College Of Engineering
University Of Anbar

كليــة الهندسة
جامعة الأنبــار

Dept. of Chem. & Petrochemical Engineering
Subject : Physics
First Stage

Physics

Chapter 5 – Energy, work, and power

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Introduction to Energy

The concept of energy is one of the most important topics in science and engineering.

Every physical process that occurs in the Universe involves energy and energy transfers or transformations.

Energy is not easily defined.

Systems

A *system* is a small portion of the Universe.

A valid system:

- May be a single object or particle
- May be a collection of objects or particles
- May be a region of space
- May vary with time in size and shape

Problem Solving Notes

The general problem solving approach may be used with an addition to the categorize step.

Categorize step of general strategy

- Identify the need for a system approach
- Identify the particular system
- Also identify a system boundary

System Example

A force applied to an object in empty space

- System is the object
- Its surface is the system boundary
- The force is an influence on the system from its environment that acts across the system boundary.

Work

The **work**, *W*, done on a system by an agent exerting a constant force on the system is the product of the magnitude *F* of the force, the magnitude Δr of the displacement of the point of application of the force, and cos θ, where θ is the angle between the force and the displacement vectors.

- The meaning of the term *work* is distinctly different in physics than in everyday meaning.
- Work is done *by* some part of the environment that is interacting directly with the system.
- Work is done *on* the system.

This is important for a system approach to solving a problem.

If the work is done on a system and it is positive, energy is transferred to the system.

If the work done on the system is negative, energy is transferred from the system.

If a system interacts with its environment, this interaction can be described as a transfer of energy across the system boundary.

- This will result in a change in the amount of energy stored in the system.

$W = F \Delta r \cos \theta$

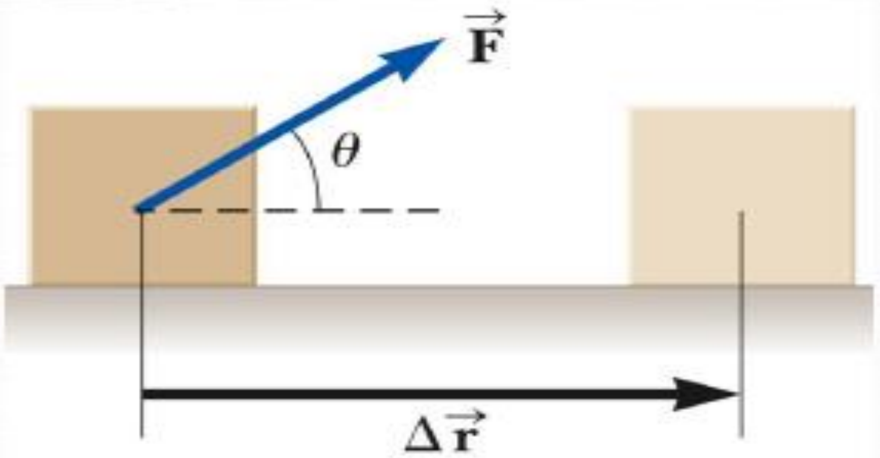
- The displacement is that of the point of application of the force.
- A force does no work on the object if the force does not move through a displacement.
- The work done by a force on a moving object is zero when the force applied is perpendicular to the displacement of its point of application.

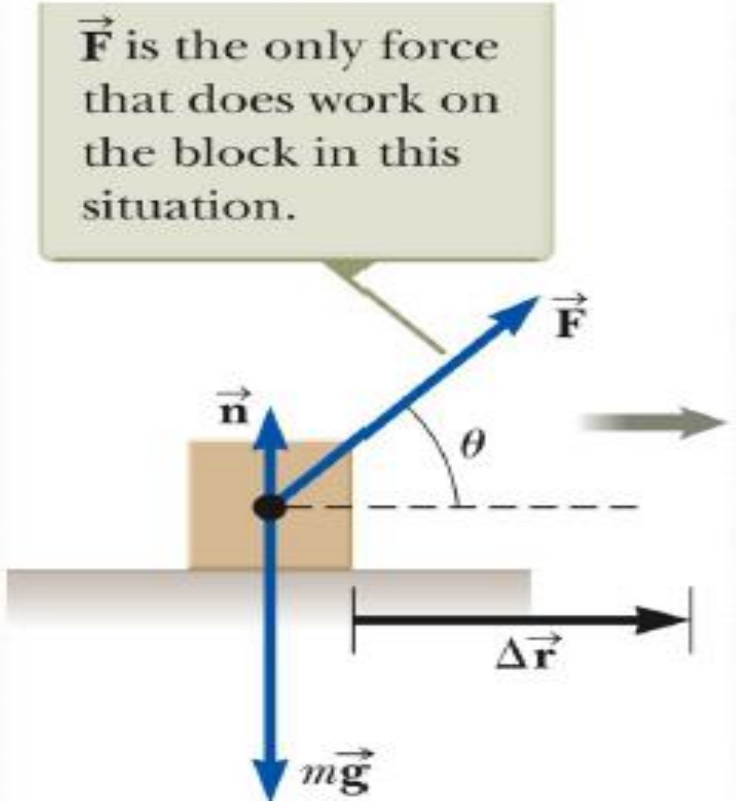
Work Example

The normal force and the gravitational force do no work on the object.

- $\cos \theta = \cos 90^\circ = 0$

The force $\vec{F}$ is the only force that does work on the object.





More About Work

The sign of the work depends on the direction of the force relative to the displacement.

- Work is positive when projection of $\vec{\mathbf{F}}$ onto $\Delta\vec{\mathbf{r}}$ is in the same direction as the displacement.
- Work is negative when the projection is in the opposite direction.

The work done by a force can be calculated, but that force is not necessarily the cause of the displacement.

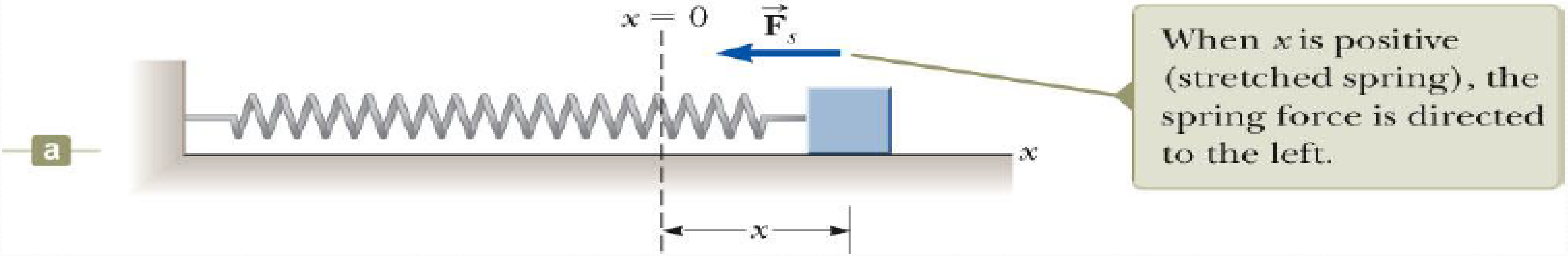
Work is a scalar quantity.

The unit of work is a joule (J)

- 1 joule = 1 newton · 1 meter = kg · m^2 / s^2
- J = N · m

$$W = F\Delta r\cos\theta = \vec{\mathbf{F}} \cdot \Delta\vec{\mathbf{r}}$$

Work Done By A Spring (Hooke's Law)



The force exerted by the spring is

$$F_s = -kx$$

- x is the position of the block with respect to the equilibrium position ($x = 0$).
- k is called the spring constant or force constant and measures the stiffness of the spring.
  - k measures the *stiffness* of the spring.

This is called Hooke's Law.

The vector form of Hooke's Law is $\vec{F}_s = F_x \hat{\mathbf{i}} = -kx\hat{\mathbf{i}}$

When x is positive (spring is stretched), F is negative

When x is 0 (at the equilibrium position), F is 0

When x is negative (spring is compressed), F is positive

Work Done by a Spring

Identify the block as the system.

Calculate the work as the block moves from $x_i = -x_{max}$ to $x_f = 0$.

$$W_s = \int \vec{\mathbf{F}}_s \cdot d\vec{\mathbf{r}} = \int_{x_i}^{x_f} \left(-kx\hat{\mathbf{i}}\right) \cdot \left(dx\hat{\mathbf{i}}\right)$$

$$= \int_{-x_{max}}^{0} (-kx)\,dx = \frac{1}{2}kx_{max}^2$$

The net work done as the block moves from $-x_{max}$ to x_{max} is zero

Assume the block undergoes an arbitrary displacement from $x = x_i$ to $x = x_f$.

The work done by the spring on the block is

$$W_s = \int_{x_i}^{x_f} (-kx)\,dx = \frac{1}{2}kx_i^2 - \frac{1}{2}kx_f^2$$

- If the motion ends where it begins, W = 0

Kinetic Energy

One possible result of work acting as an influence on a system is that the system changes its speed. The system could possess *kinetic energy*.

Kinetic Energy is the energy of a particle due to its motion.

- $K = \frac{1}{2} mv^2$
  - K is the kinetic energy
  - m is the mass of the particle
  - v is the speed of the particle

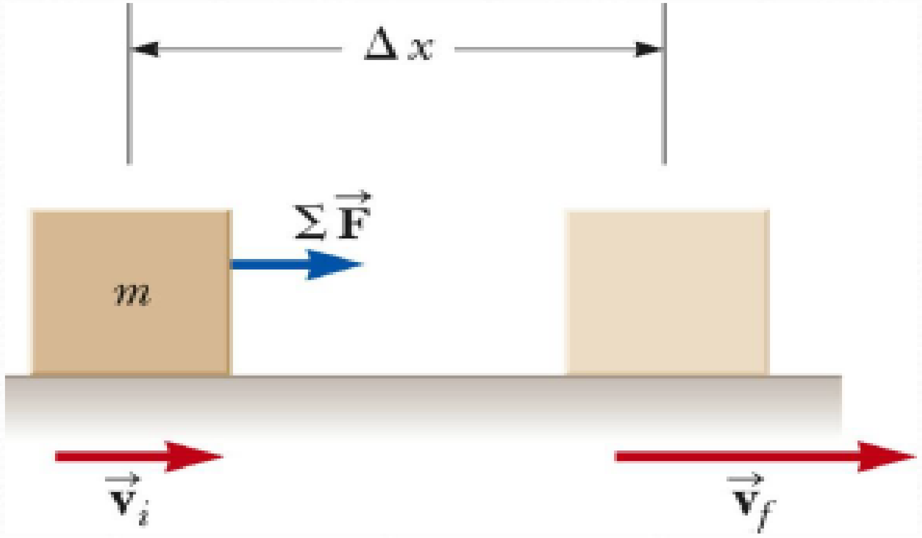
A change in kinetic energy is one possible result of doing work to transfer energy into a system. Calculating the work:

$$W_{ext} = \int_{x_i}^{x_f} \sum F\, dx = \int_{x_i}^{x_f} ma\, dx$$

$$W_{ext} = \int_{v_i}^{v_f} mv\, dv$$

$$W_{ext} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$W_{ext} = K_f - K_i = \Delta K$$



Work-Kinetic Energy Theorem

The Work-Kinetic Energy Theorem states $W_{ext} = K_f - K_i = \Delta K$

When work is done on a system and the only change in the system is in its speed, the net work done on the system equals the change in kinetic energy of the system.

- The speed of the system increases if the work done on it is positive.
- The speed of the system decreases if the net work is negative.

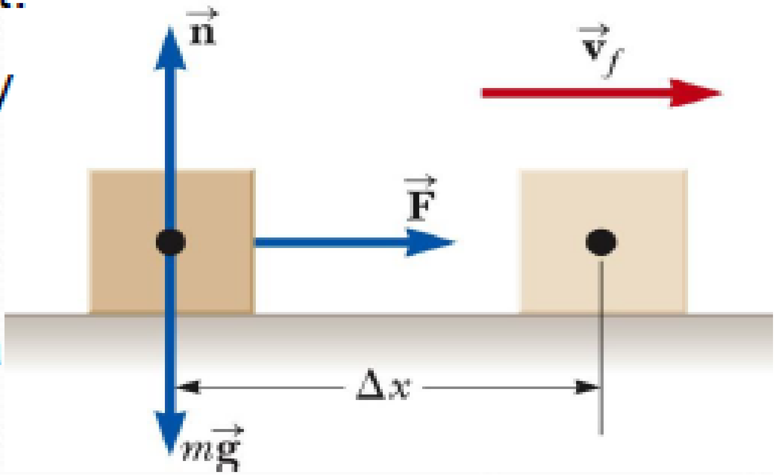
The work-kinetic energy theorem applies to the speed of the system, not its velocity.

The block is the system and three external forces act on it.

The normal and gravitational forces do no work since they are perpendicular to the direction of the displacement.

$W_{ext} = \Delta K = ½\, m v_f^2 - 0$

The answer could be checked by modeling the block as a particle and using the kinematic equations.



Potential Energy

Potential energy is energy determined by the configuration of a system in which the components of the system interact by forces.

- The forces are internal to the system.

Gravitational Potential Energy

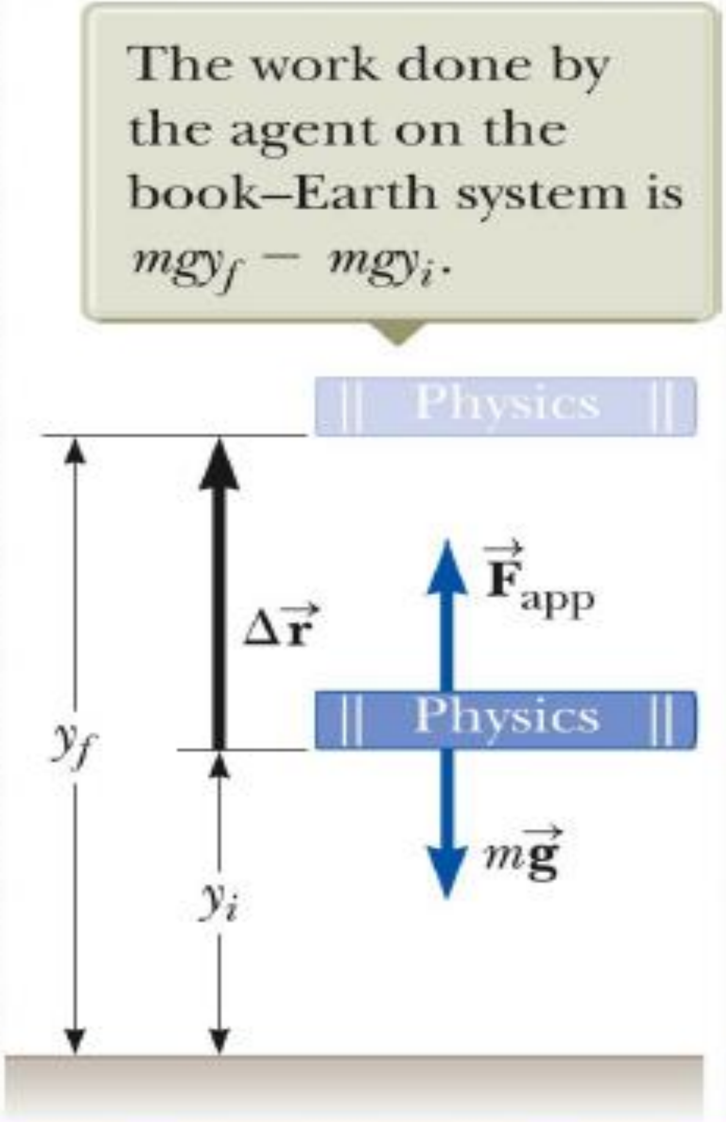
The system is the Earth and the book.

Do work on the book by lifting it slowly through a vertical displacement.

$$\Delta\vec{\mathbf{r}} = (y_f - y_i)\,\hat{\mathbf{j}}$$

The work done on the system must appear as an increase in the energy of the system.

The energy storage mechanism is called *potential energy.*



Gravitational Potential Energy, cont

Assume the book in fig. is allowed to fall. There is no change in kinetic energy since the book starts and ends at rest.

Gravitational potential energy is the energy associated with an object at a given location above the surface of the Earth.

$$W_{ext} = \left(\vec{\mathbf{F}}_{app}\right) \cdot \Delta\vec{\mathbf{r}}$$

$$W_{ext} = (mg\hat{\mathbf{j}}) \cdot \left[(y_f - y_i)\hat{\mathbf{j}}\right]$$

$$W_{ext} = mgy_f - mgy_i$$

The quantity *mgy* is identified as the gravitational potential energy, U_g.

- $U_g = mgy$

U_g is a scalar. Units are joules (J)

Work may change the gravitational potential energy of the system.

- $W_{ext} = \Delta u_g$

Potential energy is always associated with a system of two or more interacting objects.