SLO 6: Work, Energy and Power

6.1 Work

6.1.1 Define Work And State Its SI Unit

Definition:
The amount of work is the product of magnitude of force and the distance covered in the direction of force.

Units of Work:
The S.I unit of work is Joule other units of work. One joule work is done when a force of 1 Newton acting on a body moves it through a distance of 1 meter in its own direction.

1 Joule = 1Nm

Formula:
Suppose a constant force "F" acts on a body and motion takes place in a straight line in the direction of force then work done is equal to the product of magnitude of force "F" and the distance "d" through which the body moves.

$$W = Fd\cos\theta$$

The force "F" however may not act in the direction of motion of the body instead it makes some angle "θ" with it. In that case, we define the work done by the force as *the product of the component of the force along the line of motion and the distance "d" the body moves along that line*.

DIRECTION	ANGLE	WORK	FORMULA
Parallel	0	Positive	$W = Fd$
Perpendicular	90	Zero	$W = 0$
Opposite	180	Negative	$W = -Fd$

6.1.2 Solve Word Problems Related To Work Done

Practice questions available on worksheet.

6.2 Forms of Energy

6.2.1 define energy with its SI unit

Energy is defined as "the ability of a body to do work".

S.I unit of energy is joule (J). When 1 joule work is done on a body, the amount of energy spent is one joule.

6.2.2 Describe Forms Of Energy

Kinetic Energy:
The energy that a body possesses by virtue of its motion is called kinetic energy. $K.E = \frac{1}{2}mv^2$

Potential Energy:
The energy that a body possesses by virtue of its position, shape or state of a system.

Gravitational Potential Energy:
Gravitational energy is the energy a body has due to its height above the ground.

$$GPE = mg\Delta h$$

Chemical Potential Energy:
Chemical energy is the energy stored in the bonds of chemical substances.

elastic (strain) Potential Energy:
The energy stored in a stretched or compressed object of matter is called elastic potential energy.

Nuclear Energy:
Nuclear energy is the energy stored in the nucleus of an atom. It is released during nuclear fission or fusion.

electrostatic Potential Energy:
Electrostatic energy is the energy stored due to the position of electric charges.

internal (thermal) Energy:
Internal energy is the total energy of all the molecules in a body due to their motion (kinetic) and positions (potential).

6.3 Kinetic Energy and Potential Energy

6.3.1 Compare Kinetic Energy (K.E) And Potential Energy (P.E)

Feature	Kinetic Energy (K.E)	Potential Energy (P.E)
Definition	Energy possessed by a body due to its motion	Energy possessed by a body due to its position or condition
Formula	$KE = \frac{1}{2}mv^2$	$PE = mgh$
Depends On	Mass and velocity of the object	Mass, height, and gravity
Type of motion	Associated with moving objects	Associated with resting or elevated objects
Examples	- Moving car - Falling ball	- Water stored in a tank - Stretched bow
Can be zero?	Yes, if the object is at rest (v = 0)	Yes, if the object is at ground level (h = 0)
Conversion	Can convert into P.E (e.g. when a ball goes up)	Can convert into K.E (e.g. when a ball falls down)

6.3.2 Derive The Formulae Of Kinetic Energy

Suppose a body of mass *m* is moving with some velocity *v*. An opposing force *F* acting on the body through a displacement *d* brings it to rest. Then, the work done by force to bring the object to rest will be equal to the kinetic energy of moving body. Why? Because according to Newton's third law, if the object is moving due to some force, then an equal but opposite force must act on it to stop its motion. Therefore,

$$Kinetic\ Enegry = Work\ Done = F \times d$$

By Newton's second law, $F = ma$; and $a = \frac{v}{t}$

$$F = m\left(\frac{v}{t}\right)$$

$$KE = m\left(\frac{v}{t}\right)d$$

By using relationship of velocity, $v_{avg} = \frac{d}{t}$

$$d = v_{avg} \times t$$

$$KE = m\left(\frac{v}{t}\right)\left(v_{avg} \times t\right)$$

Now, lets calculate the average velocity of body.

$$Initial\ velocity = v$$

$$Final\ velocity = 0$$

$$Average\ velocity = \frac{v+0}{2} = \frac{v}{2}$$

Therefore,

$$KE = m\left(\frac{v}{t}\right)\left(\frac{v}{2} \times t\right)$$

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

6.3.2 Derive The Formulae Of Potential Energy

A ball of mass m is lifted from ground upwards to some height h with uniform velocity v. The force required to lift the ball would be equal but opposite to its weight (by Newton's third law).

We know that, $work\ done = Fd = wh$

This work done will be stored in ball in the form of potential energy. Thus, $PE = work\ done = wh$

We know that $w = mg$ Therefore, $PE = mgh$

6.4 Conversion of Energy

6.4.1 State Law Of Conservation Of Energy

Energy neither be created nor it can be destroyed but it can be converted from one form to other form. This is called law of conservation of energy.

6.4.2 Describe The Processes That Convert Energy From One Form To Another

Biomass Power Generation

It is that energy which is obtained from the biomass. Biomass consists of organic materials such as plants, waste foods, animal dung, sewage, etc. Sewage is that dirt which is left over after staining dirty water. The material can itself be used as fuel or can be converted into other types of fuels. Direct combustion is a method in which biomass, commonly known as solid waste, is burnt to boil water and produce steam. The steam can be used to generate electricity.

In another process, the rotting of biomass in a closed tank called a 'digester' produces methane rich biogas. In this process, micro-organisms break down biomass material in the absence of oxygen, Biogas produced in the tank is piped out and can be used for heating and cooking like natural gas. Biofuel such as ethanol (alcohol) can also be obtained from the biomass. It is a replacement of petrol. In this case, bacteria convert it into ethanol.

Car Engines

Fossil fuel energy is formed from decayed plants and animals that have been converted to crud oil, coal, natural gases or heavy oils by exposure to heat and pressure in the Earth's crust over hundreds of millions of years. Fossils fuels have stored chemical energy. This energy is converted by oxidation through burning.

Fossil fuels such as petrol or diesel contain chemical energy. This energy is stored in the chemical bonds of the fuel. In the engine's combustion chamber, fuel burns (combustion) and releases heat energy. This increases the temperature and pressure inside the engine. The hot gases push the pistons, which move and turn the crankshaft. This converts heat into mechanical energy that powers the wheels i.e. the car moves. Some mechanical energy runs the alternator, which converts motion into electrical energy to power lights, radio, and battery charging, etc.

Geothermal Power

Geothermal energy is stored in the Earth as its natural heat. Deep in the Earth, there is hot molten part called magma. Water close to magma changes to steam due to high temperature. This thermal energy is conducted to the surface of Earth. This energy is called geothermal energy.

A geothermal power plant utilizes geothermal energy to drive an electrical generator. Geothermal well can be built by drilling deep near hot rocks at different places, where hot molten or magma is very close, water is then pushed down into the well. The rocks quickly heat the water and change it into steam. The steam is used for heating purpose or to generate electricity.

Hydroelectric Generation

Hydro electricity is the term referring to electricity generated by hydro power by using gravitational force of falling or flowing water. Most common type of hydro electric power plants uses a dam on a river to store water in a reservoir. Water releases from the reservoir flows through a turbine, spinning it, which in turn runs a generator to produce electricity.

Nuclear Reactors

The energy released during a nuclear reaction such as fission or fusion reaction. All radioactive materials store nuclear energy. For example, Uranium, Radium etc. It is released from the nucleus in the form of radiation in addition to heat and light. A nuclear power plant utilizes nuclear energy to produce steam to turn a turbine and generate electricity.

Solar Power Panels

The energy radiated from the sun is known as solar energy. This is the most available source of energy throughout Pakistan. There are many devices which are capable of absorbing solar energy, which is then converted into electrical energy or heat energy. These devices may be photovoltaic solar panels and solar cells. Which convert the sun rays into electricity for different uses. Also, solar heaters are used to convert solar energy “sun rays” into heat energy to heat water tanks and indoor spaces.

Wind Turbine

The energy obtained by the wind is called wind energy. It is generated by wind mills. A wind mill consists of a turbine which rotates due to wind. Kinetic energy is produced due to the motion of turbine. Wind turbines convert this kinetic energy into the mechanical power. A generator converts that mechanical power into electricity.

6.4.3 Discuss That Perpetual Machines Do Not Work

Perpetual motion machines do not work because they go against the laws of physics, especially the law of conservation of energy and the presence of friction and resistance. A perpetual motion machine is a hypothetical machine that:

1. Keeps moving forever once started.
2. Produces more energy than it consumes.
3. Never needs fuel or input

It violates the Law of Conservation of Energy:
Energy cannot be created or destroyed. A perpetual machine claims to produce energy without any input, which is impossible.

Friction and Air Resistance Are Real:
In real life, friction in parts and air resistance always slow things down. Over time, the machine will lose energy and stop.

No Machine is 100% Efficient:
Every machine loses some energy as heat, sound, or vibration. So, output is always less than input, making perpetual motion impossible.

6.4.4 List The Environmental Issues Associated With Power Generation

Power generation is necessary, but it must be environment-friendly. Using renewable sources (like solar, wind, and hydro) helps reduce these problems. Power generation, especially from non-renewable sources, can harm the environment in many ways. Here are the main issues:

1. Air Pollution
Burning fossil fuels (like coal, oil, and gas) releases harmful gases such as Carbon dioxide (CO_2) – causes global warming, Sulphur dioxide (SO_2) – causes acid rain, Nitrogen oxides (NOx) – causes smog and respiratory issues

2. Global Warming / Climate Change
Power plants release greenhouse gases (especially CO_2), which trap heat in the atmosphere. This leads to climate change, melting ice caps, sea level rise, and extreme weather.

3. Water Pollution
Some power stations discharge hot water into rivers/lakes and harms aquatic life (thermal pollution). Accidental oil or chemical leaks can contaminate water bodies.

4. Land Degradation
Mining for coal or uranium damages land, removes vegetation, and creates waste heaps. Construction of power plants and dams can destroy habitats and farmland.

5. Deforestation
Trees are sometimes cut down to build power plants or lay transmission lines, reducing biodiversity.

6. Radioactive Waste (from nuclear plants)
Nuclear power produces radioactive waste, which is dangerous and must be stored safely for thousands of years.

7. Noise Pollution
Power plants and generators can produce loud noise, disturbing nearby communities and animals.

6.4.5 Differentiate Between Non-Renewable And Renewable Energy Sources

Aspect	Renewable Energy Sources	Non-Renewable Energy Sources
Definition	Sources that replenish naturally at a rate faster than or equal to their consumption	Sources that exist in finite quantities and cannot be replenished
Depletion	Do not deplete over time	Will eventually run out / deplete
Main examples	Solar, Wind, Hydropower, Biomass, tidal	Coal, Crude oil, Natural gas, Nuclear
Environmental impact	Low carbon emissions and pollution	High greenhouse gas emissions, air pollution, acid rain, oil spills
CO_2 emissions	Very low to zero during operation	High (main cause of climate change)
Reliability	Depends on weather	More consistent and dispatchable
Sustainability	Highly sustainable	Not sustainable long-term

6.4.6 Describe Advantages And Disadvantages Of Methods Of Power Generation

Method	Advantages	Disadvantages
Coal	- Very reliable baseload power - Abundant reserves in many countries - Established infrastructure - low fuel cost	- Highest CO_2 emissions - Severe air pollution - High water use & mining damage - Declining due to regulations & competition
Natural Gas	- Lowest emissions among fossil fuels - Relatively quick to build - Cheaper & cleaner than coal	- Still significant CO_2 & methane leaks - Price volatility (tied to global markets) - Environmental concerns in extraction
Nuclear	- Extremely low CO_2 emissions - Very high capacity factor - Excellent baseload - High energy density	- High upfront capital cost & long build time - Nuclear waste management - Public fear & strict regulation - Rare but severe accident risk
Solar	- Very low operating cost - Rapidly falling prices - No emissions during operation	- Daylight only and weather dependent - Needs storage or backup for 24/7 supply - Large land use for utility-scale
Wind	- Very low operating cost - Cheapest source in windy regions - Low emissions - Mature & scalable technology	- Intermittent & location-dependent - Visual & noise impact - Bird/bat collision risk - Requires large land areas
Hydropower	- Very reliable & dispatchable - Low operating cost - Long lifespan (50–100 years) - Flood control & water storage	- High upfront cost & long build time - Major ecosystem & community displacement - Methane emissions from reservoirs - Vulnerable to drought/climate change
Geothermal	- True baseload (24/7) - Very low emissions - Small land footprint - Long lifespan	- Limited to specific geological locations - High upfront exploration - Drilling risk and very costly - Can cause induced seismicity in some cases
Biomass	- Can be dispatchable - Uses waste materials - Carbon neutral in theory	- Can compete with food production - Air pollution if poorly controlled - Lower efficiency & higher cost

6.5 Efficiency

6.5.1 Define The Efficiency Of A Working System

The ratio of useful output energy and the total input energy is called the efficiency of a working system.

6.5.2 Calculate The Efficiency Of An Energy Conversion System

$$Efficiency = \frac{Useful\ output\ energy}{Total\ input\ inergy}$$

$$Efficiency\ (\%) = \frac{energy\ converted\ into\ the\ required\ form}{total\ energy\ input} \times 100$$

6.5.3 Explain That A System Cannot Have An Efficiency Of 100%

The energy output is always less than the energy input. During any conversion of energy, some energy is wasted in the form of heat. No device has yet been invented that may convert all the input energy into required output. That is why a system cannot have an efficiency of 100%. As the energy losses are inevitable in the working of a machine, hence, an ideal or perpetual machine cannot be constructed.

In any real mechanical system, some energy is always lost as heat due to friction between moving parts and air resistance etc. Thus, making it impossible for a machine to keep moving without an external source of energy. In fact, it is a consequence of the principle of conservation of energy that a perpetual energy machine is not workable.

6.6 Power

6.6.1 Define Power

Power is defined as time rate of doing work.

$$Power = \frac{Work\ Done}{Time\ Taken}$$

$$P = \frac{W}{t}$$

Since both work and time are scalar quantities, so power is also a scalar quantity. The SI unit of powers is watt (W). One watt is the work done at the rate of one joule per second.

$$1\mathbf{W} = \frac{1\mathbf{J}}{1\mathbf{s}}$$

Bigger Units of power are:

$$1\mathbf{kW} = 10^3\mathbf{W}$$

$$1\mathbf{MW} = 10^6\mathbf{W}$$

In British engineering system, the unit of power used is horse-power (hp). The horse power is defined as:

$$1\mathbf{hp} = 746\mathbf{W}$$

6.6.2 Solve Word Problems Related To The Concept Of Power

Worksheets available.