CHAPTER 4: Angular motion, projectile motion and fluid mechanics

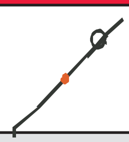
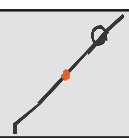
Practice questions - text book pages 77 - 80

1) 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 = $\frac{\text{angle turned through}}{\text{time taken to turn}}$*

2) a) A diver can make a number of different shapes in the air. Table 4.1 shows three of these. Explain the meaning of moment of inertia (MI) in this context. 4 marks

Table 4.1 – **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* $= \frac{\text{angular momentum}}{\text{angular velocity}}$
- *This formula means that parts of the body at a distance from the turning axis has a large effect on the MI*

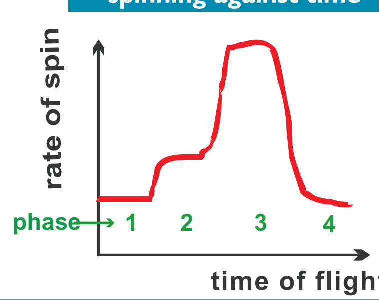
b) During a dive a diver goes through the shapes shown in table 4.1. Explain how the rate of spinning (angular velocity) would change through the dive. 5 marks

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.*

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

Answer:
- *See figure Q4.1.*
- *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.*

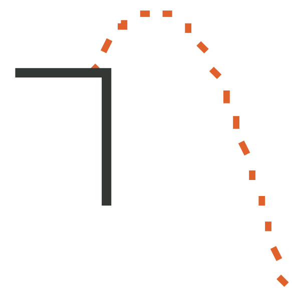
figure Q4.1 – rate of spinning against time



2) 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.*

figure Q4.2 – arc of path of diver



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

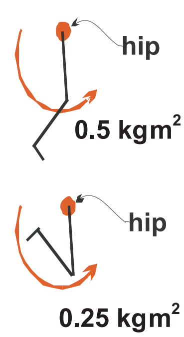
Answer:
- *The law of conservation of angular momentum.*

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

Answer:
- *See figure Q4.2.*
- *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.*

3) 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

figure 4.28 – shape of leg



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

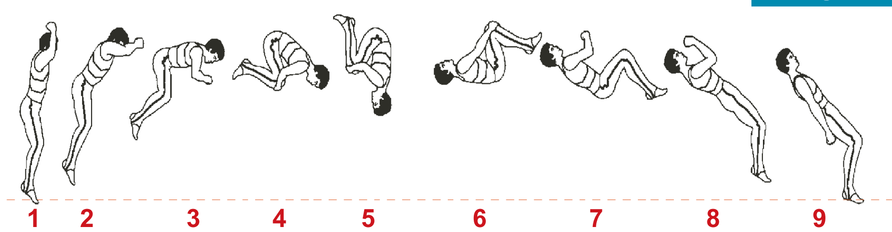
Answer:
- *You would stop the spinning by applying force to the surroundings.*
- *By the landing process*
- *Or putting your feet in contact with the ground, or hands in contact with gym equipment.*

c) Figure 4.28 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.*

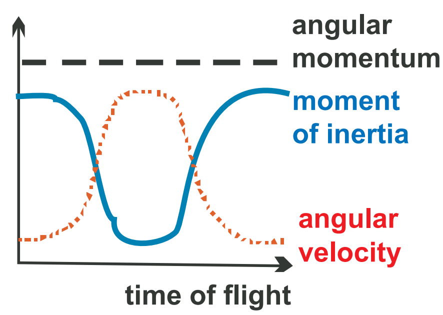
4) a) Figure 4.29 shows a gymnast undertaking a forward somersault following a run up. Sketch three traces on a single graph to represent any changes in angular momentum, moment of inertia and angular velocity for the period of activity between positions 2 and 9. 3 marks

figure 4.29 – shapes of a gymnast



Answer:
- *See figure Q4.3.*
- *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 Q4.3 – 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 4.2 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

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.*

Table 4.2 – **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

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

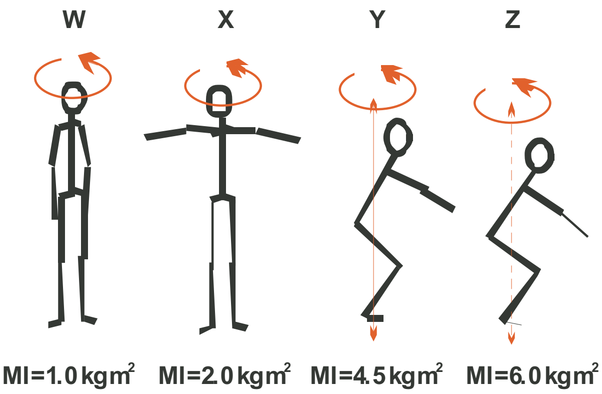
Answer:
- *From c) above, the ratio of rates of spin at X : Y is 1 : 2, therefore the ratio of MI from X : Y must be 2 : 1.*
- *If the rate of spin doubles when going from X to Y, the MI must halve when going from X to Y.*
- *So, if the MI at X = 8 kgm^2, therefore the MI at Y = 4 kgm^2.*

5) a) Figure 4.30 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 4.30 – shapes of a gymnast



Answer:

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

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

  $= \dfrac{\textit{MI in position W x angular velocity in position W}}{\textit{MI in position Z}} = \dfrac{1 \times 2}{6}$ = *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

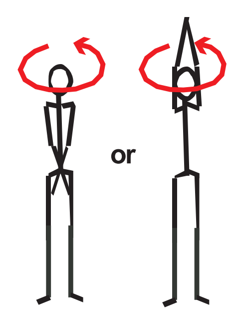
Answer:

- *See figure Q4.4.*
- *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 x 3.0
  = 3.0.

  So the new MI $= \dfrac{\textit{angular momentum}}{\textit{new rate of spin}}$
  $= \dfrac{3.0}{4.0}$
  = 0.75 kgm²

figure Q4.4 – 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 Q4.5.*
- *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 Q4.5 – position of slalom skier

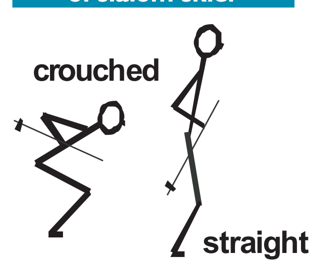
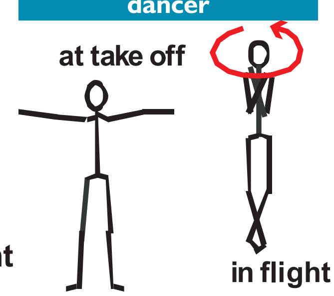


figure Q4.6 – spinning dancer



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 Q4.6.*
- *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.*

6) a) Using examples, explain how the shape of an object can alter its flight path. 4 marks

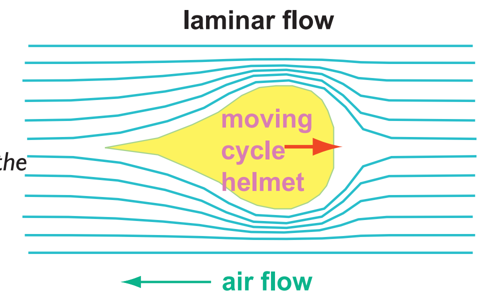
Answer:

4 marks for 4 of:

- *The size of the air resistance (drag) force depends on the size of the object as it is viewed from the forward direction (the technical name for this is forward cross section).*
- *The bigger this size the bigger the air resistance.*
- *Also, air resistance depends on the streamlining effect.*
- *The more the shape allows laminar flow (flow in layers without vortices) of air past the object, the less will be the air resistance (see figure Q4.7).*

- *The effect of air resistance is to deviate the path from the symmetric shape known as a parabola.*
- *Air resistance force acts in a direction opposite to the direction of motion of the object.*
- *Therefore the object would always be moving more slowly (than if there were no air resistance).*
- *The bigger the air resistance compared to the weight, the bigger the asymmetry of the flight path.*

figure Q4.7 – air resistance



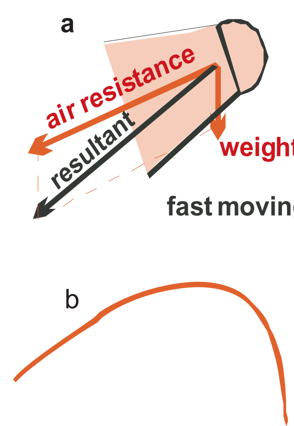
b) Explain the effect of air resistance on the flight of two badminton shuttles, one of which has been struck hard and the other gently. 10 marks

Answer:

5 marks for five of:

- *A **rapidly moving badminton shuttle** will have a very large value for air resistance at the beginning of its flight.*
- *Compared to the weight of the shuttle.*
- *Therefore the resultant force (see figure Q4.8a) is almost in the same direction as the air resistance.*
- *Later in the flight, the shuttle would have slowed considerably.*
- *Hence the air resistance value will have dropped.*
- *Until the weight is much bigger than the air resistance.*
- *Then the shuttle would fall as if under gravity only.*
- *Hence a path which differs markedly from the symmetric parabolic path which would be observed if there were zero or very little air resistance.*
- *See figure Q4.8b.*

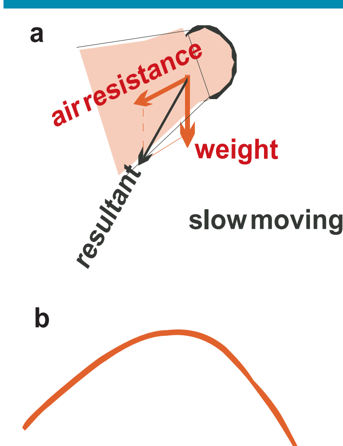
figure Q4.8 – forces acting on a badminton shuttle



5 marks for five of :

- ***Badminton shuttle struck gently** - see figure Q4.9a.*
- *Here the weight is the predominant force.*
- *Because the shuttle is moving slowly, air resistance is small.*
- *Hence resultant force is almost that of the weight only.*
- *And the flight is almost parabolic.*
- *See figure Q4.9b.*

figure Q4.9 – forces acting on a badminton shuttle



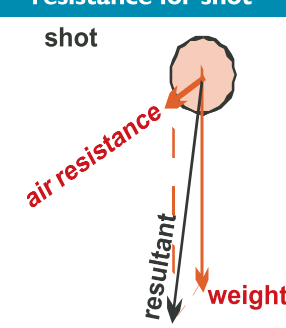
c) Briefly explain why the flight path of a shot in athletics is so different from the flight of a badminton shuttle. 4 marks

Answer:

- *Shot in flight (see figure Q4.10) - resultant force is almost in the same direction as the weight.*
- *Hence the flight of the shot is similar to gravity only.*

- *Badminton shuttle in flight - resultant force is almost in the same direction as air resistance.*
- *Opposite to the direction of motion hence marked deceleration and asymmetric path.*

figure Q4.10 – air resistance for shot



7) a) Identify three physical factors (not skill factors) which govern a swimmer's speed and explain how one of these occurs. 3 marks

Answer:
- *Thrust on the water (force exerted by hands and feet on the water).*
- *Body shape (which best allows smooth flow of water past the body).*
- *Surface effects (like hair or shiny swimsuits or skullcap etc) which change the water flow past the body.*
- *Dive entry or thrust on bath side on turning.*

b) Describe the factors which determine the amount of fluid friction acting on a swimmer. 4 marks

Answer:
- *Speed of the swimmer.*
- *Forward cross section (size of the person as viewed from the forward direction).*
- *Body shape or surface effects (smooth flow).*
- *Surface area in contact with the water (big person as opposed to small person).*
- *Avoidance of water surface effects (like for example swimming underwater after a turn).*

c) Explain how you would minimise turbulent flow (high drag) of the water past the swimmer's body. 2 marks

Answer:
- *By shaving body hair.*
- *By wearing a swim cap.*
- *Swimwear surface (shiny or directionally flocked) and shape (high neck to avoid drag at neckline).*

d) Give three examples, each from a different sporting context, to show how fluid friction affects the sportsperson. 3 marks

Answer:
3 marks for three of:
- *Air resistance involving performer (athlete running, skier, cyclist, parachutist).*
- *Air resistance involving sports vehicle (racing car, glider, cyclist).*
- *Air resistance involving projectile (badminton shuttle, ball).*
- *Water resistance involving performer (swimmer).*
- *Water resistance on sports vehicle (water skis, canoeing, rowing, sailing, speedboats).*

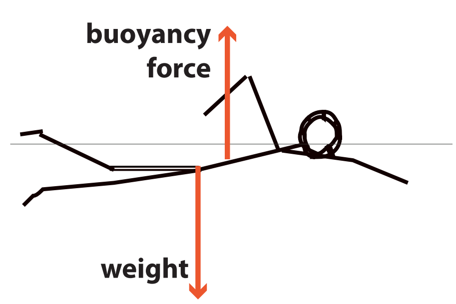
e) How would you attempt to reduce fluid friction? 3 marks

Answer:
- *Reducing forward cross sectional area by crouching. Cyclist - special bike shape to help with this, skiing.*
- *Removing resistance from surface. Special clothing (lycra), shaving head, bathing cap, removing protruding bits of cycle or boat.*
- *Reduce area of contact. Boat, windsurfer, water skis (aquaplaning).*

f) Look at figure 4.31 showing the vertical forces acting on a swimmer during a stroke. Explain why it is difficult for a swimmer to keep a horizontal floating position. 4 marks

Answer:
- *The two forces (weight and buoyancy force) do not act through the same point.*
- *The forces are eccentric (are not in line).*
- *This causes a turning effect, in this case the body is turned by these forces anticlockwise.*
- *With the swimmer's feet falling downwards relative to the head.*

figure 4.31 – forces acting on a swimmer



8) a) Fluid friction is a force which acts on a bobsleigh once it is moving. Identify the nature of the fluid friction in this case and explain how this might limit the maximum speed of the bob. 3 marks

Answer:

- *The fluid friction in this case is air resistance or drag.*
- *This increases if turbulent flow occurs, or if streamlining breaks down.*
- *This increases if the size of the bob (and its occupants) is larger than it could be (by for example a bobman putting his head out of the top of the bob).*
- *As the speed increases, the fluid friction force gets bigger, until it matches the weight component down the track, then the bob couldn't go any faster.*

b) Explain the term 'turbulent flow', and how the bobsleigh is used to minimise this factor. 3 marks

Answer:

3 marks for three of:

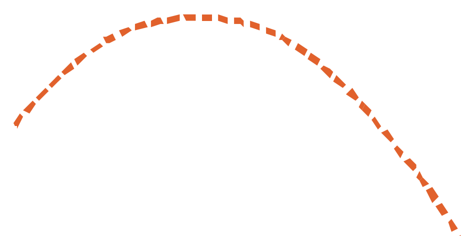
- *At low speeds, air flow past a moving object is laminar, which means the air flows in layers.*
- *When this flow is interrupted either by going too fast or by a protrusion (which upsets the streamlined shape), then the air is thrown out into vortices, the layers mix up, and this is turbulent flow.*
- *When there is turbulent flow, the air resistance is greater because the bob is forcing this air to be thrown into the vortex patterns.*
- *In order to minimise turbulent flow, the bob has to be as streamlined as possible (so that flow is as laminar as possible).*
- *This is done by having a specially designed streamlined shape to the bob.*
- *And by having no protrusions from the bob while in motion - handles, heads of bobmen (this is why the bobmen crouch down once in the bob after the start).*

9) a) Sketch a diagram to show the flight path of the shot from the moment it leaves the putter's hand to the moment it lands. 2 marks

Answer:

- *See figure Q4.11. Flight path a parabola not a circle.*

figure Q4.11 – flight path of a shot



b) State and briefly explain three factors (excluding air effects) which should be used by the putter to optimise the distance thrown. 6 marks

Answer:

- *Speed of release.*
- *The faster the shot is released the further it will go.*
- *Angle of release.*
- *The optimum angle depends on height of release, but would be between 42° and 45°.*
- *Height of release above the ground.*
- *The higher the release, the further the shot will travel.*

c) Explain why the turn in a discus throw produces greater horizontal range than the standing throw. 3 marks

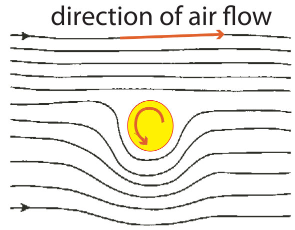
Answer:

- *Forces are applied to the discus over a larger distance.*
- *Since work = force x distance, this means that more energy is given to the discus, which therefore will have more kinetic energy on release.*
- *Or, the forces are applied over a longer time.*
- *Therefore the force x time (impulse) is bigger, and the change of momentum bigger.*
- *So the discus has a higher speed at release.*
- *Or, the discus is accelerated to some degree before the standing throw position is reached, and hence the turn produces extra velocity over and above the standing throw.*

10) a) The Magnus effect (the Bernoulli effect applied to spinning balls) states that a faster flowing liquid or gas exerts less pressure than a slower moving liquid or gas.
Using figure 4.32, show how the Magnus effect explains the swerve of a spinning ball. 4 marks

Answer:
- *The ball moving through the air causes the air flow to separate, with air flowing further past the lower half of the ball.*
- *More air is sent on the lower route, since as the air arrives at the nearest edge of the ball, it is dragged down by the downward spinning surface of the ball.*
- *In the same time as the air flow over the top of the ball (the air is a fixed entity - the ball moves through it).*
- *Therefore the air flows faster past the lower half of the ball.*
- *Therefore there is less pressure on the bottom of the ball.*
- *Hence the ball will experience a force downwards.*

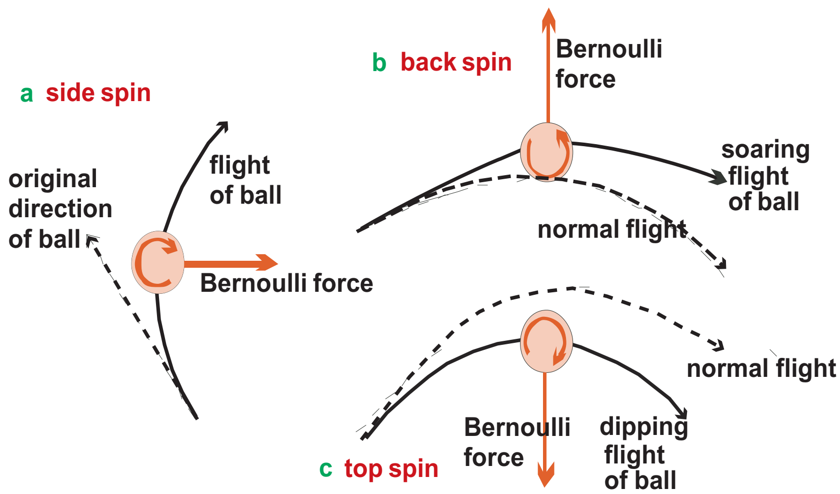
figure 4.32 – Magnus effect on a spinning ball



b) Use diagrams to show how your explanation relates to the flight of a table tennis ball with side, back and top spin. 3 marks

Answer:
- *Side spin, see figure Q4.12a.*
- *Back spin see figure Q4.12b.*
- *Note tendency of ball to travel straighter.*
- *Or even lift.*
- *Top spin see figure Q4.12c.*
- *Note pronounced curve downwards (dip).*

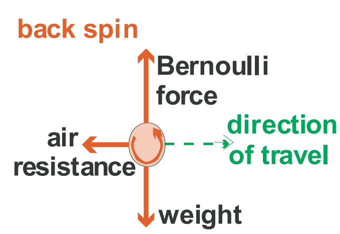
figure Q4.12 – flight path of a spinning ball



c) Sketch a vector diagram of all forces acting on a table tennis ball in flight with back spin, and explain how the resultant force on the ball predicts the actual acceleration of the ball. 4 marks

Answer:
- *See figure Q4.13.*
- *Note that the Bernoulli effect force is upwards, weight downwards, and air resistance (fluid friction) in a direction opposite to the direction of motion of the ball.*
- *Bernoulli effect force is equal or bigger than the weight.*
- *Resultant would therefore be upwards and to the left of the diagram.*
- *Acceleration of the ball (deceleration) is in the same direction as the resultant force, i.e. upwards and to the left.*
- *Hence the path upwards and to the left of original direction.*

figure Q4.13 – forces acting on a spinning ball



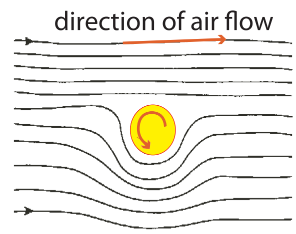
d) Identify one sport other than a ball game, in which the Bernoulli effect plays a part. 1 mark

Answer:
- *Ground effects in racing cars.*
- *Wing effects on gliding or flying or kites.*
- *Effects on ski jumping.*
- *Effects on hand shape in swimming (enables greater thrust on water).*

11) What do you understand by the Magnus effect?
Explain how a knowledge of Magnus forces can assist a tennis player to execute different types of spins. 15 marks

Answer:
- *The Magnus effect is an observable phenomenon that is commonly associated with a spinning object that drags air faster around one side.*
- *Creating a difference in pressure that moves it in the direction of the lower-pressure side.*
- *As illustrated in figure 4.31.*

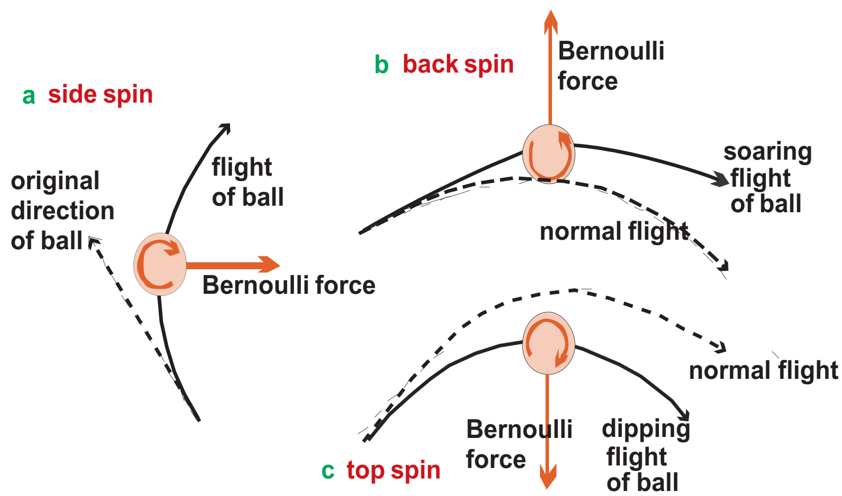
figure 4.32 – Magnus effect on a spinning ball



- *The ball moving through the air causes the air flow to separate, with air flowing further past the lower half of the ball.*
- *More air is sent on the lower route, since as the air arrives at the nearest edge of the ball, it is dragged down by the downward spinning surface of the ball.*
- *In the same time as the air flow over the top of the ball (the air is a fixed entity - the ball moves through it).*
- *Therefore the air flows faster past the lower half of the ball.*
- *Therefore there is less pressure on the bottom of the ball.*
- *Hence the ball will experience a force downwards.*

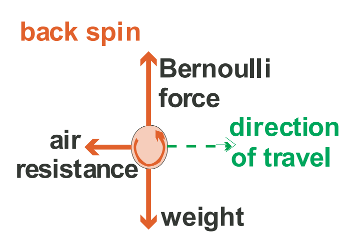
- *Side spin, top spin and back spin will cause the following effects on the spinning tennis ball.*
- *Side spin, see figure Q4.12a, foce acts sideways to the direction of motion.*
- *Back spin see figure Q4.12b.*
- *Note tendency of ball to travel straighter.*
- *Or even lift above normal flight.*
- *Top spin see figure Q4.12c.*
- *Note pronounced curve downwards (dip).*

figure Q4.12 – flight path of a spinning ball



- *For example, the forces acting on a backspinning ball are illustrated in figure Q4.13.*
- *Note that the Magnus effect force is upwards, weight downwards, and air resistance (fluid friction) in a direction opposite to the direction of motion of the ball.*
- *The Magnus effect force is equal or bigger than the weight.*
- *Resultant would therefore be upwards and to the left of the diagram.*
- *Acceleration of the ball (deceleration) is in the same direction as the resultant force, i.e. upwards and to the left.*
- *Hence the path upwards and to the left of original direction.*

figure Q4.13 – forces acting on a spinning ball



12) a) Give three examples from sport where fluid friction affects an object and a sportsperson and state the effects of fluid friction in each case. 8 marks

Answer:

- *Air resistance involving performer (athlete running, skier, cyclist, parachutist).*
- *Air resistance involving sports vehicle (racing car, glider, cyclist).*
- *Air resistance involving projectile (badminton shuttle, ball).*
- *Water resistance involving performer (swimmer).*
- *Water resistance on sports vehicle (water skis, canoeing, rowing, sailing, speedboats).*

- *In each case the fluid friction will tend to reduce the speed of travel.*
- *The fluid friction force will act backwards to the direction of motion.*
- *And will depend on the size of the moving sports object as viewed from the front (the forward cross sectional area).*
- *And will depend on factors such as the streamlining of the object (for example, the shape of the cyclist's helmet, or the shape of the body as it runs, or the complete covering of the body with lycra).*
- *And the speed of the moving object.*

b) Explain three factors that affect the amount of air resistance that acts on a body. 3 marks

Answer:

- *Laminar flow as opposed to vortex creation is the main reason that streamlining works to reduce fluid friction.*
- *Vortex creation (by parts of the moving body which stick out and prevents the smooth flow of air past the object) causes extra drag.*
- *Large amounts of air flung sideways in this manner will require force from the moving body - hence causing extra fluid friction.*
- *The speed of the moving body also affects fluid friction, the faster the object moves, the bigger the fluid friction (in proportion).*

c) State three ways in which cyclists reduce air resistance in order to maximise their speed. 3 marks

Answer:

- *Wear close fitting lycra clothing.*
- *Use a wheel profile that is designed to minimise turbulent flow.*
- *Wear a helmet designed to assist streamlining.*
- *Crouch low over the front wheel/handlebars to minimise the forward cross section of the cyclist*