CLASS 9 • PHYSICS

UNIT 4
Turning Effects of Force

Torque, Equilibrium & Centre of Gravity — Complete Notes

Definitions | Explanations | Solved Examples
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UNIT 4: Turning Effects of Force

Long Questions & Answers

1 Define like and unlike parallel forces. Explain with an example.

Like Parallel Forces: Forces acting in the same direction are called like parallel forces.
Unlike Parallel Forces: Forces acting in opposite directions are called unlike parallel forces.
Example: Consider three forces F1, F2, F3 acting on a rigid body at different points. F1 and F2 are like parallel forces (same direction); F2 and F3 are unlike parallel forces (opposite directions).

2 Define Resultant force. Explain how resultant force is found out by head-to-tail rule with example.

Resultant Force: A single force that has the same effect as the combined effect of all forces being added.
Head-to-Tail Rule: Place the tail of the second vector at the head of the first vector, and continue for more vectors. The resultant is drawn from the tail of the first vector to the head of the last vector.

3 What is meant by rigid body and axis of rotation? Explain briefly.

Rigid Body: A body in which the distance between any two points remains constant under the action of a force (no deformation).
Axis of Rotation: The straight line joining the centres of the fixed circles along which particles of a rotating rigid body move.

4 What is meant by line of action of force and moment arm?

Line of Action of Force: The line along which the force acts.
Moment Arm: The perpendicular distance from the axis of rotation to the line of action of the force. A larger moment arm gives a greater turning effect.

5 Define moment of force. Prove its mathematical relation.

Moment of Force (Torque): The product of the force and the moment arm; measures the turning effect of a force.
Formula: $\tau = F \times l$
Zero Torque: Torque is zero when the line of action passes through the axis of rotation (moment arm = 0).
Direction: Positive for anticlockwise rotation, negative for clockwise rotation.
Unit: Newton-metre (N·m).

6 Define and explain couple.

Couple: Two equal and opposite parallel forces acting at two different points of the same body form a couple, producing a pure turning effect (torque).
Examples:

- Opening/closing a water tap
- Turning a key in a lock
- Opening the lid of a jar
- Turning a steering wheel

7 Explain the concept of resolution of vectors/forces. How can a force be resolved into perpendicular components?

Resolution: The reverse of the head-to-tail rule — a vector is divided into two or more components whose resultant equals the original vector.
Rectangular Components: A force F at angle θ with the x-axis has:
$F_x = F \cos\theta \quad F_y = F \sin\theta$

8 Explain how to determine the magnitude and direction of a force from its perpendicular components.

Magnitude: $F = \sqrt{(F_x^2 + F_y^2)}$ (Pythagorean theorem)
Direction: $\tan\theta = F_y/F_x$, so $\theta = \tan^{-1}(F_y/F_x)$

9 Explain the principle of moments with an example.

Principle of Moments: When a body is balanced, the sum of clockwise moments about any point equals the sum of anticlockwise moments about that point.
Example: A metre rule balanced on a wedge at its centre of gravity, with weights w1, w2 on one side (distances l1, l2) and w3 on the other (distance l3). When balanced: w1×l1 + w2×l2 = w3×l3.

10 Explain the concept of the centre of gravity of an object and describe how to find it for an irregular-shaped lamina.

Centre of Gravity: The point where the total weight of a body appears to act. A body supported here stays balanced without rotating.
Finding it experimentally: Suspend the lamina freely from different points; the C.G lies on the vertical line through each suspension point (found using a plumb line). The intersection of these lines gives the C.G, which may lie inside or outside the body (e.g. a cup).

11 Explain the concept of centre of mass. How does it relate to centre of gravity?

Centre of Mass: The point where the whole mass of a body is assumed to be concentrated.
Relation: On Earth's surface, where g is nearly uniform, the centre of mass coincides with the centre of gravity.

12 What is equilibrium? Explain its types with suitable examples.

Equilibrium: A body is in equilibrium if it has no acceleration (resultant force is zero).
1. Static Equilibrium: Body at rest, sum of forces = 0. E.g. a book on a table (F_n = W).
2. Dynamic Equilibrium: Body moving with uniform velocity, forces balanced. E.g. a paratrooper descending at constant speed (weight = air resistance).

13 What are the conditions of equilibrium? Explain the first and second conditions with mathematical expressions and examples.

First Condition (translational): $\Sigma F = 0$, i.e. $\Sigma F_x = 0$ and $\Sigma F_y = 0$.

Second Condition (rotational): $\Sigma\tau = 0$ — the vector sum of all torques about any point is zero.
Complete equilibrium requires both $\Sigma F = 0$ and $\Sigma\tau = 0$.

14 Explain the steps involved in solving problems by applying conditions of equilibrium.

1. Select the object(s) to analyse separately.
2. Draw a free-body diagram showing only forces acting on the object.
3. Choose x, y axes to minimise resolving of forces.
4. Resolve non-axial forces into rectangular components.
5. Apply $\Sigma F_x = 0$ and $\Sigma F_y = 0$.
6. Apply $\Sigma\tau = 0$ if needed.
7. Solve the equations simultaneously.

15 Describe the three states of equilibrium with detailed explanations and examples.

1. Stable Equilibrium: Body returns to its original position after a slight tilt (e.g. a cone resting on its base).
2. Unstable Equilibrium: Body moves further away after a slight tilt (e.g. a cone balanced on its tip).
3. Neutral Equilibrium: Body rests in its new position with no change in the height of its centre of mass (e.g. a cylinder or ball on a horizontal surface).

16 How can the stability of an object be improved? Give examples.

Methods:

- Lowering the centre of gravity
- Widening the base

Vehicles: Heavy loads placed low keep buses/ships stable; loads placed high raise the C.G and risk toppling.

17 How is the concept of stability applied in racing cars and balancing toys?

Racing Cars: Centre of mass kept as low as possible; wheels placed outside the main body to widen the base.
Balancing Toys: Centre of gravity is kept below the pivot point, so any disturbance raises the C.G momentarily before it returns to its stable lowest position.

18 How do torque and force relate in rotational and translational motion?

Torque plays the same role in rotational motion as force does in translational motion. A rotating object continues with constant angular velocity unless acted on by a resultant torque (analogous to Newton's first law).

19 Define and explain circular motion and force perpendicular to the circular motion.

In circular motion, velocity is always directed along the tangent to the path, so it changes direction constantly. A force perpendicular to the velocity is required to keep the body moving in the circle without changing its speed ($F \cos 90° = 0$).

20 Define centripetal force. Write its formula and real-life examples.

Centripetal Force: The force, directed towards the centre, that causes a body to move in a circle at constant speed.
Formula: $F_c = mv^2/r$
Sources: Tension in a string (whirling stone), gravitational force (Moon/satellites), friction (washing machine drum), and centripetal force in a cream separator.

Solved Examples

Example 4.2 — Torque on a nut

Spanner length $l = 0.25$ m, Force $F = 400$ N

$\tau = F \times l = 400 \times 0.25$

$\tau = 100$ N·m

Example 4.3 — Components of a force

$F = 160$ N at $\theta = 60°$

$F_x = F \cos 60° = 160 \times 0.5 = 80$ N

$F_y = F \sin 60° = 160 \times 0.866 = 138.6$ N

Example 4.4 — Balancing torques on a pinned stick

$F = 60$ N at $30°$: $F_x = 51.96$ N, $F_y = 30$ N

$30 \times d = 18 \times 1$

$d = 0.6$ m

Example 4.5 — Tension in two strings

$w = 5$ N; taking moments about B

$T_1 \times 0.4 = w \times 0.2 \Rightarrow T_1 = 2.5$ N

$T_1 + T_2 = w \Rightarrow T_2 = 2.5$ N

Numerical Problems

1. A force of 200 N acts on a cart at 30° to horizontal. Find its components.

$F_x = 200 \cos 30° = 173.2$ N

$F_y = 200 \sin 30° = 100$ N

2. A force of 300 N is applied perpendicular to a door knob 1.2 m from the hinge. Find the torque.

$\tau = F \times l = 300 \times 1.2 = 360$ N·m (positive/anticlockwise)

3. Two weights hang on a metre rule balanced at its C.G; w1 = 4 N at 30 cm, find unknown weight w at 40 cm.

$w \times 0.4 = 4 \times 0.3$

$w = 3$ N

4. See-saw: child A (30 kg) at 2 m, child B (40 kg) at 1.5 m. Check equilibrium.

Moment A = 300×2 = 600 N·m
Moment B = 400×1.5 = 600 N·m
Equal moments – see-saw is balanced

5. Crowbar: 250 N applied at 30 cm from pivot, box at 5 cm from pivot. Find force on box.

F1×d1 = F2×d2 => 250×0.3 = F2×0.05
F2 = 1500 N

6. A 5 N ball is pulled sideways; rope makes 60° with the ceiling. Find T and F.

T sin60° = 5 => T = 5.8 N
F = T cos60° = 2.9 N

7. Signboard of weight 200 N hung by two symmetric wires. Find tension in each.

T1 = T2 (symmetry)
2T = 200 => T = 100 N each

8. Girl (30 kg) at 1.6 m from see-saw axis; boy (40 kg) sits at distance d for balance.

300 × 1.6 = 400 × d
d = 1.2 m

Short Questions

1. Define like and unlike parallel forces.
Like parallel forces act in the same direction (resultant = sum, same direction). Unlike parallel forces act in opposite directions (resultant = difference, direction of the larger force).

2. What are rectangular components of a vector?
Mutually perpendicular components of a force: $F_x = F\cos\theta$ (horizontal), $F_y = F\sin\theta$ (vertical).

3. What is the line of action of a force?
The line along which a force acts, passing through its point of application.

4. Give an example of a body which is moving yet in equilibrium.
A paratrooper descending at terminal (uniform) velocity — weight is balanced by air resistance. A car moving at uniform velocity on a level road is another example.

5. Define centre of mass and centre of gravity of a body.

Centre of mass: the point where the whole mass is assumed concentrated. Centre of gravity: the point where the total weight appears to act vertically downward.

6. Why are door knobs fixed at the edge of a door?

Since $\tau = r \times F$, torque is proportional to the moment arm r. A knob at the edge maximises r, so a small force produces enough torque to open/close the door easily.

7. Does the gravitational force on an orbiting satellite exert torque on it?

No. The force is directed toward the Earth's centre, so it is antiparallel to r (θ=180°), giving $\tau = rF \sin 180° = 0$.

Multiple Choice Questions

1. A particle is acted upon by two forces of 4 N and 3 N. The net force is:

(a) 1 N (b) between 1 N and 7 N (c) 5 N (d) 7 N

Answer: (b)

2. A force F makes 60° with the x-axis. Its y-component equals:

(a) F (b) F sin60° (c) F cos60° (d) F tan60°

Answer: (b)

3. Moment of force is called:

(a) moment arm (b) couple (c) couple arm (d) torque

Answer: (d)

4. A body is completely in equilibrium when:

(a) $\Sigma F=0$ and $\Sigma\tau=0$ (b) $\Sigma F=0, \Sigma\tau\neq0$ (c) $\Sigma F\neq0, \Sigma\tau=0$ (d) $\Sigma F\neq0, \Sigma\tau\neq0$

Answer: (a)

5. Unequal-arm balance: putting weights on the shorter-arm pan, the customer:

(a) loses (b) gains (c) neither loses nor gains (d) not certain

Answer: (a)

6. Tightrope walker balancing with a bamboo stick applies:

(a) conservation of momentum (b) Newton's 2nd law (c) principle of moments
(d) Newton's 3rd law

Answer: (c)

7. In stable equilibrium the C.G of the body lies:

(a) at the highest position (b) at the lowest position (c) at any position
(d) outside the body

Answer: (b)

8. The centre of mass of a body:

(a) always inside (b) always outside (c) always on surface
(d) may lie within, outside or on surface

Answer: (d)

9. A cylinder resting on its circular base is in:

(a) stable (b) unstable (c) neutral (d) none

Answer: (a)

10. Centripetal force is given by:

(a) rF (b) rF cosθ (c) mv^2/r (d) R

Answer: (c)

11. Seesaw balanced; one child moves closer to the fulcrum:

(a) remains balanced (b) tips towards the child who moved closer
(c) tips towards the child who stayed away (d) topples

Answer: (b)

12. Line of action passing through the pivot: moment of force is:

(a) maximum (b) minimum (c) zero (d) infinite

Answer: (c)

13. Body at rest / uniform rotation — torque acting is:

(a) maximum (b) minimum (c) zero (d) infinite

Answer: (c)

14. To loosen a stuck nut with a spanner, you should:

(a) insert a pipe to increase spanner length (b) use a shorter spanner
(c) use a soft plastic spanner (d) tie a rope to it

Answer: (a)

15. A body in equilibrium must have no:

(a) speed (b) quantity of motion (c) velocity (d) acceleration

Answer: (d)

16. A uniformly rotating fan is in:

(a) static equilibrium only (b) dynamic equilibrium only (c) both static and dynamic
(d) not in equilibrium

Answer: (b)

17. Tightrope walker's pole stability is affected if the pole is:

(a) long, vertical (b) long, horizontal (c) short, vertical (d) short, horizontal

Answer: (b)

18. Thrown weighted net sinks and opens fully — its centre of mass is now:

(a) higher (b) lower (c) same depth, shifted (d) unchanged

Answer: (a)

19. Walking on a slippery surface is harder due to:

(a) reduced friction (b) increased friction (c) high grip (d) lower weight

Answer: (a)

20. Object at terminal velocity — its acceleration:

(a) increases (b) decreases (c) is zero (d) varies

Answer: (c)