CHAPTER 4: *Linear motion and angular motion*

Practice questions - text book pages 91 to 95

1) Which of the following pairs of quantities is not a vector/scalar pair?
   a. weight/mass.
   b. reaction force/centre of mass.
   c. velocity/speed.
   d. energy/power.

Answer: d.

2) Which of the following is a vector?
   a. gravitational field strength.
   b. centripetal force.
   c. the ratio of force to acceleration for a moving body.
   d. rate of change of speed.

Answer: b.

3) Angle in radians is defined as:
   a. rate of turning.
   b. arc length subtending the angle divided by radius of the circle.
   c. radius of a circle divided by arc length subtending the angle.
   d. moment of inertia divided by angular velocity.

Answer: b.

4) Angular velocity is defined as:
   a. angular acceleration divided by time taken to turn through an angle.
   b. distance moved per second in a certain direction.
   c. angle turned through in radians divided by time taken to turn
   d. moment of inertia divided by angular momentum.

Answer: c.

5) A dancer spinning with arms out wide will spin slower than when he crosses his arms across his chest during a jump because:
   a. angular momentum is bigger with his arms out wide.
   b. angular momentum is smaller with his arms across his chest.
   c. moment of inertia of his body with his arms out wide is bigger.
   d. angular momentum is conserved during the flight of the dancer.

Answer: d.

6) Define what is meant by a scalar and a vector quantity. 2 marks

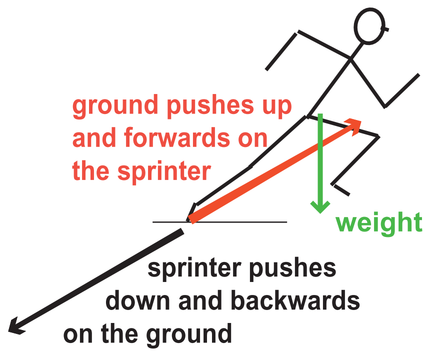
Answer:
- *A scalar quantity (such as mass, energy, speed, power) has a value/magnitude only.*
- *Whereas a vector quantity (such as velocity, force, acceleration) has a value and a direction.*

7) A sprinter uses her calf muscles to push on the blocks at the start of a run. Sketch a pin man diagram of the forces acting and use this to explain how this produces a forward force on her. 3 marks

Answer:

- *Newton's 3rd law of motion - action and reaction are equal and opposite in direction.*
- *When the sprinter pushes down and back on the ground.*
- *The ground pushes up and forward on her (figure Q4.1).*
- *Newton's 2nd law of motion - if a force is exerted, then this produces an acceleration in the same direction as the force (forwards).*

figure Q4.1 – forces acting on a sprinter

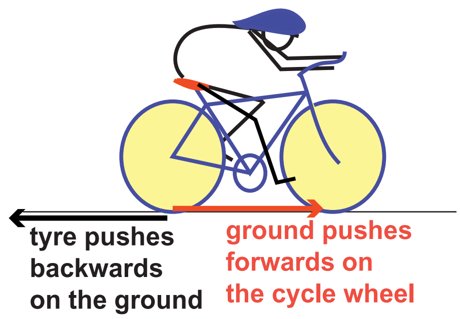


8) Explain the nature of the reaction force which provides forwards impulsion for a cyclist. 4 marks

Answer:

- *See figure Q4.2.*
- *The rear tyre of the bicycle pushes hard backwards on the ground.*
- *Provided friction is big enough to avoid slipping, this friction force becomes the force acting as reaction to the backward drive of the tyre on the ground.*
- *Hence the ground exerts a force forward on the bike.*

figure Q4.2 – forces on a cyclist



9) A weight lifter exerts an upward force of 2000 N on a barbell of 170 kg. What is the vertical acceleration? 2 marks

Answer:

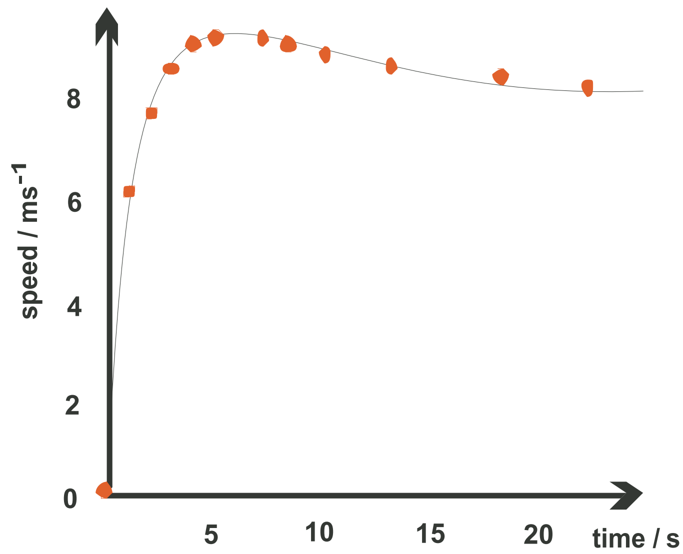
- *Using Newton's 2nd law, force = mass x acceleration.*
- *Force = 2000 N, mass = 170 kg, therefore 2000 = 170 x a.*
- *Hence* $a = \frac{2000}{170} = 11.765\ ms^{-2}$.

10) Table 4.1 shows the speed of a 19 year-old male sprinter during a 200 metres race.

Table 4.1 – **data for a 200 metre sprint**

speed (ms^{-1})	time (seconds)
0.0	0
6.0	1
7.5	2
8.2	3
8.4	4
8.5	5
8.5	7
8.4	8
8.3	10
8.2	13
8.1	18

figure Q4.3 – speed against time for 200m race



a) Plot a graph of speed against time during this race.
When does he reach maximum speed and what happens to his speed between 8 and 22 seconds? 7 marks

Answer:

- *See speed/time graph in figure Q4.3.*
- *Horizontal axis correctly scaled and labelled.*
- *Vertical axis correctly scaled and labelled.*
- *2 marks for points plotted correctly.*
- *Curve drawn correctly.*

Speed between 8 and 22 seconds:

- *Maximum speed is reached between 5 to 7 seconds.*
- *After 8 seconds there is a gradual slowing down.*

b) Acceleration is the change of speed per second. Use the graph to establish his speed at 0.5 seconds and 1.5 seconds and calculate the average acceleration between 0.5 and 1.5 seconds. 3 marks

Answer:

- *At 0.5 seconds, speed = 3.0 ms^{-1} (allow + or - 0.2).*
- *At 1.5 seconds, speed = 6.8 ms^{-1} (allow + or - 0.3).*
- *Acceleration = change of speed per second = 6.8 - 3.0 (in 1 second) = 3.8 ms^{-2}.*

c) Successful games players are often able to change their velocity rapidly in the game situation. Explain the biomechanics behind this ability using examples from a game of your choice. 6 marks

Answer:

6 marks for six of:

- *The force applied to the person is that between footwear and ground - friction.*
- *The factors which govern the size of friction force are the weight of the individual, the nature of the surface and footwear used.*
- *Newton's 3rd law applies between foot and ground.*
- *The sportsperson pushes on the ground (the action force), the ground pushes back with a reaction force (which is equal in size but opposite in direction to the action force) on the person.*
- *Acceleration = rate of change of velocity, velocity includes the direction.*
- *Newton's 2nd law tells us how much acceleration is produced by the force acting.*
- *The formula: force = mass x acceleration, enables you to work out the acceleration.*
- *Hence the bigger the force (the stronger the person) the greater the change in velocity.*
- *If the force is sideways to the direction of motion at the time, then the direction is changed.*
- *A sideways force causes swerving (change of direction but no change of speed).*
- *A force in the direction of motion causes increase or decrease in speed.*

11) a) What characterises a vector quantity? 2 marks

Answer:
- *A vector has size (or value or magnitude).*
- *And direction. For example, force. velocity, acceleration, weight.*

b) Figure 4.26 shows the forces acting on a runner at the start of a race. Use a vector diagram to show how you could work out the resultant force acting 3 marks

Answer:
- *See figure Q4.4.*
- *Note that the parallelogram rule is used to estimate the resultant.*
- *The resultant is horizontal, showing that the net force is forwards.*

figure 4.26 – forces acting on a runner

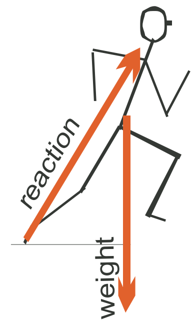
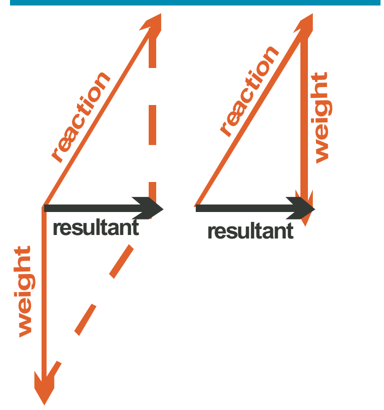


figure Q4.4 – resultant force



c) Sketch a pin man drawing of a person standing still showing all the forces acting on him. 2 marks

Answer:
- *See figure Q4.5.*
- *Note that the force arrows are equal indicating that the forces cancel out - there is zero net force.*
- *The upward reaction force R acts at the feet, the weight W acts at the centre of mass.*

d) Sketch a second diagram showing the vertical forces acting on a basketballer just before take-off while performing a jump shot. Represent the relative sizes of any forces you show by the length of the force arrows on your diagram. 2 marks

Answer:
- *See figure Q4.6.*
- *The upward reaction force R acts at the take off foot, W acts at the centre of mass.*
- *Note that the upward arrow is bigger than the downward arrow, which means that there is a net upward force acting on the jumper.*

figure Q4.5 – forces acting on a person standing still

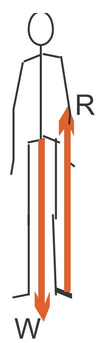
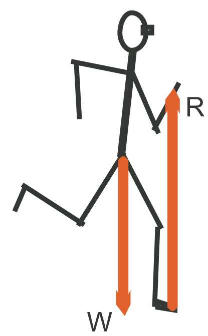


figure Q4.6 – forces acting on a basketballer

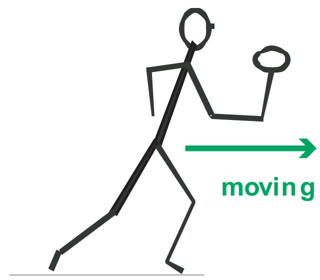


e) Use this second diagram and your understanding of Newton's laws of motion to explain why the basketballer is able to take off. If the vertical upward ground reaction force on him is 2000 N, and his weight is 800 N, estimate the net upward force acting on him. 4 marks

Answer:
- *Newton's second law of motion says that acceleration is linked to net force.*
- *So since here there is a net upward force, there will be an upward acceleration.*
- *Which of course will give him or her a vertical upward velocity which will enable the jumper to take off.*
- *Net upward force F = 2000 - 800 = 1200 N.*

12) Tennis players have to change direction quickly during a match to recover to the centre of the court.
Figure 4.27 shows a tennis player just after hitting a forehand and then starting to recover to the centre of the court in the direction shown.

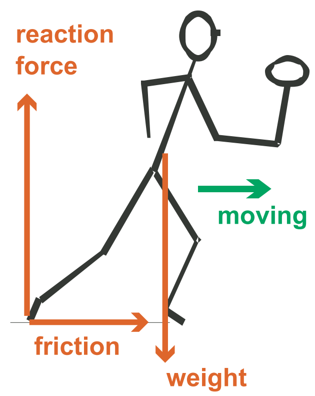
figure 4.27 – a tennis player moves between strokes



a) Draw a pin diagram of the tennis player as he pushes off the court surface to recover to the centre of the court, showing all forces acting on the tennis player at this point. All forces must be clearly identified. 3 marks

Answer:
- *See figure Q4.7.*
- *Weight acts downwards from centre of mass of tennis player.*
- *Friction acts forwards from the rear foot (in the same direction as the proposed direction of motion).*
- *Reaction force acts upwards on the rear foot (length of arrow the same or bigger than the weight arrow).*

figure Q4.7 – forces acting on a tennis player between strokes



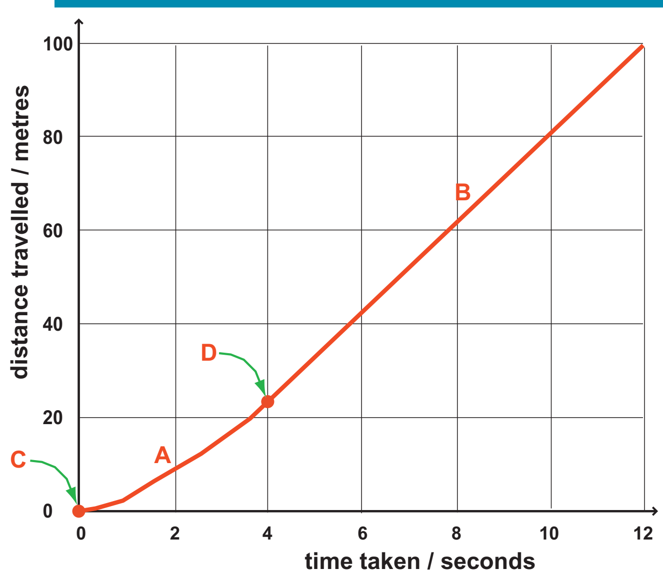
b) Explain the factors that affect the horizontal force at this point. Apply Newton's second law of motion to explain the effect of this force on the player. 4 marks

Answer:
2 marks for two of:
- *Type or roughness of footwear.*
- *Type or roughness of court surface.*
- *Amount of reaction force - how hard player presses into ground - friction force depends on the contact force pressing the two surfaces (foot and ground) together.*

2 marks for two of:
- *Using Newton's 2nd law, F = m x a, or acceleration is proportional to force.*
- *Greater frictional force the greater the acceleration of player.*
- *Direction of frictional force = direction of acceleration = direction of motion of the player.*

13) Figure 4.28 shows the distance/time graph for a 100 metres sprint.

figure 4.28 – distance time graph for 100m sprint



a) Describe the motion of the sprinter in sections A and B. 2 marks

Answer:
- ***A** - acceleration, the slope/gradient of the graph increases, therefore the speed increases.*
- ***B** - constant speed, the slope of the graph remains the same.*

b) Calculate the speed at points C and D and the average acceleration between the points. 3 marks

Answer:
- ***C** - the athlete is about to start (just started), and speed is therefore zero.*
- ***D** - the gradient of the graph is approximately 19 m in 2 seconds.*
- *Giving a speed of 19/2 = 9.5 ms^{-1}.*
- *The average acceleration is 9.5 ms^{-1} in 4 seconds.*
- *Giving acceleration of 9.5/4 = 2.375 metres per second per second (ms^{-2}).*

14) Define the term angular velocity. 2 marks

Answer:

- *Angular velocity is the rate of spin or turning of a body.*
- *Or the angle turned through per second.*
- *Angular velocity* $= \dfrac{\text{angle turned through}}{\text{time taken to turn}}$

15) Using sporting examples, explain the difference between planes of movement and axes of rotation. 4 marks

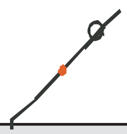
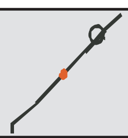
Answer:

- *The term body plane is defined as 'an imaginary flat surface running through the centre of mass of the body',*
- *There are three such planes, one horizontal dividing the top half of the body from the bottom half.*
- *The second and third divide the body front from back, and side to side.*
- *The axes of rotation are at right angles to each plane, and define (like an axle on a wheel) the axis about which the body turns when moving in the respective planes.*
- *For example, an ice dancer spinning, is turning about the vertical axis through the horizontal plane.*
- *And a gymnast tumbling in a forward somersault, is turning about a horizontal axis through a vertical plane separating side to side*

.

16) a) A diver can make a number of different shapes in the air. Table 4.2 shows three of these. Explain the meaning of moment of inertia (MI) in this context. 4 marks

Table 4.2 – **data for shapes of diver during flight**

phase of dive	shape of diver	time during flight	MI of shape kgm^2
1	Z 	0.0 - 0.5s	18
2	Y 	0.5 - 0.7s	9
3	X 	0.7 - 1.0s	3
4	Z 	1.0 - 1.1s	18
entry	axis of rotation = ●	1.1s	

Answer:

- *Moment of inertia (MI) is the rotational inertia of a body, the equivalent of mass for a rotating body.*
- *MI can be thought of as resistance to rotational motion, the tendency to remain stationary or continue to rotate at constant rate of spin.*
- *Large MI requires large turning forces (moments) to act on the body to start or stop it spinning.*
- *MI depends on the distribution of mass away from the axis of rotation.*
- *MI = the sum of the masses of all body parts multiplied by the distance squared from the axis of rotation.*
- *This means that the further a mass (body part) is away from the axis, the more effect it has on the MI.*
- *MI* $= \Sigma m r^2$.
- *Also MI* $= \dfrac{\text{angular momentum}}{\text{angular velocity}}$
- *This formula means that parts of the body at a distance from the turning axis has a large effect on the MI.*

b) During a dive a diver goes through the shapes shown in table 4.2. Explain how the rate of spinning (angular velocity) would change through the dive. 5 marks

Answer:

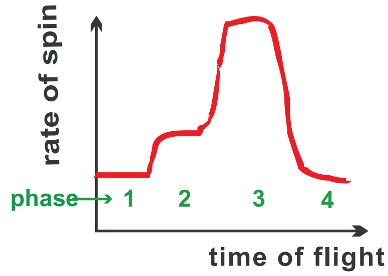
- *Phase 1 - very slow rate of spin.*
- *Phase 2 - rate of spin about twice that of phase 1.*
- *Phase 3 - fastest rate of spin, about 6 times that of phase 1.*
- *Phase 4 - very slow rate of spin (same as phase 1).*
- *Mark awarded for numerical estimates of rates of spin.*

16) continued

c) Sketch a graph of this rate of spinning against time. Your sketch need only be approximate. 4 marks

Answer:
- *See figure Q4.8.*
- *Axes correctly scaled and labelled.*
- *Same value at start and finish.*
- *Value approximately double phase 1 for phase 2.*
- *Value approximately six times phase 1 for phase 3.*

figure Q4.8 – rate of spinning against time



d) State the relationship between angular momentum, moment of inertia and angular velocity. 2 marks

Answer:
- *Angular momentum is a combination of moment of inertia and angular velocity.*
- *Angular momentum = moment of inertia x angular velocity.*

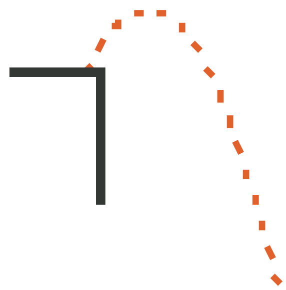
e) Name the law of conservation which accounts for these variations in rate of spin. 1 mark

Answer:
- *The law of conservation of angular momentum.*

f) Explain and sketch the arc described by the diver as he or she falls. 3 marks

Answer:
- *See figure Q4.9.*
- *The path of the centre of mass of the diver would be a parabola.*
- *Which is the arc described by all bodies falling under gravity.*

figure Q4.9– arc of path of diver



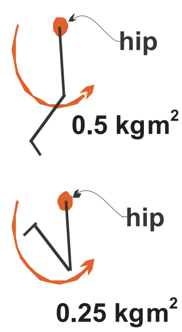
17) a) Describe in detail the body shape and movement within a chosen sporting situation where rates of spin are affected by body shape. 6 marks

Answer:
- *Mark given for appropriate choice of sport - skating, skiing, discus, gymnastics, trampolining.*
- *Slow rate of spinning with extended body position.*
- *For example, arms held out wide in skating.*
- *Rapid rate of spinning with narrow body position.*
- *For example, arms held overhead for spinning skater.*
- *No forces must act on surroundings during the spinning.*

b) How would you stop the spinning in this situation? 2 marks

Answer:
- *You would stop the spinning by applying force to the surroundings.*
- *By the landing process*
- *Or putting your feet in contact with the ground, or hands in contact with gym equipment.*

figure 4.29 – shape of leg

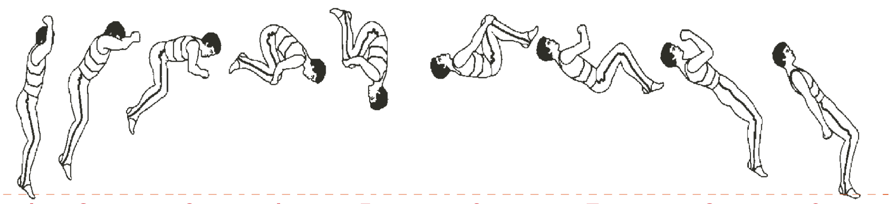


c) Figure 4.29 shows a sportsperson's leg in two different positions. The values quoted are the moment of inertia of the leg as it rotates about the hip joint (shown as a red dot on each diagram). Explain the implications of these data for the efficiency of running style in a sprinter and long distance runner 7 marks

Answer:
- *Moment of inertia (MI) as inertia requires torque (in groin muscle) to achieve acceleration of leg.*
- *Larger MI of leg (as in straight leg shape) needs more pull from groin muscles to achieve a given angular acceleration of the leg.*
- *The pull (turning force) on the leg is provided by abdominal hip flexor muscles acting on hip joint.*
- *A bigger force in these muscles will give a bigger turning force (torque or moment) on the leg.*
- *A sprinter needs to bring the leg through fastest (i.e. with the most acceleration), and therefore needs the leg to have the least possible MI, hence bent leg shape.*
- *An endurance runner doesn't need to bring the leg through quickly, less energy is required, and less force in the muscles needed, hence a larger MI would be possible (i.e. there is no need for a small MI) - and straighter leg shape would be possible.*
- *So for the endurance runner, the efficiency of leg action is better if the leg is straighter, and since speed is not required this will do.*
- *Bent leg shape is more efficient for a sprinter because there is less MI.*
- *Or, for a sprinter, a low value of MI means a high angular velocity and hence speed of movement.*

18) a) Figure 4.30 shows a gymnast undertaking a forward somersault following a run up. Sketch three traces on a single graph to represent any changes in angular momentum, moment of inertia and angular velocity for the period of activity between positions 2 and 9. 3 marks

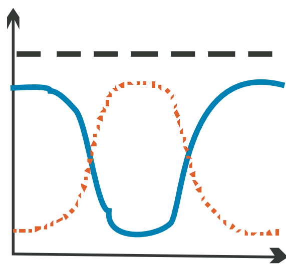
figure 4.30 – shapes of a gymnast



Answer:

- *See figure Q4.10.*
- *Angular momentum = constant.*
- *Angular velocity starts slow, speeds up during the tucked phase then slows down again as he opens out and lands.*
- *Moment of inertia starts high (body straight), becomes low (tucked position) then high again (straight and landing).*

figure Q4.10 – changes in H, ω, MI during a gymnastic tumble



b) Explain the shapes of the traces on the sketch graph that you have drawn. 6 marks

Answer:

- *Angular momentum - remains constant throughout the flight (this is a universal law obeyed everywhere provided no forces act on the body), so the graph would be a horizontal line.*
- *Moment of inertia changes with body shape.*
- *MI value high when body position straight (take-off and landing).*
- *MI value low when tucked or piked (mid-flight).*
- *Angular velocity (rate of spin) changes in the opposite sense to MI.*
- *Since angular momentum = MI x angular velocity = constant in value throughout the flight.*
- *So as MI goes down (from straight to tucked), angular velocity must increase - rate of spinning increases.*
- *Later in the flight, as MI increases again (from tucked to straight), rate of spin reduces.*

c) Table 4.3 sets out measurements of angular velocities (rates of spin) of the gymnast at successive frames from the start of the somersault.

Estimate from this table the ratio of angular velocities at times X and Y. 1 mark

Table 4.3 – **data for angular velocity of gymnast**

	frame	angular velocity (degrees s^{-1})
	1	650
X	2	750
	3	850
	4	1100
	5	1400
Y	6	1500
	7	1000
	8	850
	9	650

Answer:

- *The ratio of angular velocities at X and Y is 750 : 1500 , i.e. 1 : 2.*
- *The angular velocity doubles when going from X to Y.*

d) If the moment of inertia of the gymnast is 8 kgm^2 at time X, estimate the moment of inertia at time Y, using data from the table in the chart. 2 marks

Answer:

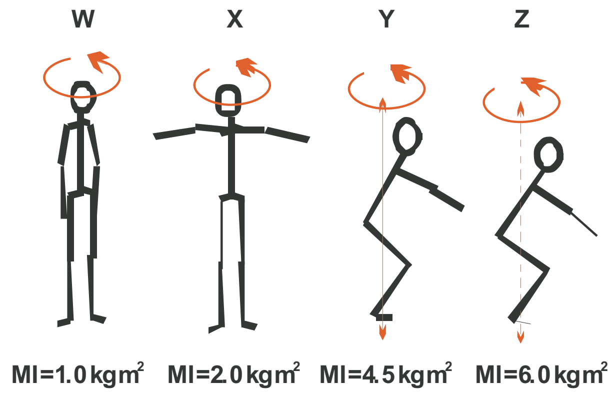
- *From c) above, the ratio of rates of spin at X : Y is 1 : 2, therefore the ratio of MI from X : Y must be 2 : 1.*
- *If the rate of spin doubles when going from X to Y, the MI must halve when going from X to Y.*
- *So, if the MI at X = 8 kgm^2, therefore the MI at Y = 4 kgm^2.*

19) a) Figure 4.31 shows a spinning skater in various positions. Under each diagram is an approximate value for the moment of inertia of the skater spinning about his or her central vertical axis.

The angular velocity of the skater in position **W** is 2.0 revolutions per second. What is the formula for calculating the skater's angular velocity?

Calculate the angular velocity for the skater in position **Z**. 2 marks

figure 4.31 – shapes of a gymnast



Answer:

- *MI x rate of spin (angular velocity) = new MI x new rate of spin.*
- *Or angular velocity* $= \dfrac{\text{angular momentum}}{\text{MI}}$.

  $= \dfrac{\text{(MI x angular velocity) at any point in the movement}}{\text{MI (at the point at which you wish to know the angular velocity)}}$
- *(Or angular velocity* $= \dfrac{\text{angle turned through}}{\text{time taken to turn}}$*).*
- *Angular velocity for the skater in position Z*

  $= \dfrac{\text{MI in position W x angular velocity in position W}}{\text{MI in position Z}} = \dfrac{1 \times 2}{6}$ = *0.33 revs per second.*

b) Sketch a figure showing a possible position which could cause the skater to attain an angular velocity of 3.0 revolutions per second and calculate what the moment of inertia of this shape must be. 2 marks

Answer:

- *See figure Q4.11.*
- *In order to spin faster, the skater must adopt a tighter shape.*
- *The skater spins at 3.0 revolutions per second when the MI is 1.0 kgm².*

  Therefore the angular momentum = MI x spin rate

  $= 1.0 \times 3.0$

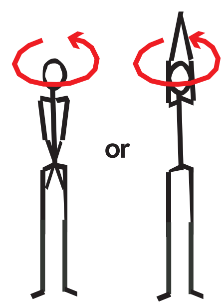
  $= 3.0.$

  So the new MI $= \dfrac{\text{angular momentum}}{\text{new rate of spin}}$

  $= \dfrac{3.0}{4.0}$

  $= 0.75\ kgm^2$

figure Q4.11 – possible position of skater



c) Principles of angular momentum can be usedto improve performance in a variety of sports. With the use of diagrams explain how a slalom skier turns through the gates at maximum speed. 4 marks

Answer:

- *See figure Q4.12.*
- *Angular momentum is remains the same (approximately because of contact with snow).*
- *So MI x rate of spin remains the same.*
- *Skier crouches (large MI) hence slow rate of turning - between gates.*
- *Skier straightens (small MI) hence rapid rate of turning - at a gate.*

figure Q4.12 – position of slalom skier

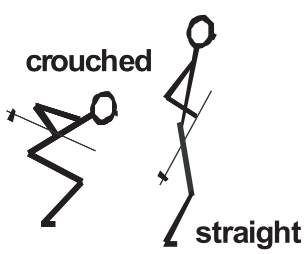
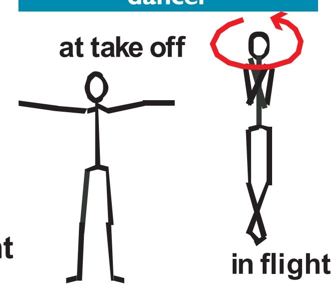


figure Q4.13 – spinning dancer



d) Explain with the use of diagrams how a dancer manages to complete a triple spin in the air before touching the ground. 4 marks

Answer:

- *See diagram Q4.13.*
- *The movement is initiated with arms held wide - highest possible MI.*
- *Once she has taken off, angular momentum is conserved.*
- *Flight shape has arms tucked across chest - lowest possible MI.*
- *Therefore highest possible rate of spin.*
- *Hopefully enough for three complete spins before landing.*