Chapter 7 Energy of a System

Energy

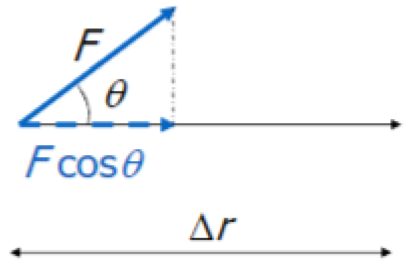
Every physical process that occurs in the Universe involves energy and energy transfer/transformations.
Conservation of Energy states that energy cannot be created or destroyed, only transferred.
If the total amount of **energy in a system changes**, it can only be due to the fact that energy has **crossed the boundary of the system by some method of energy transfer**.

Formulas

- **Work**: $\text{Force} \times \text{Displacement along the same direction}$
- **Kinetic** Energy (Associated with motion/velocity): $\frac{1}{2}mv^2$
- **Potential** Energy:
  - *Gravitational* Potential Energy: mgh
  - *Elastic* Potential Energy: $\frac{1}{2}kx^2$
- **Internal** Energy: Associated with temperature

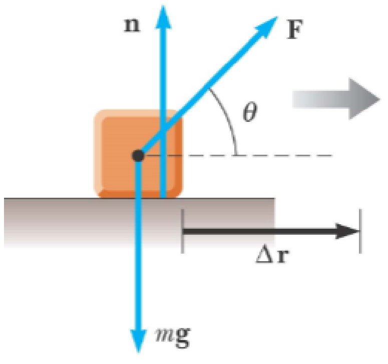
Work

Work W done on a system by an agent exerting a constant force on a 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 $\cos\theta$, where θ is the angle between the force and the displacement vectors.
$W = F\Delta r\cos\theta$



- **Displacement**: The distance over which force is applied.
- **Work Requirement**: Work occurs only if a force moves an object through displacement.
- **Perpendicular Force**: No work is done if force is perpendicular to displacement.
- **Scalar Nature**: Work is scalar and cumulative. In isolated systems with only conservative forces, zero displacement results in zero total work.

Work in Pushing a Block



- The normal force, n and the gravitational force, mg, do not work on the object
  - $\cos\theta = \cos 90^\circ = 0$
- The force F does do work on the object
- $W = (F \times \cos\theta) \times \Delta r = F \times (\Delta r \times \cos\theta)$

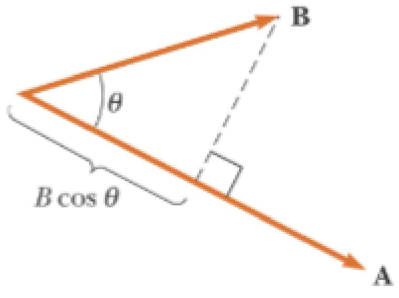
Units of Work

- Scalar quantity
- SI Unit is Joule ($J = N \cdot m$)

Energy Transfer

- If work done is **positive**, energy is *transferred to* the system
- If work done is **negative**, energy is *transferred out* from the system
- If a system interacts with its environment, this is a *transfer of energy*

Scalar Product



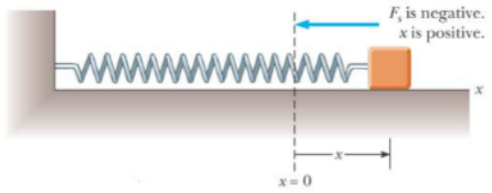
- The scalar product of two vectors is written as $\vec{A} \cdot \vec{B}$, this is also called the dot product
- $\vec{A} \cdot \vec{B} = A\,B\cos\theta$

- Scalar product is commutative
  - $A \cdot B = B \cdot A$
- The scalar product obeys the distributive law of multiplication
  - $A \cdot (B + C) = A \cdot B + A \cdot C$

Work Produced by Multiple Forces

- If more than one force acts on a system and the system ***can** be modeled as a particle*, the total work down on the system is the work produced by the net force
- If the system ***cannot** be modeled as a particle*, then the total work is equal to the algebraic sum of the work produced by the individual forces

Hooke's Law



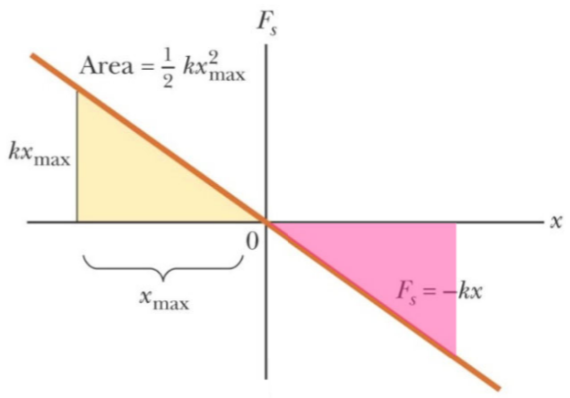
$F_s = -kx$

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

When x is **positive**: *spring is stretched*, F_s is **negative**
When x is **0**: *equilibrium position*, F_s is **0**
When x is **negative**: *spring is compressed*, F_s is **positive**

The force exerted *by the spring* is always directed opposite to the displacement from equilibrium
F_s is called the *restoring force*
If the block is released it will oscillate back and forth between x and $-x$

Work produced by a Spring



- Identify the block as the system
  - $W_s = \frac{1}{2}x_{max}^2$

Spring with an Applied Force

- Suppose a force F_{app} from an external agent, stretches the spring
- The applied force is equal and opposite to the spring force
- $F_{app} = -F_s = -(-kx) = kx = \frac{1}{2}kx_{max}^2$

Kinetic Energy

- Kinetic Energy is the energy of a particle due to its motion
  - $K = \frac{1}{2}mv^2$
- A change in kinetic energy is one possible result of doing work to transfer energy into a system
- When work is done on a system and the only change in the system is in its speed, the work done by the **net** force equals the change in kinetic energy of the system.

Work-Kinetic Energy Theorem

- The normal and gravitational forces do no work since they are perpendicular to the direction of the displacement $W = F\Delta x = \Delta K = \frac{1}{2}mv^2 - 0$

Non-isolated System

- An non-isolated system is **one that interacts with or is influenced by its environment**
  - It *would not* interact with its environment

Internal Energy

- The energy associated with an object's *temperature* is called its internal energy, E_{int}
- The friction does work and increases the internal energy of the surface

Potential Energy

- Potential energy is energy related to the *configuration* of a system in which the components of the system interact by forces
  - Elastic potential energy stored in a spring
  - Gravitational potential energy, $G.P.E. = mgh$

Power

- The *time rate of energy transfer* is called **power**
- The average power is given by $P = \frac{W}{\Delta t}$ when the method of energy transfer is work

Instantaneous Power

- The *instantaneous power* is the limiting value of the average power as Δt approaches zero
    - $P = \frac{W}{\Delta t} = \frac{dW}{dt} = \frac{F \times dr}{dt} = F \times \frac{dr}{dt} = F \times v$

Units of Power

- The SI unit of power is called the *Watt*
    - $1\, Watt = 1\, Joule/second = 1kg \cdot m^2/s^3$
- *Horsepower* can also be used
    - $1\, hp = 746\, W$
- Units of power can also be used to express units of work or energy
    - $1\, kWh = (1000\, W)(3600\, s) = 3.6 \times 10^6\, J$, Energy transferred in 1 hour at a constant rate