

Chapter 4 — Turning Effect of Forces

C. Constructed Response Questions

1. A car travels at the same speed around two curves with different radii. For which radius does the car experience more centripetal force? Prove your answer.

Ans: The car experiences more centripetal force on the curve of smaller radius. Proof: the centripetal force needed to keep a body of mass m moving with uniform speed v in a circle of radius r is $F_c = mv^2 / r$. Here the same car takes both curves, so its mass m is the same, and it travels at the same speed, so v is the same as well. Therefore mv^2 is a constant quantity and $F_c \propto 1 / r$, that is, the centripetal force is inversely proportional to the radius of the curve. For the two curves, $F_1 / F_2 = r_2 / r_1$. So if the first curve has half the radius of the second one ($r_1 = r_2 / 2$), then $F_1 = 2F_2$ — the car needs twice as much centripetal force on the sharper curve. This force has to be supplied by the friction between the tyres and the road, which is why a car is more likely to skid on a sharp turn than on a gentle one, and why the driver must slow down before a sharp turn.

2. A ripe mango does not normally fall from the tree. But when the branch of the tree is shaken, the mango falls down easily. Can you tell the reason?

Ans: A hanging mango is in equilibrium: its weight acts downward and the stalk pulls it upward with an equal and opposite force, so the vector sum of the forces on it is zero and it stays where it is. When the branch is shaken, the branch and the stalk are forced to move to and fro along a curved path. To keep the mango moving along that curved path, a centripetal force is needed, and the only thing that can supply it is the stalk. The heavier and riper the mango, the greater the force the stalk has to supply, because $F_c = mv^2 / r$ increases with the mass and with the speed of shaking, while the radius of the swing is small. As soon as the required force becomes greater than the strength of the joint, the stalk snaps, no force is left acting on the mango, and it moves off along the tangent and falls to the ground — exactly like the stone that flies off along the tangent when the string is released. This is also why a ripe mango falls more easily than an unripe one: the stalk of a ripe mango is already weak.

3. Discuss the concepts of stability and centre of gravity in relation to objects toppling over. Provide an example where an object's centre of gravity affects its stability, and explain how altering its base of support can influence stability.

Ans: A body stays in equilibrium as long as its centre of gravity lies within its base. If it is tilted so far that the vertical line through the centre of gravity falls outside the base, the weight produces a torque about the edge which turns the body further over, and it topples. Example: if a bus is loaded on its floor, its centre of gravity is low and a slight tilt brings it back, but if it is loaded with steel sheets on the top, the centre of gravity is raised and a couple will turn it over. Stability can therefore be improved by lowering the centre of gravity or by widening the base, because a wider base has to be tilted through a much larger angle before the line of the weight leaves it — as in racing cars, whose centres of mass are kept low and whose wheels are placed outside the main body.

4. Why can an accelerated body not be considered in equilibrium?

Ans: A body is said to be in equilibrium if it has no acceleration. The first condition of equilibrium states that a body will be in translational equilibrium only if the vector sum of all the external forces acting on it is equal to zero, that is $\Sigma F = 0$. Now by Newton's second law of motion the resultant force on a body is $F = ma$. If the body is accelerating, then $a \neq 0$, and since its mass m can never be zero, it follows that $\Sigma F = ma \neq 0$. The first condition of equilibrium is therefore not satisfied, so the body cannot be in equilibrium. The same argument holds for rotation: if a body has an angular acceleration, a resultant torque must be acting on it, so $\Sigma \tau \neq 0$ and the second condition of equilibrium fails as well. In short, acceleration is the proof that the forces (or the torques) on the body are unbalanced, and an unbalanced body is by definition not in equilibrium.

5. Two boxes of the same weight but different heights are lying on the floor of a truck. If the truck makes a sudden stop, which box is more likely to tumble over? Why?

Ans: The taller box is more likely to tumble over. Both boxes have the same weight, but the centre of gravity of the taller box lies much higher above the floor, while that of the shorter box lies close to the floor. When the truck stops suddenly, each box tends to tip forward about its front bottom edge, and the vertical line through its centre of gravity swings towards the edge of the base. A body remains in equilibrium only as long as its centre of gravity lies within the base. For the tall box, the centre of gravity is far from the base, so only a small tilt is enough to carry that vertical line outside the base; once it goes outside, the weight w produces a torque about the edge which turns the box further over and it topples. For the short box the centre of gravity is low and its base is wide compared with its height, so it has to be tilted through a much larger angle before

the line of action of its weight can leave the base, and it stays upright. This is the same reason why the stability of a body is improved by lowering its centre of gravity or by widening its base, as in a bus loaded on the floor rather than on the roof, or a racing car with a low centre of mass and wide wheel base.

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