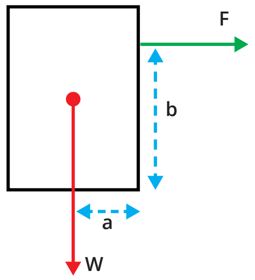
GCE Physics Unit 4 Option C, The Physics of Sports

We can assume the weight of an object acts from its **centre of gravity** (see unit 1.1). This is important as the **centre of gravity** of an object directly affects its stability. For example, sailors in a racing boat will move to ensure the centre of gravity is such that the boat will not topple, and a F1 racing car will be designed so that its centre of gravity is close to the ground so that the torque required to topple it is very large.

Calculating the moment (= Fd see unit 1.1) will determine whether this object will topple. If the clockwise moment, *Fb*, is larger than the anticlockwise moment due to its weight, *Wa*, then the object will topple.



Moments are also important when considering **muscle systems** in the human body. For example, the moment will depend on the **distance from the joint to where the tendons are connected** as well as the **tension in the muscle**.

Collisions:

Interactions involving collisions occur frequently in sports, for example a cricket bat hitting a ball or two stones colliding in curling. Conservation of momentum will still apply (see unit 1.3). The forces acting during a collision must obey Newton's laws. As such, when a squash ball hits a wall, the force can be calculated using Newton's 2nd law.

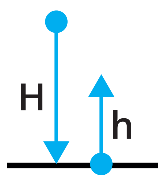
$$Ft = mv - mu$$

The **coefficient of restitution**, e, is the ratio of relative speed after a collision to the relative speed before a collision.

$$e = \frac{\text{relative speed after collision}}{\text{relative speed before collision}}$$

This can be used to calculate the change in velocity described above. It is also possible to use this equation to **predict the bounce of a ball** in the form:

$$e = \sqrt{\frac{h}{H}}$$



Rotating objects:

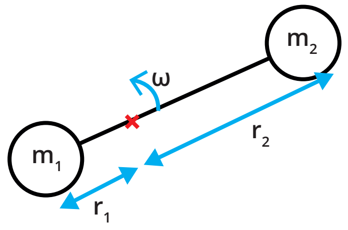
The equations for rotational motion are similar to the equations for linear motion.

The equivalent of mass in linear motion is the **moment of inertia**, ***I***. It is defined as $I = \sum m_i r_i^2$ for all points in the body, where m_i and r_i are the mass and distance of each point from the axis.

For a solid sphere $I = \frac{2}{5}mr^2$ and for a thin spherical shell, $I = \frac{2}{3}mr^2$.

For this rotating dumbbell,

$$I = m_1 r_1^2 + m_2 r_2^2$$



The **angular acceleration**, ***α***, of a rotating object (equivalent to the acceleration of linear motion), is defined as the rate of change of angular velocity.

$$\alpha = \frac{\Delta\omega}{t} = \frac{\omega_2 - \omega_1}{t}$$

To accelerate the rotation, torque must be applied. **Torque**, ***τ***, is defined as $\tau = I\alpha$, where I is the moment of inertia and α is the angular acceleration. It can also be defined as the rate of change of angular momentum.

Angular momentum, ***J***, can be calculated using this equation:

$$J = I\omega$$

Conservation of angular momentum acts provided no external torque acts. This applies in many sporting contexts but the most common example is a spinning figure skater. With outstretched arms, the figure skater has larger I, by drawing their arms in the skater decreases I and in order **for *J* to remain constant** the angular velocity increases and the figure skater will spin more quickly. To slow the rotation, the skater will extend their arms and increase I.

$$I_1\omega_1 = I_2\omega_2$$

Rotational kinetic energy, ***KE***, can be calculated using this equation:

$$\text{KE} = \frac{1}{2}I\omega^2$$

In most sporting applications, rotating bodies, such as balls, will have both linear kinetic energy and rotational kinetic energy. This means the total kinetic energy can be calculated using this equation.

$$\text{KE} = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$$

Conservation of energy still applies to rotating objects, so the kinetic energy can still be transferred as in unit 1.4 but the rotational energy must be considered.

Projectile motion where frictional forces are negligible apply to many sporting contexts, such as shotput. (The application is the same as from unit 1.2.) However, there are contexts where the frictional force of air resistance or drag have more effect. For example, throwing a javelin. Drag can be calculated using the following equation:

$$F_D = \frac{1}{2}\rho v^2 A C_D$$

Where ρ is the density of the air and C_D is the drag coefficient. As the angle of the javelin changes during its flight the drag will change. This equation can also be used to explain why objects like cricket balls travel further at altitude as the air density is lower.

Bernoulli's equation:

$$p = p_o - \frac{1}{2}\rho v^2$$

This equation predicts that **air travelling at a higher velocity will have a lower density**. For example, an aerofoil on the spoiler of an F1 car will force the air to travel faster underneath than above, this will create a lower pressure below and force the aerofoil down to improve the car's grip. This also applies to a rotating ball; the rotation of a ball will change the air pressure on one side compared to the other and make the ball curve through the air.

F = force in N v = final velocity in m s⁻¹ I = inertia in kg m² ω = angular velocity in rad s⁻¹ KE = kinetic energy in J F_D = drag in N t = time in s u = initial velocity in m s⁻¹ r = radius in m

τ = torque in N m p = pressure in Pa A = area in m² m = mass in kg e = coefficient of restitution α = angular acceleration in rad s⁻² J = angular momentum in kg m² rad s⁻¹ ρ = density in kg m⁻³ C_D = drag coefficient