10 Work, Energy and Power

10.1 Work and Energy

Energy is needed to make stationary objects move, to change their shape or to warm them up.

Objects can possess energy in different types of stores.

- **Gravitational potential stores** - position of objects in a gravitational field.
- **Kinetic stores** - moving objects.
- **Thermal stores** - hot objects.
- **Elastic stores** - objects compressed or stretched.

Energy can be transferred between objects

- By **radiation**.
- **Electrically**.
- **Mechanically**.
  - E.g. by sound.

Energy is measured in **joules** - one joule is equal to the energy needed to raise 1N weight through a vertical height of 1m.

Whenever energy is transferred, the total amount of energy is unchanged, this is known as the **principle of conservation of energy**.

Energy cannot be created and destroyed.

Work Done by Force

Work is done on an object when a force acting on it makes it move, as a result energy is transferred to the object.

$$\text{Work done} = \text{force} \times \text{distance moved in the direction of the force}$$

The unit of work is the joule - equal to the work done when a force of 1N moves its point of application by a distance of 1m in the direction of the force.

Force-distance Graphs

Force-distance graph is a graph of force against distance.

- If a **constant force** F acts on an object makes it move a distance s in the direction of the force, the work done on the object is $W = Fs$. The area under the lien is a rectangle with the same area.

  Therefore the area under the line represents the work done.

- If a **variable force** F acts on an object and causes it to move in the direction of the force, the work done for a small amount of distance Δs, $\Delta W = F\Delta s$.

  The total work done is therefore the **sum of the areas** under the line.

In both case, the area under the line of a force-distance graph represents the **total work done**.

10.2 Kinetic Energy and Potential Energy

Kinetic Energy

Kinetic energy is the energy of an object **due to its motion** - the faster an object moves, the more kinetic energy it has.

Consider an object of mass m initially at rest, acted on by a constant force F for a time t.

$$\text{distance travelled } s = \frac{1}{2}vt \qquad \text{where } u = 0$$
$$\text{acceleration } a = \frac{v}{t}$$
$$F = ma = \frac{mv}{t}$$

Therefore the work done W by a force F to move the object through a distance s is

$$W = Fs = \frac{mv}{t} \times \frac{vt}{2} = \frac{1}{2}mv^2$$

Because the gain of kinetic energy is due to the work done

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

Potential Energy

Potential energy is the energy of an object due to its position.

If an object of mass m is raised through a vertical height Δh at steady speed, the force needed to raise it is equal and opposite to its weight mg.

$$\text{Work done} = Fd$$
$$= mg\Delta h$$

The work done on the object increases its **gravitational potential energy**.

$$\text{Change in gravitational potential energy } \Delta E_p = mg\Delta h$$

10.3 Power

Energy can be transferred from one object to another by means of

- **Work done** by a force due to one object making another object move.
- Heat transfer from a hot object to a cold object.
- Electricity, sound waves and electromagnetic radiation also transfer energy.

Power is defined as the rate of transfer of energy, the unit of power is the **watt**, equal to an energy transfer rate of 1 joule per second.

If energy ΔE is transferred steadily in time Δt

$$P = \frac{\Delta E}{\Delta t}$$

Because energy transferred is equal to the work done by the force, the rate of transfer of energy is equal to the work done per second.

Engine Power

The **motive power** is the output power of an engine.

When a powered object moves at a **constant velocity** at a constant height, the **resistive forces** are equal to the **motive force** - the work done by the engine is transferred into the internal energy of the surroundings by the resistive forces.

$$P = Fv$$

When a powered object gains speed, the output force exceeds the resistive forces on it.

$$\begin{aligned}\text{Motive power} &= \text{energy per second wasted due to resistive forces} \\ &+ \text{gain of kinetic energy per second}\end{aligned}$$

10.4 Energy and Efficiency

Useful energy is energy transferred for a purpose. In any machine where friction is present, some of the energy transferred by the machine is wasted.

$$\text{efficiency} = \frac{\text{useful energy transferred}}{\text{energy supplied}}$$