Unit III – Energy & Society

Topics covered:

- Energy, Work
- Law of Conservation of Energy
- Work-Energy Principle
- Kinetic Energy
- Gravitational Potential Energy
- Efficiency
- Power

Energy, Work

Energy (E)

The ability to do work.

Forms of Energy:

- ***Kinetic****
- ***Gravitational Potential****
- ***Elastic Potential****
- Electric Potential
- Nuclear Potential
- Chemical Potential
- Thermal
- Radiant
- Sound

*Mechanical Energy: The sum of kinetic energy, gravitational potential energy and elastic potential energy

Work (W)

The amount of energy transferred to (or taken away from) an object when acted upon by a force over some displacement:

$$W = \vec{F} \cdot \Delta\vec{d}$$ (*dot product of force vector and displacement vector*)

$$W = Fd\cos\theta$$

$W = work\ (units: joules, J)$
$F = magnitude\ of\ force\ (units: Newtons, N)$
$d = magnitude\ of\ displacement\ (units: metres, m)$
$\theta = angle\ between\ force\ vector\ and\ displacement\ vector\ (units: degrees, °)$

Units of Work: the Joule (J)

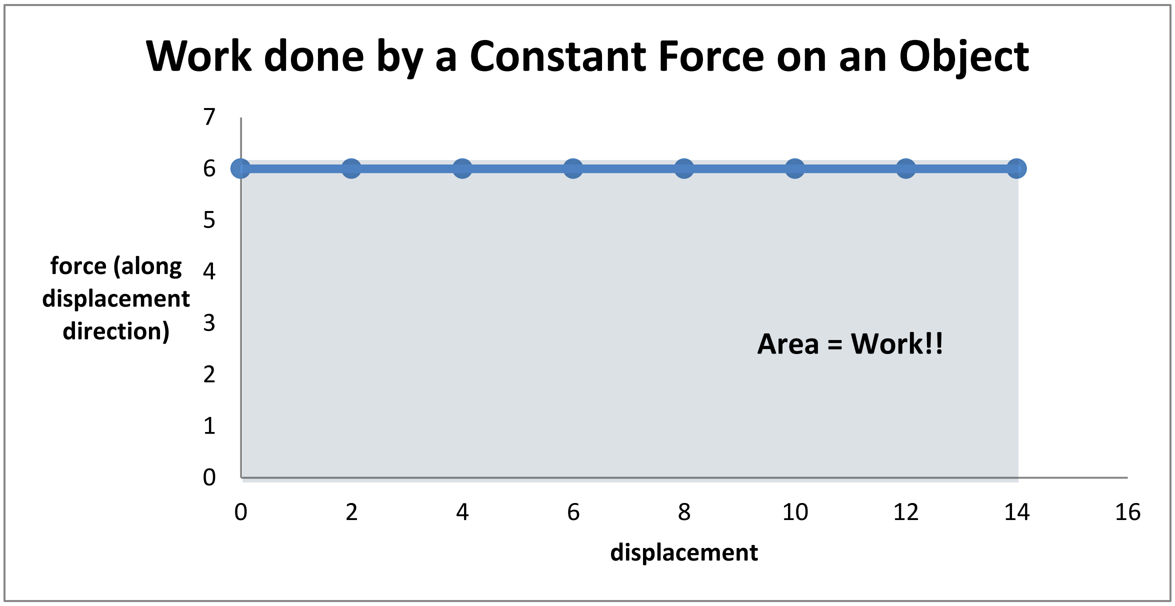
$$W = Fd\cos\theta$$

$$1\,J = 1\,N \cdot m = 1\,kg\frac{m^2}{s^2}$$

Work Examples

example	**work**	**energy**
$\theta = 0°$	$W > 0$	gained
$\theta = 180°$	$W < 0$	lost
$\theta = 90°$	$W = 0$	no change
$F = 0\,N$	$W = 0$	no change
$d = 0\,m$	$W = 0$	no change

If one were to plot the force applied on an object against its displacement, the area under the `curve` represents the work done on the object:



Law of Conservation of Energy

The total amount of energy in an isolated system is constant.

OR

$\Delta E_T = 0$ (the change in the total energy of an isolated system is zero).

**Isolated system – A system where energy or matter cannot enter or exit (e.g. the universe).*

OR

Energy is never created or destroyed, but transferred from one form to another.

Energy Transformation Equations

We use *energy transformation equations* to account for these transformations

e.g. Using a microwave oven to heat some soup

electric potential energy → radiant energy → thermal energy

Work-Energy Principle

The work done by non-conservative forces acting on an object is equal to the total change in its kinetic and potential energies:

$$W_{NC} = \Delta E_K + \Delta E_P$$

$W_{NC} = work\ done\ by\ all\ nonconservative\ forces\ (units: joules, J)$
$\Delta E_K = change\ in\ an\ object's\ kinetic\ energy\ (units: joules, J)$
$\Delta E_P = change\ in\ any\ of\ an\ object's\ potential\ energies\ (units: joules, J)$

Non-conservative Forces

Forces whose work they do depends on the path of the object.

Conservative Forces	Non-conservative Forces
Gravitational	Applied forces (pushes & pulls)
Electric	Friction
Elastic	Air resistance
	Tension
	etc.

E_K – Kinetic Energy

Take an object: of mass ***m***, travelling at a speed v_i, experiencing a force ***F***, over a displacement ***Δd***

As a result, the object will: experience an acceleration ***a*** and achieve a final velocity v_f

The work done on the object is:

$$W = F\Delta d$$

But F = ma, so substituting

$$W = ma\Delta d$$

Recall, from kinematics:

$$v_f^2 = v_i^2 + 2a\Delta d$$

$$a\Delta d = \frac{v_f^2 - v_i^2}{2}$$

Substituting, we get

$$W = ma\Delta d = m\left(\frac{v_f^2 - v_i^2}{2}\right) = \frac{mv_f^2 - mv_i^2}{2}$$

To simplify, if we assume $v_i = 0$, we get

$$W = \frac{mv^2}{2}$$

The work done on this object is converted into the motion of the object, which is called *kinetic energy*, and at last we get:

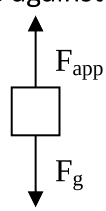
$$E_K = \frac{1}{2}mv^2$$

Kinetic Energy is the energy of motion. If an object has a velocity, it has kinetic energy.

E_g – Gravitational Potential Energy

When doing work against the force of gravity to lift an object, the object now has an increased ability to do work, that is, to fall back down. This energy is stored in the object by merely being above the surface of the earth (i.e. the centre of the earth). Stored energy is called *potential energy*, so work done against gravity is called *gravitational potential energy:*

FBD



After analyzing forces:

$$F_{app} = |F_g| = mg$$

Recall work

$$W = F\Delta d$$

The displacement, in this case, is simply going to be the change in height, Δh, of the object.

$$W = mg\Delta h$$

If we assume $h_i = 0$, we get

$$E_g = mgh$$

Efficiency

The 2nd Law of Thermodynamics

'In any natural process, there exists an inherent tendency towards the dissipation of useful energy'. In any natural process, then, we are concerned with two specific values: the amount of energy supplied in order to execute the process, (energy input, E_{in}) and the energy of the process itself, (energy output, E_{out}). And because inevitably, energy will be lost in any process (i.e. perpetual motion machines are impossible):

$E_{in} > E_{out}$

Efficiency, therefore, is the percentage of the energy output to the energy input for any process:

$$efficiency = \frac{E_{out}}{E_{in}} \times 100\%$$

Example #1: efficiency of a Halogen Light Bulb:

What is the purpose of providing energy to a light bulb? *To provide light.*

Amount of energy used by a 100-W light bulb in 1 hour: *6000 J*

Efficiency of a halogen light bulb: *5 % !!!*

How much energy is 'wasted' during one hour?

$$E_{out} = \frac{E_{in} \times \ efficiency}{100\%}$$

$$E_{out} = \frac{6000\ J \times \ 5\%}{100\%}$$

$$E_{out} = 300\ J$$

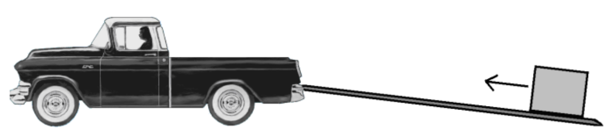
Amount of waste energy produced:

$E_{waste} = 6000\ J – 300\ J = 5700\ J$ *(or, 95%)*

Where did this energy go? *Into producing heat (maybe some sound too)*

Example#2: What is the efficiency Sliding a piano up a ramp into a truck?

Ramp length: 3.0m
Mass piano: 350 kg
Height: 81 cm
Force applied: 1500 N



$E_{in} = W = F\Delta d$
$= 1500N \times 3.0\ m$
$= 4500\ J$

$E_{out} = E_g = mgh$
$= 350\ kg \times 9.8\ m/s^2 \times 0.81\ m$
$= 2778.3\ J$

$$efficiency = \frac{E_{out}}{E_{in}} \times 100\%$$

$$efficiency = \frac{2778.3\ J}{4500\ J} \times 100\%$$

$$efficiency = 62\%$$

Where did the 'waste' energy go? *Heating the ramp, moving the air, creating sound, etc...*

Power

Power – the rate of doing work (or transforming energy).

The time it takes to achieve work is a very important variable to consider:

Those processes that can do the same amount of work in less time are considered more "powerful".

Those processes that can do the more work in the same amount of time are considered also more "powerful".

$$Power\ (P) = \frac{W}{\Delta t}$$

Units: 1 Joule/second = 1 Watt

1 J/s = 1 W

Horsepower (h.p.) - the power of one horse (apparently). 1 h.p. = 746 W