WJEC (Wales) Physics GCSE

2.3: Work & Energy

Detailed Notes

(Content in **bold** is for higher tier **only**)

Work Done

When a force acts on an object causing it to move, energy is transferred i.e. energy is converted from one form to another (usually **chemical** energy to **kinetic or potential** energy). This is known as **work** being done.

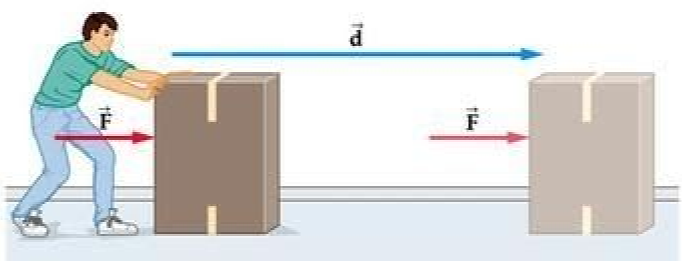
$$W = Fd$$

W is work done (J), F is the force applied (N) and d is the distance moved along the line of action of the force (m).

It is important to note that during this energy transfer, the **total amount of energy remains constant** (as it must do according to the law of conservation of energy).

An example of work being done includes a book being lifted 1m in the air. Here, work is being done against gravity to raise the book 1m off the ground. Energy is **transferred** from your **muscles**, causing the **gravitational potential energy** of the book to be increased. As a byproduct, energy from your muscles may also be converted to other non-useful forms of energy such as heat.

The amount of work done is the amount of energy transferred 'usefully'.



Work is done moving the box a distance, d (pintrest.com).

In the above example of a person moving a box, we can see how an object can store energy as a result of:

Position

Objects can have **gravitational potential energy (GPE)**. An elevated object has **more energy** and can **lose or gain** energy as it changes elevation. GPE depends on the **height** and the **mass** of the object.

$$GPE = mg\Delta h$$

m is mass (kg), g is gravitational field strength (N/kg) and Δh is the change height (m).

Movement
Objects can have **kinetic energy (KE)** when moving with a **velocity**. The faster it is moving, the greater its kinetic energy. KE also depends on the **mass** of the object.

$$KE = \frac{1}{2}(mv^2)$$

m is mass (kg), v is velocity (m/s).

Deformation
Forces have the capability to deform objects. Some may store **elastic potential energy** as a result. A prime example of this is when an elastic band, a catapult or a spring is stretched.

Forces on a Spring

Springs are **elastic** objects meaning they can store **elastic potential energy** when deformed. This deformation can be stretching or squashing, so typically involves a **change in length**.

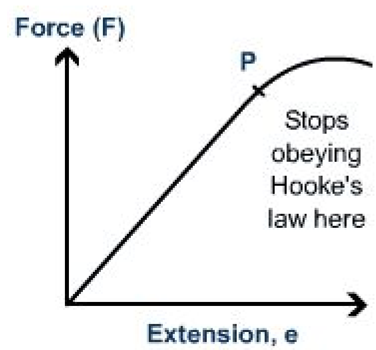
Hooke's Law

The change in length or **extension** of a spring depends on the **force applied** and a value known as the **spring constant (k)**. This spring constant is specific to each spring and is a measure of its **stiffness**.

$$F = kx$$

F is the force applied (N), k is the spring constant (N/m) and x is the extension (m).

Springs can be compared by plotting a **force-extension graph**. These graphs show the spring constant as the **gradient**, so the relative **stiffnesses** of different springs can be assessed. A steeper gradient means a stiffer spring, so it extends less when a force is applied.



Force-extension graph showing elastic behaviour of a loaded spring (saturninenotes.wordpress.com).

These graphs assume the springs are undergoing **elastic deformation**, so will return to their **original length** when the force is removed. Therefore, all lines should pass through the **origin**.

If too great a force is applied, the spring will pass its **elastic limit** and the gradient will no longer be a straight line. The spring **no longer obeys Hooke's Law** at this stage and can now be said to be **plastic**, undergoing **plastic deformation** if further force is added.

Work is done on the spring when it is extended because a force is applied. This work done can be found as the area under a force-extension graph. Up to the elastic limit, this area forms a triangle, so the work done follows the equation of a triangle.

$$W = \frac{1}{2}(Fx)$$

F is the force applied (N) and x is the extension (m).

Energy Efficiency

Vehicles are very inefficient. In order for a vehicle to move and hence do **useful work**, it must firstly **convert** the **chemical energy** in fuel to **mechanical energy**, which drives wheel axles. Petrol engines typically have a <38% conversion rate. As a result >62% of the chemical energy in the fuel is **lost** to **non-useful** energy forms, such as heat.

Frictional forces between the **tyres and the road surface** and the **wheels and axles** further reduce efficiency, since they convert some of the mechanical energy generated by the engine into heat. **Mechanical friction** within the engine, as fuel and air are pumped in and out, also partially explains the energy conversion rate of petrol engines.

Drag forces must also be overcome in order to do useful work. As a result, more energy is lost to non-useful forms. This results in a further reduction in vehicle efficiency.

The amount of energy lost in non-useful forms can be **reduced** by making the vehicle more **energy efficient**. This can be done by **improving engine efficiency** and/or **reducing the effect of frictional and drag forces**.

Engines

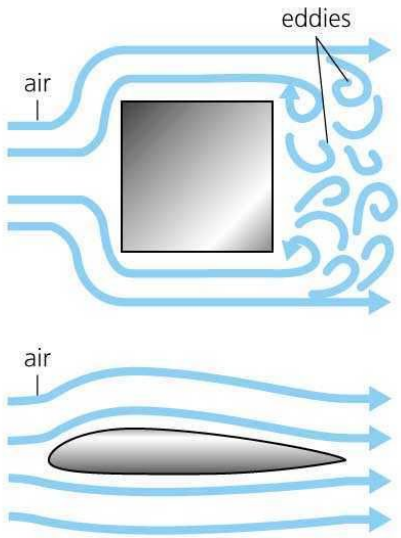
Car engines come in **different sizes**, providing different amounts of **power**. A 3 litre engine provides more power than a 1.2 litre engine. More powerful engines tend to run faster, allowing the car to **travel faster**. However, these engines require more fuel to run and are often less energy efficient.

Consequently larger engines use up **more fuel,** are **more expensive** to run and are **worse for the environment**.

Aerodynamics

Vehicles can be made to be **streamlined**, so that air travels more smoothly over or around them, reducing air resistance and drag forces. This means less power is required from the engine to **overcome air resistance**. Therefore less fuel is used. As a result the vehicle is more efficient.

Air **deflectors** can be fitted onto cars and lorries to **channel the air** around the vehicle. Lots of sports cars are designed to have very **smooth shapes** that are tapered, greatly minimising the effect of air resistance.



Example of the difference in shapes for air resistance (yourdictionary.com).

Friction

Friction **increases energy loss** through production of non-useful energy such as heat. This reduces the efficiency of the vehicle as well as potentially causing dangerous **overheating**.

Rolling resistance is a measure of the force necessary to move the tyre forward, which is directly proportional to the weight of the load supported by the vehicle's tyres. It is influenced by the friction between the wheels and the road and that between the wheels and axles. A variety of new technologies have been developed to reduce rolling resistance. These include using newly developed materials in tyres and new tyre tread designs to improve the traction between the tyre and the ground.

Idling and Inertial Losses

Another significant energy loss comes when a vehicle **idles** at traffic lights or in traffic. New vehicle technologies have been developed to try and reduce these losses by **turning the engine off** when the vehicle comes to a stop. It then **restarts automatically** when the accelerator is pressed again.

The repeated acceleration and deceleration, made necessary by traffic lights, requires more energy than travelling at an approximately constant velocity. Although arguably unavoidable, since traffic lights are perhaps a necessary safety measure, this **inertial energy expenditure** means that more fuel is burnt making travel **less energy efficient**.