground at the same time.

  A sheet of paper and a stone in vaccum (absence of air) [In a glass Jar from which air has been sucked out] will fall at the same rate and reach the surface at the same time when dropped from the same height. FREE FALL

- In real world, there is air resistance. It acts more on a body with more surface area.

  A sheet of paper falls slower than one that is crumpled into a ball. A sheet of paper has more surface area exposed to air, so air exerts more resistance which slows it down.

  A crumpled paper has a much smaller surface area, so air resistance is less and it falls faster.

  NOT FREE FALL

Thrust and Pressure

Thrust :- The force acting on an object perpendicular to the surface.
S.I Unit of thrust is Newton (N).

pressure :- Thrust per unit area.

$$P = \frac{\text{Thrust}}{\text{Area}} = \frac{F_\perp}{A}$$

$$cm^2 \xrightarrow[\frac{1}{10^4}]{} m^2$$

S.I Unit of pressure $\Rightarrow \frac{N}{m^2} = Pa$

smaller the Area, More is pressure for given force

$P = \frac{F}{A}$ $\quad F_\perp = 100N$ $\quad A \longrightarrow 100, 10, 1, 0.1, 0.01$

$P \longrightarrow 1, 10, 100, 1000, 10000$

Pressure in Fluids

1) All liquids and gases are fluids.
2) Fluids exert pressure on the base and also on the walls of container in which they are closed.
3) Pressure exerted by fluid is same in all direction at a given depth.

(4) In liquids, pressure increases with depth.

(5) Liquids with more density exert more pressure.

Buoyancy or Upthrust :-

When an object is partially or fully immersed in a fluid (liquid or gas). the fluid exerts an upward force on the object. This upward force is called up upthrust or Buoyancy.

S.I Unit of upthrust is Newton (N)

Q.20 A bucket of water feel lighter when it is inside the well than when it is out of the well.

Reason -

When the bucket is inside water, it experiences an upward buoyant force (Upthrust). This upward force reduces the apparent weight of the bucket, so it feels lighter inside the well.

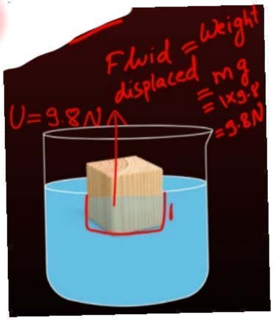
When the bucket is taken out of the water, there is No buoyant force, so it feels heavier.

Archimede's principle :-

- Archimede's principle gives the value / measure of upthrust.

"When a body is fully or partially immersed in a fluid, it experinces an upward force that is equal to the weight of fluid displaced by it"

- Upthrust (U) = Weight of fluid displaced by object



Upthrust is more if

- volume of object inside fluid or Volume of fluid Displaced is more
- Density of fluid is more

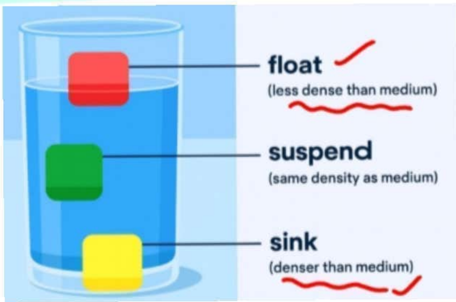
Why object Float or Sink? → Density!

Density of an object is mass per unit volume

density (ρ) = $\frac{\text{Mass}}{\text{Volume}}$

S.I Unit = kg/m^3

other unit = g/cm^3



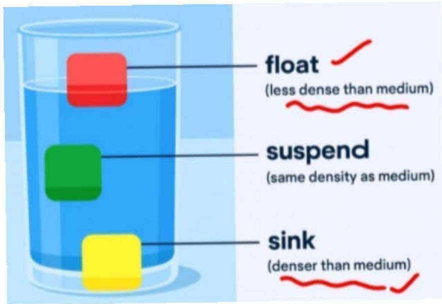
✡ if density of an object > density of liquid → object sinks in the liquid.

e.g an iron nail

✡ if density of an object < density of liquid → object floats on the liquid.

e.g a cork (wooden)

✡ if density of an object = density of liquid → object remains suspended.

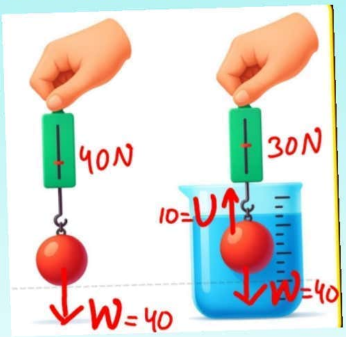


Activity 9.7

Q.21 The elongation of string (or reading on the balance) decreases when a stone is immersed in water compared to when it is in air.

Reason → The elongation produced in string is due to the force on string, which is weight of the stone in air.

When stone is immersed in water, an upward force (upthrust) acts on it. Thus the net force on string decreases & hence the elongation decreases (reading also decreases)



Activity 9.4

1) When you push the bottle into the water, you feel an upward force.
Reason: Water exerts an upward force (upthrust) on the bottle.

2) When you try to push the bottle deeper & deeper, it becomes more & more difficult until the bottle is completely immersed in water.
Reason: The upward force on bottle (upthrust) exerted by liquid goes on increasing as amount of water displaced increases , till it is completely immersed and has displaced maximum amount of water

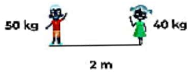
3) When you release the bottle, it bounces back to the surface.
Reason: The upward force on the bottle (upthrust) is greater than weight of bottle, hence it rises upward.

Q.1 Find the unit of Gravitational Constant G.

$F = \frac{G m_1 m_2}{d^2}$ $\quad G = \frac{F d^2}{m_1 m_2} = \frac{N m^2}{Kg^2} \rightarrow N m^2 Kg^{-2}$

$G = 6.67 \times 10^{-11} N m^2 Kg^{-2}$

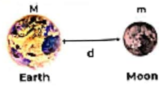
Q.2 Find the force of gravitation



$F = \frac{G m_1 m_2}{d^2} = \frac{6.67 \times 10^{-11} \times 50 \times 40}{2^2}$

$\approx 3 \times 10^{-10} N$ $\quad \frac{3}{10000000}$

Q.3 The mass of the earth is 6×10^{24} kg and that of the moon is 7.4×10^{22} kg. If the distance between the earth and the moon is 3.84×10^5 km, calculate the force exerted by the earth on the moon. (Take $G = 6.67 \times 10^{-11}$ N m² kg⁻²)



A) 3.4×10^{18} N

B) 1.02×10^{19} N

C) 1.8×10^{24} N

D) 2.02×10^{20} N

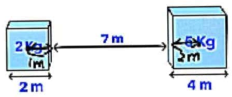
$F = \frac{G M_1 m_2}{d^2}$

$= \frac{6.67 \times 10^{-11} \times 6 \times 10^{24} \times \_\_\_\_}{d^2}$ $\quad Km \xrightarrow{\times 1000} m$

H.W.

$\approx 2.02 \times 10^{20} N$

Q.4 Gravitation Force of attraction will be?



A) $\frac{10G}{49}$ ✗

B) $\frac{G}{10}$ ✓

C) $\frac{10G}{81}$

D) $\frac{10G}{169}$

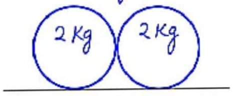
$F = \frac{G m_1 m_2}{d^2} = \frac{G \times 2 \times 5}{7^2}$

$= \frac{10G}{49}$ ✗

$d \Rightarrow 1 + 7 + 2 = 10m$

$= \frac{G \times 2 \times 5}{10^2} = \frac{G \times 10}{10 \times 10}$

Radius of Spheres = 1m



COMMENT

Force of Gravitation →

H.W.

A) 0

B) $\frac{G}{4}$

C) G

D) $\frac{1}{0}$

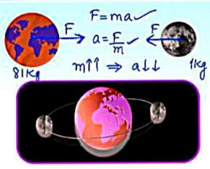
Q.5 Earth attracts Moon due to Gravitational Force, Does Moon also attracts Earth. If Yes , then Why does Earth not move towards moon? *NCERT*

Yes , By Newton's Third Law , Every action has equal and opposite reaction. So if Earth attracts moon , moon also attracts earth. Also the force of gravitation acts on both the bodies involved.

The mass of Earth is 81 times mass of moon.

For a given force, more is the mass, lesser is the acceleration.

So , the acceleration of Earth is so small that we dont see any movement of Earth towards moon



Q.6 If the Gravitational Force due to Earth becomes zero. Will the moon still keep moving around Earth ?

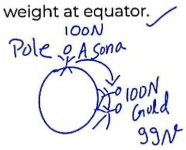
NO. In the absence of any Force , the moon will go in a uniform straight line motion according to Newton's First Law of Motion.

Q.7 Amit buys gold at the poles for his friends. He hands it to him at the equator. Will the friend agree with the weight of gold bought? If not, why? *NCERT*

No, the friend will not agree with the weight .

Reason- Weight W = mg , depends on g. The value of g is greater at the poles and smaller at the equator

So the same mass shows more weight at poles and less weight at equator.



Q.8 Weight of an object of mass 10 kg on Earth & Moon? (g=9.8 m/s²) *NCERT*

$m = 10 Kg$

$W_E = mg = 10 \times 9.8 = 98N$ (Force)

$W_m = \frac{1}{6} W_E = \frac{1}{6} \times 98 = 16.33N$

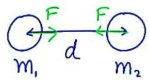
Q.9 An object has mass 40kg on Moon. What is its mass on Earth ?

mass = 40kg

g

W

1)



$F = \frac{G m_1 m_2}{d^2}$

2) $G = 6.67 \times 10^{-11} Nm^2/Kg^2$

3)

Centripetal Force ⇐ = Gravitational Force

4) $W = mg$

5) $W = mg = \frac{GMm}{R^2}$

6) $g = \frac{GM}{R^2}$

7) $g \approx 9.8 m/s^2$ Near Earth's Surface

8) $W_{moon} = \frac{1}{6} W_{earth}$; $g_{moon} = \frac{1}{6} g_{earth}$

Q.10 Find gravitational force between the earth and a 1 kg object on its surface? $G = 6.67 \times 10^{-11}$ Nm² kg⁻² , mass of Earth $= 6 \times 10^{24}$ kg , Radius of Earth $= 6.4 \times 10^6$ m (6400 km) *NCERT*

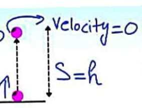
$F = \frac{GMm}{d^2} = \frac{GMm}{R^2} = \frac{6.67 \times 10^{-11} \times 6 \times 10^{24} \times 1}{(6.4 \times 10^6)^2}$

$= 9.8N$

$W = mg$
$= 1 \times 9.8$
$= 9.8N$

Case 1

Object is thrown upwards, reaches a height (maximum height).



Q.11 A ball is thrown vertically upwards with a velocity of 49 m/s. Find the maximum height to which it rise. *NCERT*

A) 250 m

B) 75 m

C) 122.5 m

D) 152.5 m

$V = 0$

$S = h$ $\quad a = g = -9.8 m/s^2$

$u = 49 m/s$

$V^2 = u^2 + 2aS$

$0 = (49)^2 + 2 \times (-9.8) \times S$

$2 \times 9.8 \times S = 49 \times 49$

$S = \frac{49 \times 10}{4}$

$S = \frac{490}{4}$

$= 122.5m$

Case 2

Object is thrown upwards, time to return to surface.

$v=0$, t, t, u — Total time $= t+t = 2t$

Q.12 A ball is thrown vertically upwards with a velocity of 49 m/s. Find the total time it takes to return to the surface of Earth. *NCERT*

- A) 0.5 s
- B) 0.1 s
- C) 5 s
- D) 10 s

$v=0$, upward, $a=g=-9.8\,m/s^2$, $u=49\,m/s$

$v = u + at$

$0 = 49 + (-9.8)t$

$\frac{98}{10}t = 49$

$t = \frac{10}{2} = 5s$

$T = 2 \times t$, $5s$, $5s$, $= 10s$

Case 3

Object dropped, falls, released — $u=0$

Q.13 A stone is released from the top of a tower of height 19.6 m. Calculate its final velocity just before touching the ground. *NCERT*

- A) $\sqrt{9.8}$ m/s
- B) $\sqrt{19.6}$ m/s
- C) 9.8 m/s
- D) 19.6 m/s

$u=0$, Downward, $a=g=+9.8\,m/s^2$, u, a, s, v?, $s=h$, 19.6m, $v=?$

$v^2 = u^2 + 2as$

$v^2 = 0 + 2\times 9.8 \times 19.6$

$v^2 = 2\times 9.8\times 2\times 9.8$

$v = 2\times 9.8$

$19.6\,m/s$

Case 4 Average Velocity = $\frac{\text{Total Displacement}}{\text{Total Time}} = \frac{1.225m}{0.5} = 2.450\,m/s$

Q.14 A car falls off a ledge and drops to the ground in 0.5 s. (use g = 10 m/s²)
Calculate - i) Speed on striking ground $= 4.9\,m/s$
ii) How high is the ledge $= 1.225m$
iii) Average speed in during 0.5 s. $= 2.450\,m/s$ *NCERT*

$u=0$, $h=S$, $t=0.5s$, $v=?$, downward, $a=g=+9.8\,m/s^2$

$v = u + at$

$= 0 + 9.8 \times \frac{1}{2}$

$= 4.9\,m/s$

a, u, t, v

$S = ut + \frac{1}{2}at^2$

$S = 0 + \frac{1}{2}(9.8)\left(\frac{1}{2}\right)^2$

$S = \frac{9.8}{8}$

$S = \frac{9.8}{8} = 1.225\,m$

Q.15 A stone is thrown vertically upward with an initial velocity of 40 m/s. (g = 10 m/s²). Calculate:
1) Maximum height reached $= 80m$
2) Net displacement (Total) $= 0$
3) Total distance covered by stone. $= 160m$ *NCERT*

$v=0$, upward, $a=g=-10\,m/s^2$, $S=h$, $u=40\,m/s$

v, u, a $S=?$

$v^2 = u^2 + 2aS$

$0 = (40)^2 + 2(10)(S)$

$20S = 40 \times 40$

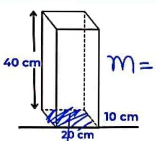
$S = 80m$

Net Disp = 0

80, 80

Q.16 Mass of wooden block kept on atable is 5 kg. Find Pressure exerted on Table. *NCERT*

$\{cm^2 \xrightarrow{\frac{1}{10^4}} m^2$



$m = 5kg$

$W = mg$

$F_\perp = 5 \times 9.8$

Comment

$P = \frac{F_\perp}{A}$

$A = l \times b = 20 \times 10\,cm^2$

$= \frac{20\times 10}{10000}\,m^2$

Q.17 When you stand on loose sand, your feet go deep into it. But when you lie down on the same sand, your body does not sink much. Explain.

When we stand on loose sand, the weight of our body falls on a small area (our feet). This produces more pressure, so the feet go deep into the sand. But when we lie down, the same weight spreads over a large area (whole body). This produces less pressure, so the body does not sink much in the sand.

Q.18 Why a truck has much wider tyres ?

A truck is very heavy, so it puts a large force (its weight) on the ground.

Wide tyres increase the area of contact with the ground, so the pressure due to weight of truck decreases. This helps the truck to move smoothly without sinking or damaging the road.

Q.19 Why a camel can run in a desert easily?

P↓ Feet A↑

A camel can run easily in a desert because it has broad feet. Its weight (thrust) spreads over a large area of sand. So, the pressure on the sand becomes less. That is why its feet do not sink much in the sand, and it can walk or run easily. Humans have smaller feet → less area → more pressure → feet sink in sand.

A → very small ↓ P↑↑

Q.20 Why cutting tools have sharp edges?

Cutting tools like knives, blades, and axes have sharp edges so that the area of contact becomes very small.
This large pressure helps the tool to cut objects easily.

Q.21 A bucket of water feel lighter when it is inside the well than when it is out of the well.

Reason -
When the bucket is inside water, it experiences an upward buoyant force (Upthrust) . This upward force reduces the apparent weight of the bucket, so it feels lighter inside the well.
When the bucket is taken out of the water, there is No buoyant force , so it feels heavier.

Q.22 You find your mass to be 42 kg on a weighing machine. Is your mass more or less than 42 kg? *NCERT*

Ans. Your mass is more than 42 kg.

When you stand on a weighing machine, you are surrounded by air. The displaced air exerts an upthrust (upward force). Because of this upthrust, the machine shows a slightly lower reading than your true weight. Therefore, your real mass is more than 42 kg.

Q.23 You have a bag of cotton and an iron ball each indicating a mass of 100 kg when measured on a weighing machine. In reality, one is heavier than the other. Can you tell which one? *NCERT*

Ans. The weighing machine reads net force acting on it. Air around the cotton and iron will exert an upward force (upthrust) on it. The upthrust on 100 kg cotton will be more because 100kg of Cotton will dislace more volume of air than 100 kg of iron.
So the machine shows much less weight of cotton than iron.

Q.24 If density of water is 1g / cm³, will the substance given float or sink in water?

Mass = 50g
Volume = 20 cm³

Q.25 If density of water is 1g / cm³, will the substance given float or sink in water?

Mass = 50g
Volume = 20 cm³

$\text{Density} = \frac{\text{mass}}{V} = \frac{50g}{20cm^3} = 2.5g/cm^3 > \text{water } 1g/cm^3$ → Sink

Mass of water displaced $= V \rho$ (V: solid inside water; ρ: liquid water)

Q.26 Why is swimming in sea water easier than swimming in fresh water?

Sea water contains dissolved salts, which makes it denser than fresh water. Because of this higher density, the buoyant force (upthrust) on our body is greater in sea water. This extra upthrust helps us float more easily, so swimming in sea water is easier than in fresh water.

12N, 10N — U↑ AIR, W=1000N / Hollow

Q.27 Why does an iron nail sink in water but a ship made of iron floats?

An iron nail is small and dense, so it displaces only a little water. The upthrust on it is less than its weight, so it sinks. But a ship is hollow and has a large volume. It displaces a large amount of water, and the upthrust becomes equal to or more than its weight. That is why a big iron ship floats, while a small iron nail sinks.

Q.28 How can you keep the bottle completely immersed in water?

By applying a downward force, at least equal to difference between the upward force (upthrust) and weight of the bottle.