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BTU 1113 Physics

Chapter 5: Work and Energy

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Chapter Description

- Aims
  - Identify work done by a constant force.
  - Measure the scalar products of two vectors.
  - Calculate work done by a varying force.
  - Identify kinetic energy, Work-Kinetic energy and potential energy .
  - Understand the conservative and non-conservative forces.
  - Apply work and energy knowledge to measure power.

- Expected Outcomes
  - Students should be able to identify work done by a constant force.
  - Students should be able to measure the scalar products of two vectors.
  - Students should be able to calculate work done by a varying force.
  - Students should be able to identify kinetic energy, Work-Kinetic energy and potential energy.
  - Students should be able to understand the conservative and non-conservative forces.
  - Students should be able to apply work and energy knowledge to measure power.

- References
  - Giancoli, D.C., 2008. Physics for Scientists & Engineers. 4th edition. Prentice Hall, USA.
  - Jones, E., 2002. Contemporary College Physics. 3rd Ed, McGraw-Hill, Singapore.
  - Young, H. D. and Freedman, R. A., 2012. University Physics with Modern Physics. 13th edition, Pearson, San Francisco

1st aim:
Identify work done by a constant force.

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Work Done by a Constant Force

The work done by a constant force is defined as the distance moved multiplied by the component of the force in the direction of displacement:

$$W = Fd \cos \theta$$

In the SI system, the units of work are joules:

$$1 \text{ J} = 1 \text{ N} \cdot \text{m}$$

2nd aim:
Measure the scalar products of two vectors.

Work Done by a Constant Force

Solving work problems:

1. Draw a free-body diagram.

2. Choose a coordinate system.

3. Apply Newton's laws to determine any unknown forces.

4. Find the work done by a specific force.

5. To find the net work, either find the net force and then find the work it does, or find the work done by each force and add.

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Work done by forces that oppose the direction of motion, such as friction, will be negative.

Centripetal forces do no work, as they are always perpendicular to the direction of motion.

3rd aim:
Calculate work done by a varying force.

Work Done by a Varying Force

For a force that varies, the work can be approximated by dividing the distance up into small pieces, finding the work done during each, and adding them up. As the pieces become very narrow, the work done is the area under the force vs. distance curve.

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4th aim:
Identify kinetic energy, Work-Kinetic energy and potential energy.

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Kinetic Energy and the Work-Energy Principle

Energy was traditionally defined as the ability to do work. We now know that not all forces are able to do work; however, we are dealing in these chapters with mechanical energy, which does follow this definition.

- If we write the acceleration in terms of the velocity and the distance, we find that the work done here is $W_{\text{net}} = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$

- We define the kinetic energy:

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

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- This means that the work done is equal to the change in the kinetic energy:

$$W_{net} = \Delta KE = \tfrac{1}{2} m v_2^2 - \tfrac{1}{2} m v_1^2.$$

- If the net work is positive, the kinetic energy increases.

- If the net work is negative, the kinetic energy decreases.

Because work and kinetic energy can be equated, they must have the same units: kinetic energy is measured in joules.

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Potential Energy

An object can have potential energy by virtue of its surroundings.

Familiar examples of potential energy:

- A wound-up spring

- A stretched elastic band

- An object at some height above the ground

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In raising a mass *m* to a height *h*, the work done by the external force is

$$W_{\text{ext}} = F_{\text{ext}} d \cos 0° = mgh$$
$$= mg(y_2 - y_1)$$

We therefore define the gravitational potential energy:

$$PE_G = mgy.$$

Potential Energy → Kinetic Energy

This potential energy can become kinetic energy if the object is dropped.

Potential energy is a property of a system as a whole, not just of the object (because it depends on external forces).

If $PE_G = mgy$, where do we measure y from?

It turns out not to matter, as long as we are consistent about where we choose $y = 0$. Only changes in potential energy can be measured.

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Potential Energy → Kinetic Energy

Potential energy can also be stored in a spring when it is compressed.

The force required to compress or stretch a spring is:

$$F_S = -kx$$

where k is called the spring constant, and needs to be measured for each spring.

The force increases as the spring is stretched or compressed further. We find that the potential energy of the compressed or stretched spring, measured from its equilibrium position, can be written:

$$PE_{el} = \frac{1}{2}kx^2.$$

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5th aim:
Understand the conservative and non-conservative forces.

Conservative and Nonconservative Forces

TABLE 6–1 Conservative and Nonconservative Forces

Conservative Forces	Nonconservative Forces
Gravitational	Friction
Elastic	Air resistance
Electric	Tension in cord
	Motor or rocket propulsion
	Push or pull by a person

If friction is present, the work done depends not only on the starting and ending points, but also on the path taken. Friction is called a nonconservative force.

- Therefore, we distinguish between the work done by conservative forces and the work done by nonconservative forces.

- We find that the work done by nonconservative forces is equal to the total change in kinetic and potential energies:

$$W_{\mathrm{NC}} \; = \; \Delta \mathrm{KE} \; + \; \Delta \mathrm{PE}$$

Mechanical Energy and Its Conservation

If there are no nonconservative forces, the sum of the changes in the kinetic energy and in the potential energy is zero—the kinetic and potential energy changes are equal but opposite in sign.

This allows us to define the total mechanical energy:

$$E = \mathrm{KE} + \mathrm{PE}$$

And its conservation:

$$E_2 = E_1 = \text{constant.}$$

Some other forms of energy:

• Electric energy, nuclear energy, thermal energy, chemical energy.

Work is done when energy is transferred from one object to another.

Accounting for all forms of energy, we find that the total energy neither increases nor decreases. Energy as a whole is conserved.

Energy Conservation with Dissipative Processes; Solving Problems

If there is a nonconservative force such as friction, where do the kinetic and potential energies go?

They become heat; the actual temperature rise of the materials involved can be calculated.

6th aim:
Apply work and energy knowledge to measure power.

Power

Power is the rate at which work is done

$$\overline{P} = \text{average power} = \frac{\text{work}}{\text{time}} = \frac{\text{energy transformed}}{\text{time}}$$

In the SI system, the units of power are watts:

$$1W = 1 \text{ J/s}$$

The difference between walking and running up these stairs is power—the change in gravitational potential energy is the same.

Power is also needed for acceleration and for moving against the force of gravity.

The average power can be written in terms of the force and the average velocity:

$$\overline{P} = \frac{W}{t} = \frac{Fd}{t} = F\overline{v}$$

Conclusion of The Chapter

- Work: $W = Fd \cos \theta$

- Kinetic energy is energy of motion: $KE = \frac{1}{2} mv^2$

- Potential energy is energy associated with forces that depend on the position or configuration of objects.

- The net work done on an object equals the change in its kinetic energy.

- If only conservative forces are acting, mechanical energy is conserved.

- Power is the rate at which work is done.

Reference

Giancoli, D.C., 2008. Physics for Scientists & Engineers. 4th edition. Prentice Hall, USA.

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