BioMedical Admissions Test (BMAT)

Section 2: Physics

Topic P3 - Mechanics

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Kinematics

Speed
Speed is a **scalar quantity** (it only has a magnitude); if we know the speed of an object, we only know how fast it is travelling.

Speed (m/s) = Distance (m) / Time (s)

Across the course of a journey, the speed of an object is unlikely to remain constant. Fluctuations in speed are far more likely so we calculate **average speed** for the journey. This is calculated by dividing total journey distance by total journey time.

Velocity
Velocity, unlike speed, is a **vector quantity** (it has both a magnitude and a direction). The velocity of an object describes both its speed and direction.

Velocity (m/s) = Displacement (m) / Time (s)

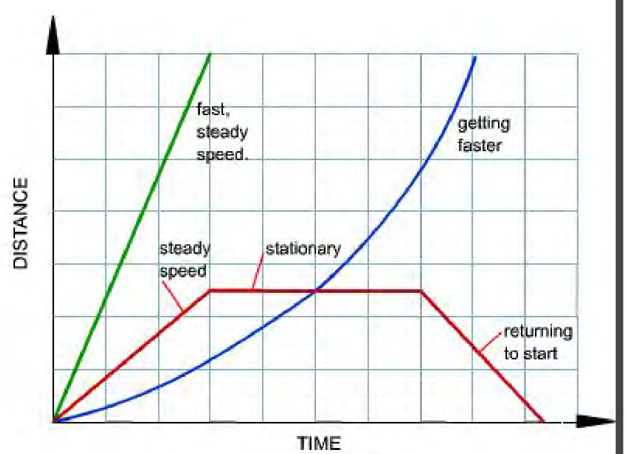
Acceleration
Acceleration is also a vector quantity and is the rate of change of velocity. Deceleration has a negative value but is otherwise the same as acceleration.

Acceleration (m/s^2) = ΔVelocity (m/s) / Time (s)

Exam Tip: be careful when dealing with vector quantities such as velocity and acceleration. An object can have a constant speed but a changing velocity by changing direction. Therefore, although the object is travelling at a constant speed, it is technically accelerating.

Distance-Time Graphs
Distance-Time Graphs describe a number of properties of an object:

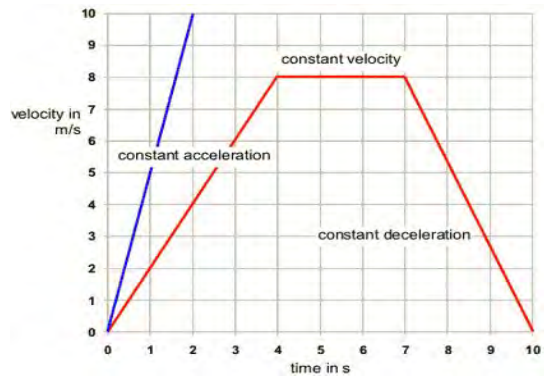
- A horizontal line - a stationary object.
- A straight diagonal line - an object moving with constant velocity.
- Velocity can be calculated by taking the gradient of the line.
- Distance can be read directly off the y-axis.
- A curved line - an accelerating object.



<u>Velocity-Time Graph</u>

Velocity-Time Graphs also describe a number of properties:

- A horizontal line - an object moving with constant velocity.
- A straight diagonal line - an object moving with constant acceleration.
- Acceleration can be calculated by taking the gradient of the line.
- The displacement (distance travelled) can be calculated by taking the area under the graph.



The following equations can be derived from velocity time graphs and are a useful alternative when solving problems which involve uniform acceleration:

- $v = u + at$
- $s = 0.5(u+v)t$
- $v^2 = u^2 + 2as$

V = final velocity (m/s)
U = initial velocity (m/s)
a = acceleration (m/s^2)
s = displacement (m)
t = time (s)

Forces

A **force** is any interaction between two or more objects that, if unopposed, will cause an **acceleration**.

- Forces are **vector quantities** and are measured in **newtons (N)**
- Every force acting upon an object is **opposed** to some extent by another force acting in the opposite direction e.g. the weight of an object on the ground is opposed by the **normal** force of the ground acting upwards on the object.
- All forces acting on an object can be **labelled** using an arrow to show their direction and the type and magnitude of the force should be specified to create a **force diagram**.

Once the magnitude, type and direction of all of the forces have been labelled on the force diagram, the **resultant force** can be calculated by finding the sum of all of the forces (remember to account for the direction as force is a **vector** quantity).

- A resultant force acting on an object will cause it to **accelerate** in the **direction** of the resultant force.

➔ If no resultant force acts on the object (all forces cancel out) then the object will **not** accelerate.

An object may have forces acting in more than one dimension. In that case the resultant force in each dimension can be calculated by just using the forces that act in that dimension.

Force and Extension

When a spring/string/wire is pulled by equal and opposite external forces at each end as shown, it is said to be subjected to a **tension** force

➔ This tension force usually causes the length of the spring /string wire to increase slightly (**extension**).
➔ It is usually the case that the greater the tension force, the greater the extension.

A graph can be drawn that shows the **force-extension characteristics** of a particular spring/string/wire.

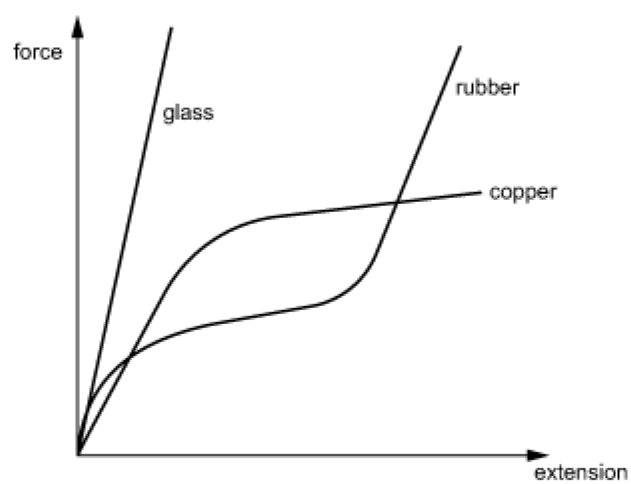
➔ The steeper this graph, the more force is required to produce a given extension.
➔ The shallower this graph, the greater the extension for a given force.

A material is described as **rigid** if its deformation is small even with a large tension force.

The characteristics of the spring/string/wire can change as it stretches, becoming more or less stiff. A point usually comes where the extension can increase no more and the material breaks

Different types of material have different **force-extension** characteristics:

- **Copper** wire stretches uniformly initially, but then suddenly stretches much more just before reaching the breaking point.
- **Glass** is very rigid and deforms only very slightly before breaking.
- **Rubber** stretches non-uniformly.



<u>Elastic vs Inelastic</u>

- If the extension of the material is **elastic**, it means that the material will return to its original length when the tension is removed.
- If the extension is **inelastic**, the material does not return to its original length when the tension is removed (**plastic deformation**).
- The point at which extension goes from elastic to inelastic is known as the **elastic limit** of the material.

Materials undergoing elastic extension obey **Hooke's law** which states that extension is proportional to the force applied:

$$F = Kx$$

F = force in Newtons (N)
x = extension in metres (m)
K = spring constant in N/m

The spring constant is a measure of **rigidity** - a higher spring constant means that a higher force is required to produce a certain extension (it is the **gradient** of a force - extension graph).

The **limit of proportionality** is the point on a force extension graph where the line is no longer straight. At this point, the material no longer obeys **Hooke's law** (this is often also the elastic limit).

The spring constant is affected by:

- The cross sectional **area** of the spring - increased cross sectional area increases the spring constant.
- The **length** of the spring - the longer the spring, the smaller the spring constant.

Two identical springs in **series** will have a resultant spring constant of **0.5 x the spring constant of 1 spring.**

Two identical springs in **parallel** will have a resultant spring constant of **2 x the spring constant of 1 spring.**

When a spring is stretched, **work** is done and energy is stored as **elastic potential energy** in the spring (given by the area under the force - extension graph).

If the elastic limit is not exceeded, this energy can be recovered as **kinetic** energy.

The area under a force - extension graph can be given by the equations:

$$E = 0.5Fx \text{ and } E = 0.5Kx^2$$

If the material is stretched beyond its elastic limit, then the work done becomes partially or completely **irretrievable** as the material will no longer return to its original length.

Newton's Laws

Newton's First Law: An object will remain stationary or moving at a constant velocity unless a force acts upon it. Objects with multiple forces acting upon them in opposite directions will also remain stationary or moving at a constant velocity as there is no resultant force. When a resultant force acts upon an object, the object will accelerate in the direction of the force.

Newton's Second Law: The acceleration of an object is directly proportional to the resultant force acting upon the object. Furthermore, the acceleration of an object is inversely proportional to the mass of the object.

Resultant Force (N) = Mass (Kg) x Acceleration (m/s^2).

Newton's Third Law: The force exerted by object A on object B is equal in magnitude and opposite in direction to the force exerted by object B on object A.

Momentum

Momentum is a quantity of motion of a moving body that is a product of its mass and velocity. It has the symbol *p* and is measured in kilogram-metres per second (Kgm/s).

In a **closed system** momentum is **conserved**.

- ➔ This is useful when considering collisions as the total momentum before the collision is equal to the total momentum after the collision.

A force must be applied in order to change an object's momentum. The force applied to change its momentum can be calculated by using the following equation:

Force (N) = Change in momentum (Kgm/s) / Change in time (s)

The relationship between force, momentum and time is useful when it comes to car safety features. By extending the time over which momentum changes, through the use of seatbelts and crumple zones, the force exerted on the passengers is reduced.

> **Exam Tip:** when considering momentum questions involving guns, remember that the starting momentum of 0kgm/s before firing is conserved by the positive momentum of the bullet and the negative momentum of the recoil of the gun after firing as they move in opposite directions.

Mass, Weight and Free-fall

Mass is a quantity of an object, regardless of its volume or any forces acting on it. It has the symbol M and is standardly measured in kilograms (Kg).

Weight is the force exerted on a body by gravity. It has the symbol W and is measured in Newtons (N).

Weight is calculated by multiplying the mass of the object by the acceleration due to gravity (g). For the purpose of the BMAT, $g = 10 m/s^2$.

When an object is in **free fall**, the two forces acting on the object is its **weight downwards** and **aerodynamic drag** acting in the opposite direction. These forces change over the course of free fall creating several stages:

- As the object starts falling, the object's weight acting downwards is greater than aerodynamic drag acting upwards. Hence the object accelerates downwards
- As the object accelerates, the magnitude of aerodynamic drag increases.
- Drag increases until it is equal to the object's weight. At this point there is no resultant force acting on the object so it moves at a constant velocity known as terminal velocity.

Skydivers can increase their aerodynamic drag by deploying a parachute. This causes them to decelerate until the forces are once again balanced and they continue to fall at a new, lower terminal velocity.

Energy

Energy is the capacity of a body to do work and work done is analogous to energy transferred. Both energy and work done are measured in Joules (J).

Work done (J) = Force (N) x Distance (m)

It is important to note that the distance over which a force is applied must be in the same direction in which the force is acting for this equation to work.

Power is the rate of energy transfer: **Power (W) = Energy (J) / Time (s)**

Gravitational potential energy (GPE) is the energy stored in an object due to its position in a gravitational field (as it is moved to a higher position in space):

Change in GPE = Mass (Kg) x Acceleration due to Gravity (m/s^2) x Change in Height (m)

Kinetic energy is the energy possessed by a moving object:

Kinetic energy = 0.5 x Mass (Kg) x $Velocity^2$ (m/s^2)

In a system where there is no drag/resistance, all of the gravitational potential energy will be converted to kinetic energy so you can link the above two equations:

$$M \times G \times H = 0.5 \times M \times V^2$$

Energy can neither be created or destroyed but can be converted from one form to another.

The nine **forms of energy** are:

1. **Heat**	**4. Kinetic**	**7. Elastic Potential**
2. Light	**5. Electric**	**8. Gravitational Potential**
3. **Sound**	**6. Nuclear**	**9. Chemical Potential**

Conversion of one form of energy to another can be useful but it is never 100% efficient. We can calculate the efficiency of energy conversion using the following equation:

Efficiency (%) = [Useful Energy Output (J) / Total Energy Inpu t(J)] x100