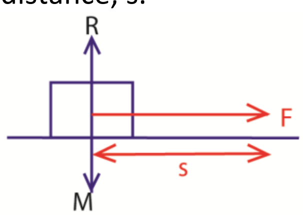
SENIOR FIVE TERM 1

TOPIC 5/6: WORK, ENERGY AND POWER

Competency: The learner investigates the resources and transformations of energy in the environment in order to ensure sustainable and improved efficiency of energy utilisation.

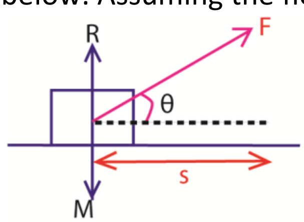
Work, power, energy

Work is the product of force and distance moved. This distance must be in the direction of the force. Consider a body of mass, M, being pulled on a smooth horizontal table by a force F through a distance, s.



Work done = (F x s) joules

When a body is moved and the force acts at an angle θ to the horizontal as shown below. Assuming the flow is smooth



Work = Fcosθ joules

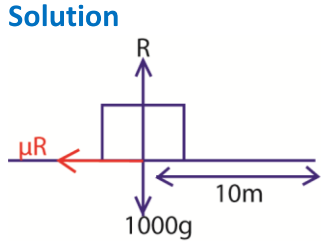
Work is a scalar quantity and its units are joules.

A joule is the work done when a force of 1N moves a distance of 1m in the direction of force from the point of application of force.

Example 1

A car of mass 1000kg moving on a rough horizontal surface is brought to rest in a distance of 10m by steady application of brakes. If the coefficient of sliding frictional force between the surface and the tyres is 0.4, calculate the work done by the frictional force.

Solution



Work done = f x s

But f = μR

R = 1000 x g
f = 0.4 x 1000 x 9.81 = 3934N
w = 3934 x 10 = 39,240J

Energy

This is the ability to do work. The S.I units of energy are joule. There are various forms of energy which include the following

- Mechanical energy
- Light energy
- Chemical energy
- Heat energy
- Tidal energy
- Magnetic energy

Mechanical energy

This type of energy is divided into two forms potential and kinetic energy.

Kinetic energy

This is the energy possessed by a body by virtue of its motion.

Suppose a constant force F, acts on the body of mass m, which is initially at rest on a smooth horizontal surface and moves distance, s.

But F =ma

But $v^2=u^2+ 2as$

as = $\frac{v^2-u^2}{2}$

work = mas = m$\frac{v^2-u^2}{2}$

if u = 0 (initially at rest)

Work done = $\frac{1}{2}mv^2$

The quantity ½ mv^2 is called kinetic energy of the body of mass **m** moving with velocity **v** with zero initial velocity.

For a body with initial velocity u.

Work done = m$\frac{v^2-u^2}{2}$

The above expression is called the work energy theorem which states that the work done by an external force is equal to the change in kinetic energy of the body.

Potential energy

This is the energy possessed by a body by virtue of its position.

Potential energy is divided into

Gravitation potential energy

This is the energy possessed by a body by virtue of its position in the gravitational field.

Consider a body of mass m raised from the ground at a position which is at a height, h, above the ground.

Work done against gravity = mgh and this gives the expression for gravitation potential energy.

Elastic potential energy

This is the energy possessed by a body when stretched or compressed.

Consider a material with elastic constant, k, which is stretched or compressed by amount, x.

Elastic potential energy = $\frac{1}{2}kx^2$

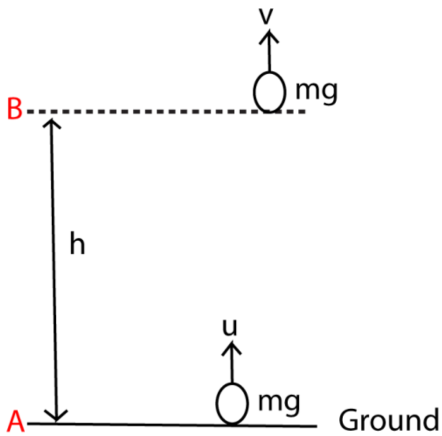
Principle of conservation of mechanical energy

In any mechanical system, mechanical energy is conserved provided there is no dissipative force acting on the system

Dissipative forces are forces whereby work done against them cannot be recovered e.g. frictional force, air resistance, and viscous drag.

Proof of the principle of conservation of mechanical energy

Suppose, a body of mass, m, is projected vertically upwards with a speed, u, from the ground up to a height, h, and at that point the velocity of the body is v.



Solution

At A, potential energy = mg(0) = 0

Kinetic energy = $\frac{1}{2}mv^2$

Total mechanical energy

= Kinetic energy + potential energy

= $\frac{1}{2}mv^2$ + 0

= $\frac{1}{2}mv^2$ ……………………………………………..(i)

At B, potential energy = mgh

If the velocity at B is v

From $v^2 = u^2 + 2as$

$v^2 = u^2 - 2gh$

Kinetic energy = $\frac{1}{2}mv^2$

= $\frac{1}{2}m(u^2 - 2gh)$

Total mechanical energy

= mgh + $\frac{1}{2}m(u^2 - 2gh)$

= $\frac{1}{2}mv^2$ …………………… (ii)

From (i) and (ii), the mechanical energy at A is equal to mechanical energy at B, hence mechanical energy is conserved

Principle of conservation of energy

It state that energy can be changed from one form to another but is neither created nor destroyed.

Conservative force

This is one for which work done to the body from one point to another is independent of the path taken and only depends on initial and final positions of the body.

The work done to move a body round a closed path is zero and mechanical energy is conserved.

Examples include: gravitational force, electrostatic force, and elastic force.

Non conservative forces

This is one for which the work is done against such force moving the path taken

Work done to move a body around a closed path is not zero; mechanical energy is not conserved example include viscous drag, friction force, air resistance, etc.

Work done against gravity and friction

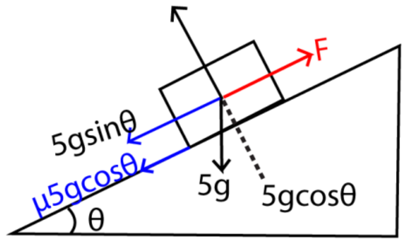
When a block is pulled at a uniform speed up the surface of a rough incline plane, work is done both against gravity and against the frictional force which is acting on the body due to the contact with the rough surface of the plane.

Example 2

A rough surface is inclined at $\tan^{-1}(\frac{7}{24})$ to the horizontal, a body of mass 5kg on the surface and is pulled at uniform speed, a distance of 75cm up the surface by a force acting along a line of greatest slope. The coefficient of friction between the body and the surface is $\frac{5}{12}$. Find

(a) The work done against gravity
(b) The work done against friction
(c) Total work done

Solution



tan θ $= \frac{7}{24}$, cosθ = $\frac{24}{25}$, sin θ =$\frac{7}{25}$

Work done against gravity

= mgsinθ x d

= 5 x 9.81 x $\frac{7}{25}$ x $\frac{75}{100}$

= 10.3J

Work done against friction

= μR

= $\frac{5}{12}$ x 5 x 9.81 x $\frac{24}{25}$ x $\frac{75}{100}$

= 14.72J

Total work done = (10.3 + 14.72)J

= 25.02J

Power

This is the rate of doing work or the rate of change of energy.

Power = $\frac{work\ done}{time\ taken}$ = $\frac{F\ x\ s}{t}$ = Fv

Thus, power is proportional to velocity

The S.I units of power are Js^{-1} or watts

A watt is the rate of transfer of energy at 1 joule per second.

Example 3

A car of mass 750kg stats from rest to a level road and is uniformly accelerated for 10 second until its speed is $18kmh^{-1}$. If the resistance to motion is 49N, find the power of the car 10 seconds after the start.

Solution

v = $\frac{18\ x\ 1000}{3600} = 3ms^{-1}$

v = u + at

5 = 0 + 10a

a = $0.5ms^{-1}$

ma = F- friction force

750 x 0.5 = F – 49

F = 424N

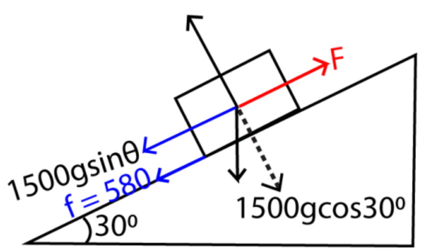
But P = Fv = 5 x 424 = 2120 watts

Example 4

A truck of mass 1500kg moves with uniform velocity of $5.0ms^{-1}$ up a straight track inclined at an angle 300 to the horizontal. The total frictional resistance to the motion of the truck is 580N. Calculate

(i) The power developed by the engine
(ii) If the engine of the track in (i) above cannot develop a power than 75kW. Calculate the maximum speed attained by the track.

Solution



ma = F – (mgsinθ +f)

since the velocity is uniform, a = 0

T = 1500gsin 30 + 580 = 7637.5N

But P = Fv = 5 x 7637.5 = 39687.5W

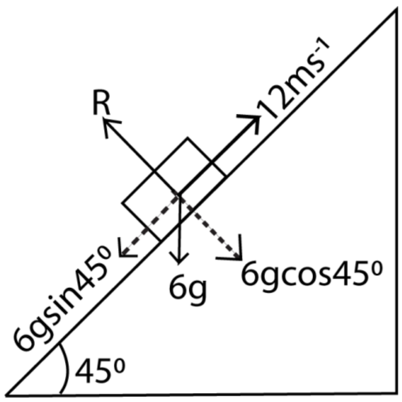
(ii) $P_{max} = Tv_{max}$

$v_{max} = \frac{p_{max}}{T} = \frac{75 \, x \, 10^3}{7637.5} = 9.45 ms^{-1}$

Example 5

A block of mass 6.0kg is projected with v=12ms^{-1} up a rough plane inclined 45^0 to the horizontal. If it travels 5m up the plane. Find the frictional force and the coefficient of friction.

Solution



K.E lost = P.E gained + Work done against friction

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

But sin 45^0 = $\frac{h}{5}$

h = 5sin45^0

⇨ $\frac{1}{2} \, x \, 6 \, x \, 12^2 = 6 \, x \, 9.81 \, x \, 5 \sin 45^0 + f \, x \, 5$

f = 44.8N

But f = μR

μ = $\frac{f}{R}$

$= \frac{44.8}{6 \, x 9.81 \cos 45^0}$

= 1.1

Example 6

A block of mass 3.95kg rests on a smooth horizontal surface. The wooden block is attached to light spring of force constant 100Nm^{-1}, whose other end is fixed. A bullet of mass, 0.02kg is fired into the block embedded itself and the spring is compressed by 0.4m. Find the velocity of the bulled just before it hits the block.

Solution

By conservation of mechanical energy

K.E after collision = elastic potential energy

$$\frac{1}{2}(m_1 + m_2)v^2 = \frac{1}{2}x \, kx^2$$

$$\frac{1}{2}(0.02 + 3.98)v^2 = \frac{1}{2} \, x \, 100 \, x \, (0.4)^2$$

v = 2ms^{-1}

From the principle of conservation of momentum

$m_1u_1 + m_2u_2 = v(m_1 + m_2)$

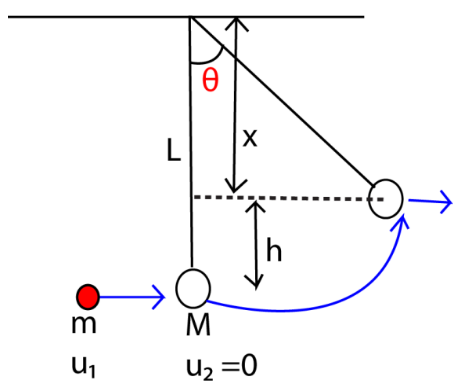
$0.02u_1 + 3.98 \text{ x } 0 = 2(0.02 + 3.98)$

$u_1 = 400ms^{-1}$

therefore the velocity of the bullet before hitting the mass = 400ms^{-1}.

Ballistic pendulum

Consider a bullet of mass, m, travelling with initial velocity, u, being fired horizontally into a stationary block of mass m which is suspended by light vertical string of length, L. If v is the common velocity of the block and bullet just after collision, the following can be noted.



By conservation of momentum

$mu_1 + M \text{ x } 0 = (m+ M)v$

$$u = \frac{(m+M)v}{m}$$

K. E after collision = P.E after collision

$$\frac{1}{2}(m+M)v^2 = (m + M)gh$$

$$v^2 = 2gh \text{ .... (i)}$$

but $\cos\theta = \frac{x}{L}$

$x = L\cos\theta$

and $h = L - L\cos\theta = L(1-\cos\theta)$....................(ii)

substituting h in (i)

$v^2 = 2gl(1- \cos\theta)$

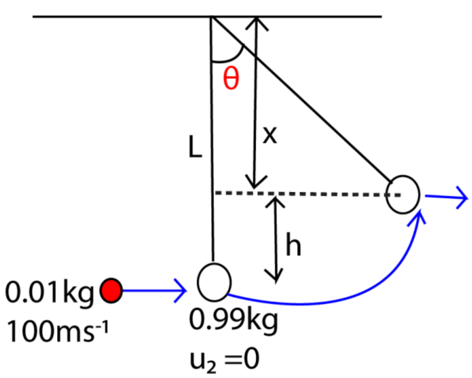
$\cos\theta = 1 - \frac{v^2}{2gL}$

or

$\theta = \cos^{-1}\left[1 - \frac{v^2}{2gL}\right]$

Example 7

A bullet of mass 10g travelling horizontally at 100ms^{-1} embeds itself in a block of mass 990g suspended by a string so that is can swing vertically. Find the height through which the block can rise.



By conservation of momentum

$$mu_1 + Mu_2 = (m+ M)v$$

$$0.01 \times 100 + 0.99 \times 0 = (0.01 + 0.99)v$$

$$v = 1ms^{-1}$$

From $v^2 = 2gh$

$$h = \frac{v^2}{2g}$$

$$= \frac{1}{2 \times 9.81}$$

$$= 0.05m$$

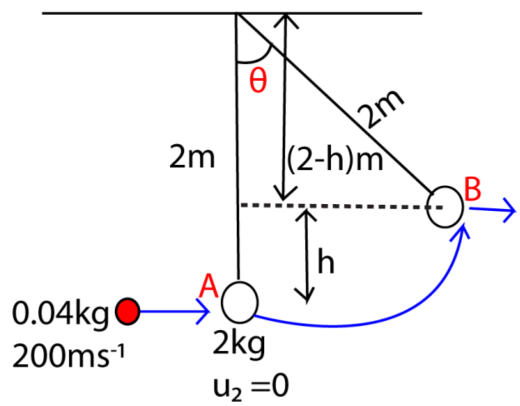
Example 8

(a) distinguish between conservative and non-conservative forces

(b) A bullet of mass 40g is fired from at 200ms^{-1} and hits a block of mass 2kg which is suspended by a light vertical string 2m long. If the bullet gets embedded in the wooded block; calculate

(i) the maximum angle the string makes with the vertical

(ii) State a factor on which the angle of swing depends.



By conservation of momentum

$$mu_1 + Mu_2 = (m+ M)v$$

$$0.04 \times 200 + 2 \times 0 = (0.04 + 2)v$$

$$v = 3.92ms^{-1}$$

From $v^2 = 2gh$

$$h = \frac{v^2}{2g} = \frac{3.92^2}{2 \times 9.81} = 0.784m$$

But, $\cos\theta = \frac{2-h}{2}$

$$\theta = 52.5^0$$

(ii) – speed of the bullet

- Mass of the block
- Length of the string
- Air resistance

The structure and the energy production process of the Sun and its implication to life on Earth

The Sun is a massive sphere of hot gases, structured in distinct layers, and it produces energy through nuclear fusion in its core. This energy sustains life on Earth by providing light, warmth, and driving ecosystems.

Structure of the Sun

The Sun is composed mainly of hydrogen (about 74%) and helium (about 24%), with trace elements. Its structure is divided into several layers:

- **Core**
  - Innermost region, about 25% of the Sun's radius.
  - Temperature reaches **~15 million °C**.
  - Site of **nuclear fusion**, where hydrogen nuclei fuse into helium, releasing enormous energy.
- **Radiative Zone**
  - Surrounds the core.
  - Energy moves outward as radiation (photons).
  - Photons can take thousands to millions of years to escape due to dense plasma.
- **Convective Zone**
  - Outer layer of the Sun's interior.
  - Energy is transported by convection currents—hot plasma rises, cooler plasma sinks.
  - This creates the dynamic surface activity we observe.
- **Photosphere**
  - The visible "surface" of the Sun.
  - Temperature ~5,500 °C.
  - Emits the sunlight we see.
- **Chromosphere & Corona**
  - Outer atmospheric layers.
  - Corona extends millions of kilometers into space, with temperatures reaching millions of degrees.
  - Source of solar wind.

▯ Energy Production Process

- The Sun's energy comes from **nuclear fusion** in the core.
- Specifically, the **proton-proton chain reaction**:
  - Four hydrogen nuclei (protons) fuse to form one helium nucleus.
  - This releases energy in the form of gamma rays, neutrinos, and kinetic energy.
- The released energy gradually travels outward through radiation and convection, eventually escaping as sunlight.

Implications for Life on Earth

- **Light & Heat**: Essential for photosynthesis, climate regulation, and sustaining ecosystems.
- **Solar Energy**: Drives weather patterns, ocean currents, and the water cycle.
- **Habitability**: Earth's position in the "habitable zone" ensures temperatures suitable for liquid water.
- **Renewable Power**: Humans harness solar radiation for electricity and heating.
- **Risks**: Solar storms and radiation can disrupt satellites, communications, and power grids, reminding us of our dependence on the Sun.

In short, the Sun's **layered structure** ensures stability, while its **fusion process** powers life on Earth. Without this constant energy supply, Earth would be a frozen, lifeless rock drifting in space.

Renewable energy

Renewable energy is power derived from natural sources that replenish themselves over time, such as sunlight, wind, water, and geothermal heat.

Types of Renewable Energy

- **Solar Energy**: Captures sunlight using photovoltaic cells to generate electricity.
- **Wind Energy**: Uses turbines to convert wind movement into electrical power.
- **Hydropower**: Harnesses the energy of flowing water, often through dams.
- **Geothermal Energy**: Utilizes heat from beneath the Earth's surface.
- **Biomass Energy**: Converts organic materials like wood, crops, and waste into fuel.

Non-renewable energy comes from sources that **cannot be replenished** within a human lifetime. These resources are finite and will eventually run out, making them less sustainable than renewable alternatives.

Types of Non-Renewable Energy

- **Fossil Fuels**: Includes coal, crude oil, and natural gas, formed over millions of years from decomposed organic matter.
- **Nuclear Fuels**: Uranium and plutonium are used in nuclear reactors to generate electricity.

Operation of solar thermal technologies

Solar thermal technologies work by capturing sunlight and converting it into heat, which is then used directly for heating or indirectly to generate electricity.

How Solar Thermal Technologies Operate

Solar thermal systems rely on three coordinated components: **collectors, heat transfer, and storage**.

- **Solar Collectors**
  - Devices with absorber surfaces that capture solar radiation.
  - They convert short-wave sunlight into long-wave infrared radiation, trapping heat (similar to the greenhouse effect).
  - Types include flat-plate collectors, evacuated tube collectors, and concentrating mirrors.
- **Heat Transfer Fluid**
  - A liquid (often water, oil, or molten salt) circulates through the collector.
  - It absorbs the heat and transports it to where it's needed.
  - In power plants, this fluid drives turbines to generate electricity.
- **Thermal Storage**
  - Heat can be stored in insulated tanks or molten salt reservoirs.
  - This allows energy use even when the Sun isn't shining (e.g., at night or on cloudy days).

Types of Solar Thermal Systems

Solar thermal technologies are categorized by operating temperature:

Type	Temperature Range	Main Uses
Low-temperature (<65 °C)	Domestic hot water, space heating	Homes, swimming pools
Medium-temperature (100–300 °C)	Industrial heating, cooling	Factories, commercial buildings
High-temperature (>500 °C)	Electricity generation	Solar thermal power plants

Applications

- **Electricity Generation**: Concentrated solar power (CSP) plants use mirrors to focus sunlight, heating fluids to drive turbines.
- **Domestic Heating**: Rooftop collectors provide hot water and heating for households.
- **Industrial Use**: Provides process heat for manufacturing, food processing, and desalination.
- **Mechanical Energy**: Can power engines like Stirling engines for specialized applications.

Implications for Sustainability

- **Renewable & Clean**: Reduces reliance on fossil fuels, cutting greenhouse gas emissions.
- **Scalable**: Works for small household systems or large-scale power plants.
- **Energy Security**: Thermal storage ensures stable supply even when sunlight is intermittent

Operation of solar photovoltaic (PV) systems

Solar photovoltaic (PV) systems operate by converting sunlight directly into electricity using semiconductor materials, typically silicon. The electricity produced is managed through inverters, storage, and distribution systems to power homes, businesses, or feed into the grid.

Core Operation of PV Systems

- **Photovoltaic Effect**
  - When sunlight strikes a PV cell, photons excite electrons in the semiconductor material.
  - This creates an electric current as electrons flow through an external circuit.
  - The basic unit is the **solar cell**, grouped into **modules** (panels) and then into **arrays** for larger systems.
- **Direct Current (DC) Output**
  - PV cells generate electricity in the form of **DC power**.
  - Since most appliances and grids use **AC power**, conversion is necessary.
- **Inverter System**
  - A **DC–AC inverter** converts the electricity into usable alternating current.
  - Advanced inverters also manage grid synchronization, safety shutoffs, and efficiency optimization.

Components of a PV System

- **PV Array**: Collection of panels that capture sunlight.
- **Inverter**: Converts DC to AC.
- **Battery Bank (optional)**: Stores excess electricity for use at night or during outages.
- **Charge Controller**: Regulates voltage/current to protect batteries.
- **Monitoring & Control Systems**: Track performance, detect faults, and optimize energy flow.

Types of PV Systems

System Type	Operation	Use Case
Grid-tied	Connected to utility grid; excess power exported	Homes, businesses
Off-grid	Uses batteries; independent of grid	Remote areas, cabins
Hybrid	Combines grid connection with storage	Reliable backup + efficiency

Implications for Energy & Sustainability

- **Clean Energy**: No greenhouse gas emissions during operation.
- **Scalability**: Works for small rooftop setups or large solar farms.
- **Energy Independence**: Reduces reliance on fossil fuels and centralized grids.
- **Economic Benefits**: Lower electricity bills, potential income from selling excess power.
- **Challenges**: Efficiency depends on sunlight availability; requires land/space for large installations.

Thank you
Dr. Bbosa Science