1. Details of Module and its structure

Module Detail	
Subject Name	Physics
Course Name	Physics 01 (Physics Part-1, Class XI)
Module Name/Title	Unit 4, Module 2, Kinetic energy of moving bodies Chapter 6, Work, Energy and Power
Module Id	Keph_10602_eContent
Pre-requisites	Kinematics, laws of motion, basic vector algebra
Objectives	After going through this module, the learners will be able to • Know the different forms of energy • Understand- moving bodies possess kinetic energies • Relate Work and energy • Derive work energy theorem • Apply work energy theorem for problem solving • Define mechanical power
Keywords	Kinetic energy ,work energy theorem, power, mechanical energy,

2. Development Team

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1. UNIT SYLLABUS

UNIT IV: WORK ENERGY AND POWER

Work done by a constant force and a variable force; kinetic energy; work energy theorem; power; Notion of potential energy; potential energy of a spring conservative and non-conservative forces; conservation of mechanical energy (kinetic and potential energies) non-conservative forces ; motion in a vertical circle; Elastic and inelastic collisions in one and two dimensions.

2. MODULE-WISE DISTRIBUTION OF UNIT SYLLABUS 7 Modules

The above unit is divided into 7 modules for better understanding.

Module 1	• Meaning of work in the physical sense • Constant force over variable displacement • variable force for constant displacement • Calculating work • Unit of work • Dot product • Numerical
Module 2	• Different forms of energy • Kinetic energy • Work energy theorem • Power
Module 3	• Potential energy • Potential energy due to position • Conservative and non-conservative forces • Calculation of potential energy
Module 4	• Potential energy • Elastic Potential energy • Springs • Spring constant • problems
Module 5	• Motion in a vertical circle • Applications of work energy theorem • Solving problems using work power energy
Module 6	• Collisions • Idealism in Collision in one dimension • Elastic and inelastic collision • Derivation
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MODULE

3. WORDS YOU MUST KNOW

Let us remember the following concepts we will be using in our study of this physics course.

- Rigid body: An object for which individual particles continue to be at the same separation over a period of time.
- Point object: **Point object** is an expression used in kinematics: it is an **object** whose dimensions are ignored or neglected while considering its motion.
- Distance travelled: change in position of an object is measured as the distance the object moves from its starting position to its final position. Its SI unit is m and it can be zero or positive.
- Displacement: a **displacement** is a vector whose length is the shortest distance from the initial to the final position of an object undergoing motion. . Its SI unit is m and it can be zero, positive or negative.
- Speed: Rate of change of position .Its SI unit is ms^{-1}.
- Average speed: $\frac{\text{total path length travelled by the object}}{\text{total time interval for the motion}}$

  Its SI unit is ms^{-1}.

- Velocity (v): Rate of change of position in a particular direction.
  Its SI unit is ms^{-1}.

- Instantaneous velocity: velocity at any instant of time.

$$v_{instaneous} = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t}$$

Instantaneous velocity is the **velocity** of an object in motion at a specific time. This is determined by considering the time interval for displacement as small as possible .the instantaneous velocity itself may be any value .If an object has a constant **velocity** over a period of time, its average and **instantaneous velocities** will be the same.

- Uniform motion: a body is said to be in uniform motion if it covers equal distance in equal intervals of time

- Non uniform motion: a body is said to be in non- uniform motion if it covers unequal distance in equal intervals of time or if it covers equal distances in unequal intervals of time

- Acceleration (a): time rate of change of velocity and its SI unit is ms^{-2}. Velocity may change due to change in its magnitude or change in its direction or change in both magnitude and direction.

- Constant acceleration: Acceleration which remains constant throughout a considered motion of an object

- Momentum (p): The impact capacity of a moving body. It depends on both mass of the body and its velocity. Given as p = mv and its unit is kg ms^{-1}.
- Force (F): Something that changes the state of rest or uniform motion of a body. SI Unit of force is Newton (N). It is a vector, because it has both magnitude ,which tells us the strength or magnitude of the force and direction. Force can change the shape of the body.

- Constant force: A force for which both magnitude and direction remain the same with passage of time

- Variable force: A force for which either magnitude or direction or both change with passage of time

- External unbalanced force: A single force or a resultant of many forces that act externally on an object.
- Dimensional formula: An expression which shows how and in which way the fundamental quantities like, mass (M), length (L) and time (T) are connected
- Kinematics: Study of motion of objects without involving the cause of motion.
- Dynamics: Study of motion of objects along with the cause of motion.
- Vector: A physical quantity that has both magnitude and direction .displacement, force, acceleration are examples of vectors.
- Vector algebra: Mathematical rules of adding, subtracting and multiplying vectors.
- Resolution of vectors: The process of splitting a vector into various parts or components. These parts of a vector may act in different directions. A vector can be resolved in three mutually perpendicular directions. Together they produce the same effect as the original vector.
- Dot product: If the product of two vectors (A and B) is a scalar quantity. Dot product of vector A and B: A.B= $|A||B|cos\theta$ where θ is the angle between the two vectors

  Since Dot product is a scalar quantity it has no direction. It can also be taken as the product of magnitude of A and the component of B along A or product of B and component of A along B.

- Work: Work is said to be done by an external force acting on a body if it produces displacement W= F.S cosθ, where work is the dot product of vector F(force) and Vector S (displacement) and θ is the angle between them . Its unit is joule and dimensional formula is ML^2T^{-2}. It can also be stated as the product of component of the force in the direction of displacement and the magnitude of displacement. Work can be done by constant or variable force and work can be zero, positive or negative.
- Energy: The ability of a body to do work.

4. INTRODUCTION

Looking at the pictures we get the sense of energy and motion.

We are familiar with statements like **'The cheetah runs energetically', 'the water falls with a lot of energy'.**

In both cases work is also being done, we relate energy by saying it is the ability to do work. It is also true for **mechanical work.**

In the previous module we learnt about the physical meaning of work, where a force actually displaced a body from its initial position.

Work and energy are two closely related terms. Energy is a measure of the total amount of work that can be done by a given body. It is like a currency for performing work. If a person needs to do 200 joules of work, it means that he has to spend 200 joules of energy. Alternatively, work can also be understood in terms of the amount of energy transferred from one body to the other by means of a force. For example a work of 10 J by object A on object B refers to a loss of 10 J of energy by object A and a gain of the same amount of energy by object B.

The S.I. unit of energy is, therefore, the same as that of work *i.e.* joule (J).

Let us now consider the example of a cricketer swinging his bat and hitting a ball which was bowled towards him. Here, the energy first gets transferred from the player to the bat as he swings his bat in the air to hit the ball hard..

The bat then passes this energy to the ball. It does so by applying a force on the ball that makes the moving ball change in its velocity which means changes its direction and speed.
It is important to note that the word "transfer" here can be misleading. It does not mean the flow of any material thing.
It is more like the electronic transfer of money between two bank accounts. The 'number' in one account, goes up and in the other goes down without any actual money passing between the two accounts.

We will study the types of mechanical energy and relation between mechanical work and mechanical energy.

5. DIFFERENT FORMS OF ENERGY

We have learnt about energy in our earlier classes.

All living things need energy, energy makes things grow, keeps us warm there are different forms of energy

Here is a list of different forms of Energy:

i. Mechanical Energy
ii. Internal energy
iii. Heat Energy
iv. Chemical Energy
v. Electrical Energy
vi. Nuclear Energy
vii. Light energy
viii. Sound energy
……etc

i) Mechanical Energy

the energy linked to mechanical work is called mechanical energy

The total sum of kinetic and potential energies is called mechanical energy. Kinetic energy is due to motion of a body while potential energy is due to position or configuration.

ii. Internal Energy

The molecules of a body possess kinetic energy due to their motion and potential energy due to their attractions and repulsions. The sum of these energies is called internal energy.

iii. **Heat or Thermal Energy**

A body possesses heat energy due to the random motion of its molecules. This energy ids indicated by the temperature of the body

iv. **Chemical Energy**

A stable chemical compound has less energy than its constituent atoms, the difference being in the arrangement and motion of electrons in the compound. This difference in energy is called Chemical energy.

v. Electrical Energy

Electric charges exert forces of attraction and repulsion. Work has to be done to move charges with respect to one another. This work is called electrical energy.

vi. Nuclear Energy

Neutrons and protons attract each other very strongly at distance of order of 10^{-15} m and bind together to form nuclei. The associated energy is called nuclear energy.

ix. **Light Energy** the energy which allows us to see our environment is called light energy

6. LAW OF CONSERVATION OF ENERGY

In our day to day life, we observe many phenomena in which ‘energy’ changes from one form to another. Energy may be transformed from one form to another but the total energy of an isolated system always remains constant. **Energy can neither be created nor be destroyed**, **it can change from one form to another**

This is the **law of conservation of energy**.

No violation of this law has been observed so far. And the law is regarded as a fundamental law governing all natural phenomena.

You might have wondered why?

All the fuss about energy conservation if, "energy can never be created or destroyed"

Well, we need certain type of energy and it is this form that we may like to conserve, like electrical energy, or petrol for chemical energy to make things move and work.

Energy exists in many forms.

However, we would be focusing mainly on 'mechanical energy 'and 'mechanical work' in this unit.

Mechanical Energy

Mechanical energy is the energy possessed by an object due to its motion (kinetic energy) or due to its position or configuration (potential energy) or both. The total mechanical energy of a system is defined as the sum of its kinetic and potential energies.

A moving cyclist, a cricket ball hit by a batsman in a cricket match, a bird perched on a branch of a tree, etc., all possess mechanical energy.

Kinetic Energy

- **A stone thrown at a glass window pane has the capacity to smash it into pieces.**
- **A hammer when struck on the head of a nail can fix it into a wooden plank or a wall.**
- **Running water can rotate the blades of a turbine at a hydro-electric power station**
- **An object, hit by a fast moving car, can get damaged very badly.**

All the objects in the examples mentioned above have the ability to do some sort of work on other objects which they come in contact with, because **they possess (the so called) energy of motion or kinetic energy.**

Kinetic energy is the energy possessed by an object by virtue of its motion.

Potential energy

The word 'potential' here suggests possibility or capacity for action. The term potential energy brings to one's mind 'stored' energy. A stretched bow-string possesses potential energy. When it is released, the arrow flies off at a great speed, similar to a stone thrown using a slingshot or 'gulel'

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7. NOTION OF WORK AND KINETIC ENERGY: THE WORK-ENERGY THEOREM

In the previous units on kinematics and dynamics, we have learnt equations of motion and laws of motion. Equations of motion of an object for constant acceleration are given as:

$$\mathbf{v = u + at}$$

$$\mathbf{s = ut + \frac{1}{2}at^2}$$

$$\mathbf{v^2 = u^2 + 2as}$$

Here, we say that acceleration is constant, produced by a constant force. But , the force is changing the velocity of the body. If the mass of the body is m, the force using Newton's second law will be given by:

F = m a

Work, as we have learnt in module 1, given as

W = F S

Now let us consider the body to start from rest: so u = 0

Using the third equation of motion, we have

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

$$v^2 = 2as$$

$$\mathbf{\frac{1}{2}v^2 = as}$$

The right hand side when multiplied by m will give us the work done by force, F = m a

So to keep the equality, we multiply both sides by m:

$$\mathbf{\frac{1}{2}m\,v^2 = FS}$$

Also in general, if we say the initial velocity is some value u, then

$$\mathbf{\frac{1}{2}mv^2 - \frac{1}{2}mu^2 = m\,a\,s = F\,s}$$

The above equation provides a motivation for the relating work and kinetic energy. The left side of the equation is the difference in the quantity 'half the mass times the square of the speed' from its initial value to its final value. We call each of these quantities the 'kinetic energy', denoted by K. The right side is a product of the displacement and the component of the force along the displacement. This quantity is called 'work' and is denoted by W.
So we can say:

$$\mathbf{K_f - K_i = W}$$

Where, K_i and K_f are respectively the initial and final kinetic energies of the object.

Work refers to the relation between force and the displacement over which it acts.

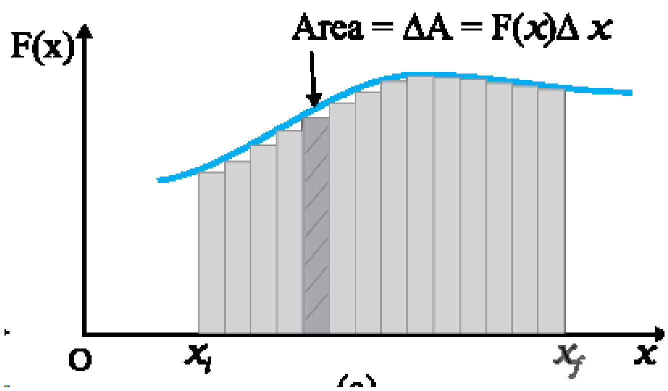
The relation between work and energy is called work- energy theorem.
This also explains the reason for units of energy and work to be the same.

Unit of kinetic energy is also joule denoted by J the dimensional formula is:
ML^2T^{-2}.

The change in kinetic energy of a particle is equal to the work done on it by a net force. And this work is done by a force on the body over a certain displacement.

1. WORK ENERGY THEOREM FOR WORK DONE BY A VARIABLE FORCE

A constant force is not commonly encountered in everyday life. It is the variable force, which is more commonly observed. The graph showing a **plot of a variable force versus displacement** in one dimension has been done in module 1..



Plot of a variable force versus displacement in one dimension

If the displacement Δx is small, we can take the force F(x) as approximately constant and the work done is then:

$\Delta W = F(x)\,\Delta x$

This represents area of one thin rectangle. Adding successive rectangular areas, we get the total area which in turn gives the total work done by the variable force:

Total Work done is given by

$$W \cong \sum_{x_i}^{x_f} F(x)\Delta x$$

Where, the summation is from the initial position x_i to the final position x_f. If the displacements are allowed to approach zero($\lim \Delta x \to 0$), then the number of terms in the sum increases without limit, but the sum approaches a definite value equal to the area under the curve. Then the work done is:

$$= \int_{x_i}^{x_f} \mathbf{F(x)dx}$$

We are now familiar with the concepts of work and kinetic energy to prove the work-energy theorem for a variable force. **We confine ourselves to one dimension**. The time rate of change of kinetic energy is:

$$\frac{dK}{dt} = \frac{d}{dt}\left(\frac{1}{2}mv^2\right)$$

$$= m\frac{dv}{dt}v = Fv \text{ (From Newton's Second law)}$$

$$= F\,\frac{dx}{dt}$$

$$K_f - K_i = \int_{x_i}^{x_f} F dx$$

Where, K_i and K_f are the initial and final kinetic energies corresponding to x_i and x_f.

Thus, the **Work Energy theorem is proved for a variable force.**

You may like to know

- **While the Work Energy theorem is useful in a variety of problems, it does not, in general, incorporate the complete dynamical information of Newton's second law. It is an integral form of Newton's second law.**

- **Newton's second law gives a relation between acceleration and force at any instant of time.**
  Work-energy theorem involves an integral over an interval of time. In this sense, the temporal (time) information contained in the statement of Newton's second law is 'integrated over' and is not available explicitly.

- **Another observation is that Newton's second law for two or three dimensions is in vector form whereas the work-energy theorem is in scalar form. In the scalar form, information with respect to directions contained in Newton's second law is not present.**

- **The total mechanical energy of the system is conserved if the forces, doing work on it, are conservative. If some of the forces involved are non-conservative, part of the mechanical energy may get transformed into other forms such as heat, light and sound.**

However, the total energy of an isolated system does not change, as long as one accounts for all forms of energy because though energies may be transformed from one form to another- the total energy of an isolated system remains constant.

- **Energy can neither be created nor destroyed. So, since the universe as a whole may be viewed as an isolated system, the total energy of the universe is constant. If one part of the universe loses energy, another part must gain an equal amount of energy. The principle of conservation of energy cannot be proved.**

The concept of conservation and transformation of energy into various forms links together various branches of physics, chemistry and life sciences. It provides a unifying, enduring element in our scientific pursuits. From engineering point of view all electronic, communication or mechanical devices rely on some forms of energy transformation.

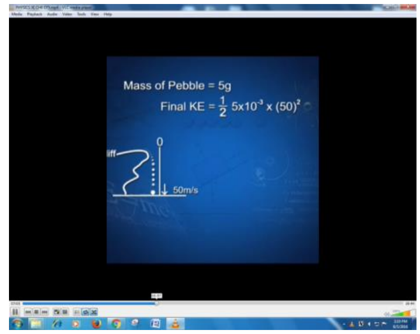
8. APPLICATIONS OF WORK ENERGY THEOREM

The value of work done against resistive forces is difficult to calculate, this can be calculated using the work energy theorem

EXAMPLE:

A small pebble of mass say 5 g is falling off a cliff of vertical height 1 km.
If it strikes the ground at a speed of 50 ms^{-1}, calculate the work done against resistive forces.

SOLUTION:



Let us see calculate is the work done by the resistive forces?

Change in kinetic energy of the pebble

$dK = \frac{1}{2}mv^2 - 0$

$= \frac{1}{2} 5 \times 10^{-3} \times 50 \times 50$

dK = 6.25 J

Here, we have assumed that the pebble is initially at rest on top of the cliff

Work done in moving the pebble through a distance of 1 km by gravity = $mg.s$

$= 5 \times 10^{-3} \times 9.8 \times 10^3$

W = 49J

Hence the work done by resistive forces will be

Change in kinetic energy = net work done = 6.25 J

$6.25 = \text{work done by gravity} + \text{work done by resistive forces}$

$6.25 = 49 + \text{work done by resistive forces}$

Work done by resistive forces= $6.25 - 49 = -42.75$ J, this value would otherwise be difficult to calculate

The resistive forces on a freely falling body are due to air, which are ignored as we consider only gravitational force acting on the falling object

EXAMPLE:

In a ballistics demonstration a police officer fires a bullet of mass 50.0g with a speed 200m/s on soft plywood of thickness 2.00cm. The bullet emerges with only 10 % of its initial kinetic energy. What is the emergent speed of the bullet?

SOLUTION:

The initial kinetic energy of the bullet is $mv^2/2 = 1000$ J.

It has a final kinetic energy of $0.1 \times 1000 = 100$ J.

If v_f is the emergent speed of the bullet,

$$\frac{1}{2} m v_f^{\,2} = 100\ J$$

$$v_f = \sqrt{\frac{2 \times 100\ \text{J}}{0.05\text{kg}}} = 63.2\ \text{m s}^{-1}$$

Notice that the speed is reduced by approximately 68% (not 90%).

2. POWER

Often it is interesting to know not only the work done on an object, but also the rate at which this work is done. We say a person is physically fit if he not only climbs four floors of a building but climbs them fast.

Power is defined as the time rate at which work is done or energy is transferred.

The average power of a force is defined as the ratio of the work, W, to the total time t taken as

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

The instantaneous power is defined as the limiting value of the average power as time interval approaches zero,

The work dW done by a force F for a displacement dr is dW = F.dr. The instantaneous power can also be expressed as:

$$\mathbf{P = F.\frac{dr}{dt} = F.v}$$

Where **v is the instantaneous velocity** and the **force is F.**

Power, like work and energy, is a scalar quantity.

Its dimensions are [ML^2T^{-3}].

Its unit is called a watt (W). One watt is 1 J s^{-1}.

The SI unit of power is named after James Watt, one of the innovators of the steam engine in the eighteenth century.

There is another unit of power, namely the horse-power (hp) in another unit system as

1 hp = 746 W

Sometimes this unit is used to talk about power or the output of automobiles, motorbikes, engines.

Electrical energy is often only called power, say **there is no power**, or power **of the LED bulb is 18 W**

We also encounter the unit 'watt' when we buy electrical goods such as bulbs, heaters and refrigerators. **A 100 watt bulb which is on for 10 hours uses 1 kilowatt hour (kWh) of electrical energy.**

Energy= 100 (watt) × 10 (hour)

= 1000 watt hour

=1 kilowatt hour (or kW h)

= 10^3 (W) × 3600 (s)

Or 1 kW h = 3.6×10^6 J

Our electricity bills carry the energy consumption in units of kW h. Note that kW h is a unit of energy and not of power.

EXAMPLE:

An elevator can carry a maximum load of 1800 kg (elevator + passengers) is moving up with a constant speed of 2 m s^{-1}. The frictional force opposing the motion is 4000 N.

Determine the minimum power delivered by the motor to the elevator in watts as well as in horse power. (g = 10 ms^{-2})

SOLUTION:

The downward force on the elevator is

$F = m\,g + F_f = (1800 \times 10) + 4000 = 22000$ N

The motor must supply enough power to balance this force. Hence,

$P = F.\,v = 22000 \times 2 =$ **44000 W = 59 hp**

3. SUMMARY

In this module you have learnt:

- Definition of energy: Ability to do work
- Mechanical energy ability to do mechanical work.
- The unit of work and energy are the same.
- Relation between work and energy, energy and work done by a body should be related.
- Work energy theorem relates work done and change in mechanical energy given by:

$$\frac{1}{2}mv^2 - \frac{1}{2}mu^2 = m\,a\,s = F\,s$$

- Power: $P = \frac{W}{t} = \frac{FS}{t}$
- Commercial unit of power is watt and Horse power.