OCR A Physics A-level

Topic 3.3: Work, Energy, and Power

Notes

Work and conservation of energy

Work done

When a force is required to provide motion, there is a **transfer of energy**. The magnitude of this energy transferred depends on the force required and the distance the object moves as a result of this force. This energy is called the **work done**. The work done by a force is defined as the product of the magnitude of the force and the distance moved by the object in the direction of the force. If the force used is at an angle to the direction of movement of the object, then the component of the force **parallel** to this direction is used.

Work done is a measure of energy, so its unit is **joules**. One joule is the work done when a force of 1 N moves an object 1m in the direction of the force. It can also be measured in Nm, and the SI base unit is kgm^2s^{-2}.

The principle of conservation of energy

Energy is the capacity for doing work. It is a scalar quantity, measured in joules. There are several different forms of energy, which are all interchangeable. This means energy can be **transferred between different forms**.

Forms of energy:

- Kinetic – the energy associated with the motion of an object with mass.
- Gravitational potential – the energy stored by an object at a point in a gravitational field
- Elastic potential – the energy stored as a result of a reversible change in an object's shape.
- Electric potential – the energy of charges due to their position in an electric field.
- Sound – the energy of a mechanical wave due to the movement of atoms.
- Internal – the sum of the randomly distributed kinetic and potential energies of the molecules in a substance.
- Electromagnetic – the energy from electromagnetic waves, stored within oscillating fields.
- Nuclear – the energy stored in nuclei, released when particles in nuclei rearrange
- Chemical – the energy contained in chemical bonds, released when atoms rearrange.

Although energy can be transferred between different forms, the total energy after the transferal is always equal to the total energy before the transferal. The principle of **conservation of energy** stated that in a **closed system**, energy cannot be created or destroyed, but only **transferred** from one form to another.

Work done is equivalent to the energy transfer. For example, if you lift up a book in a gravitational field, it will gain gravitational potential energy as work is done against gravity. If the book is dropped, as it falls, the GPE will be converted to kinetic energy. The work done here will be the weight of the book multiplied by the distance it falls, and this is equal to the amount of energy converted from GPE to kinetic.

Kinetic and Potential energies

Kinetic energy

Kinetic energy is associated with an object as a result of its **motion**. It is measured in joules, and it SI base unit is kgm^2s^{-2}. The formula for kinetic energy can be derived from the equations of motion.

$$v^2 = u^2 + 2as \text{ , if we take take u} = 0 \text{ then } s = \frac{v^2}{2a}$$

As kinetic energy is work done, then it is equal to the force acting on the object multiplied by the distance the object has travelled in the direction of the force. We can use the expression for displacement we have just found in the formula W = Fx.

$$W = Fx = \frac{Fv^2}{2a}$$

As F = ma, we can replace the F$/a$ part of this formula with m, resulting in

$$Ek = \frac{1}{2}mv^2$$

Gravitational potential energy

Gravitational potential energy is an object's capacity to do work as a result of **its position in a gravitational field**, such as the gravitational field of the Earth. By assuming that the gravitational field on the surface of the Earth is uniform, we can derive a formula for GPE.

We consider GPE an energy, so W = Fx

In vertial motion, the force is the weight mg and distance moved is height h

so W = Ep = mgh

Gravity is an **attractive force**, so GPE is gained when an object gets higher in a gravitational field, as energy must be supplied to move it against the gravitational attraction. GPE is lost when the object falls back down and gets closer to the source of the gravitational field.

Energy exchange between Ek and Ep

When an object is moving up and down in a gravitational field (such as a carriage on a roller coaster), its kinetic and gravitational potential energy **exchange** several times. If we consider this as a closed loop system with **no external energy transfer** (so no work is done against resistance forces) then we can derive a formula for the velocity of the object at a given position in the gravitational field. All of the initial GPE will be converted to kinetic energy as the object falls down, and all of this kinetic energy will be converted back to GPE as the objected rises back up again.

As Ek_{max} is equal to Ep_{max} then

$$mgh = \frac{1}{2}mv^2$$

$$2gh = v^2$$

$$v = \sqrt{2gh}$$

This shows that the mass of an object has no bearing on its final speed. This is because the acceleration of free fall is the same for all objects.

Power and efficiency

Power is a measure of the **rate** of which **energy is transferred**. Power is defined as the rate of work done, and is given by the formula $P = \frac{W}{t}$. It is measured in watts, where one watt is defined as a rate of energy transfer of 1 joule per second. The SI base unit for power is kgm^2s^{-3}.

We can use the equation for power to derive an equation for the power required to move an object at a **constant velocity** against **resistive forces** (e.g. driving a car). For a car to move at a constant velocity, the **net acceleration must be 0**. This means the net force acting on the object must be 0, and so the magnitude of the driving force of the car, acting forward, must be equal to the resistive forces, acting to oppose the motion. It is the **driving force** of the car that is used when considering the power required by the car to maintain the constant velocity.

$$P = \frac{W}{t} = \frac{Fx}{t} = F\frac{x}{t} = Fv$$

Efficiency of a mechanical system

The conservation of energy principle states that energy is constant in a closed loop. In reality, we have **energy 'loss'** – where energy is transferred from the closed loop to a form that is not as useful, such as the thermal energy generated by a lightbulb. The **total energy is still conserved**.

Efficiency is a measure of how much energy is conserved as useful energy. A greater efficiency means **less energy is wasted**.

$$\text{Efficiency (\%)} = \frac{\text{Useful Output Energy}}{\text{Total Input Energy}} \times 100$$