Phys 103

Chapter 7

Energy and Energy Transfer

By

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LECTURE OUTLINE

Introduction

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

In everyday life, we think of energy in terms of fuel for transportation and heating, electricity for lights and appliances, and foods for consumption. However, these ideas do not really define energy. They merely tell us that fuels are needed to do a job and that those fuels provide us with something we call energy.

The definitions of quantities such as position, velocity, acceleration, and force and associated principles such as Newton’s second law have allowed us to solve a variety of problems. Some problems that could theoretically be solved with Newton’s laws, however, are very difficult in practice. These problems can be made much simpler with a different approach. In this and the following chapters, we will investigate this new approach, which will include definitions of quantities that may not be familiar to you.

Introduction

Other quantities may sound familiar, but they may have more specific meanings in physics than in everyday life. We begin this discussion by exploring the notion of energy.

Energy is present in the Universe in various forms. *Every* physical process that occurs in the Universe involves energy and energy transfers or transformations. Unfortunately, despite its extreme importance, energy cannot be easily defined. The variables in previous chapters were relatively concrete; we have everyday experience with velocities and forces, for example. The notion of energy is more abstract, although we do have *experiences* with energy, such as running out of gasoline, or losing our electrical service if we forget to pay the utility bill.

Introduction

The concept of energy can be applied to the dynamics of a mechanical system without resorting to Newton's laws. This "energy approach" to describing motion is especially useful when the force acting on a particle is not constant; in such a case, the acceleration is not constant, and we cannot apply the constant acceleration equations that were developed in Chapter 2. Particles in nature are often subject to forces that vary with the particles' positions. These forces include gravitational forces and the force exerted on an object attached to a spring. We shall describe techniques for treating such situations with the help of an important concept called *conservation of energy*. This approach extends well beyond physics, and can be applied to biological organisms, technological systems, and engineering situations.

Our problem-solving techniques presented in earlier chapters were based on the motion of a particle or an object that could be modeled as a particle. This was called the *particle model*. We begin our new approach by focusing our attention on a *system* and developing techniques to be used in a *system model*.

7.2 Work Done by a Constant Force

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 Δ**r** of the displacement of the point of application of the force, and cosθ, where θ is the angle between the force and displacement vectors:

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

if θ= 90°, then W = 0 because cos 90o= 0

If an applied force **F** is in the same direction as the displacement Δ**r**, then θ= 0 and cos 0 = 1. In this case, Equation 7.1 gives:

$$W = F\Delta r$$

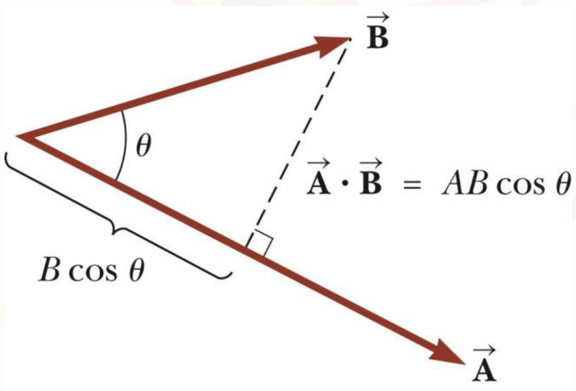
Work is a *scalar quantity*, and its units are force multiplied by length. Therefore, the SI unit of work is the newton.meter (N. m). This combination of units is used so frequently that it has been given a name of its own: the *joule*(J).

7.3 The Scalar Product of Two Vectors

Because of the way the force and displacement vectors are combined in Equation 7.1, it is helpful to use a convenient mathematical tool called the scalar product of two vectors.

In general; for any two vectors **A**and **B**; Scalar product is defined as:

$$A.B = AB\cos\theta$$
$$W = F\Delta r\ \cos\theta = F.\Delta r$$



In other words, **F.Δr**(“F dot Δr”) is a shorthand notation for *F*Δr*cos*θ*.*

7.3 The Scalar Product of Two Vectors

Dot Products

Note that the scalar product is commutative.

That is:

$$A.B = B.A$$

Although (7.3) defines the work in terms of two vectors, *work is a scalar*. *All types of* energy and energy transfer are scalars. This is a major advantage of the energy approach. We don't need vector calculations!

Dot Products of Unit Vectors

$$\hat{\mathbf{i}}\cdot\hat{\mathbf{i}} = \hat{\mathbf{j}}\cdot\hat{\mathbf{j}} = \hat{\mathbf{k}}\cdot\hat{\mathbf{k}} = 1$$

$$\hat{\mathbf{i}}\cdot\hat{\mathbf{j}} = \hat{\mathbf{i}}\cdot\hat{\mathbf{k}} = \hat{\mathbf{j}}\cdot\hat{\mathbf{k}} = 0$$

Using component form with vectors:

$$\vec{\mathbf{A}} = A_x\hat{\mathbf{i}} + A_y\hat{\mathbf{j}} + A_z\hat{\mathbf{k}}$$

$$\vec{\mathbf{B}} = B_x\hat{\mathbf{i}} + B_y\hat{\mathbf{j}} + B_z\hat{\mathbf{k}}$$

$$\vec{\mathbf{A}}\cdot\vec{\mathbf{B}} = A_xB_x + A_yB_y + A_zB_z$$

In the special case where

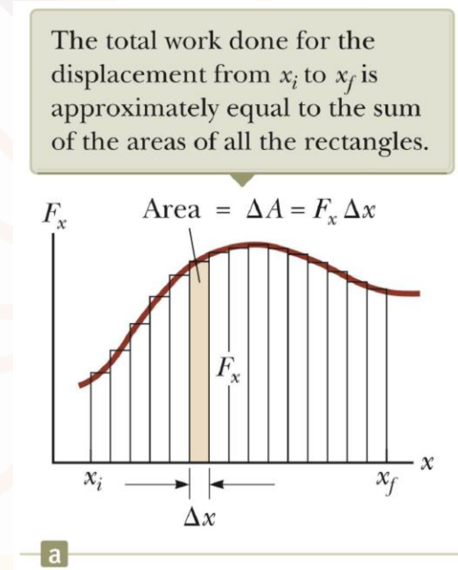
$$\vec{\mathbf{A}} = \vec{\mathbf{B}};$$

$$\vec{\mathbf{A}}\cdot\vec{\mathbf{A}} = A_x^2 + A_y^2 + A_z^2 = A^2$$

7.4 Work Done by a Varying Force

If a force $\mathbf{F}_x$ is varying with position, *x*, we can express the work done by $\mathbf{F}_x$ as the particle moves from x_i to x_f as:

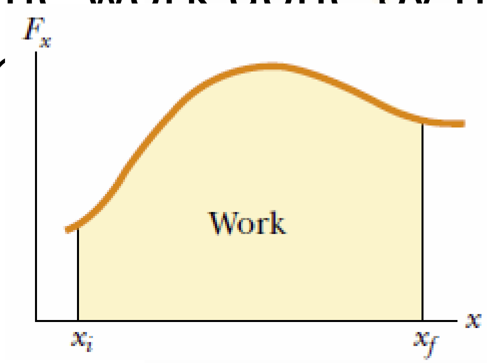
$$W \approx \sum_{x_i}^{x_f} F_x \, \Delta x$$



or

$$W = \int_{x_i}^{x_f} F_x \, dx$$

The work done by the component $\mathbf{F}_x$ *of* the varying force as the particle m



xactly equal to the area under this curve.

$$W = \int_{x_i}^{x_f} F_x \, dx$$

7.5 Kinetic Energy and the Work–Kinetic Energy Theorem

When work (W) is applied on a system; its kinetic energy (K) changes from initial value (K_i) to final value (K_f) so that:

$$W = K_f - K_i$$

We define k as: $K = \frac{1}{2}mv^2$

$$W = \frac{1}{2}m({v^2}_f - {v^2}_i)$$

The **work–kinetic energy theorem** is defined as:

$$W = K_f - K_i = \Delta K$$

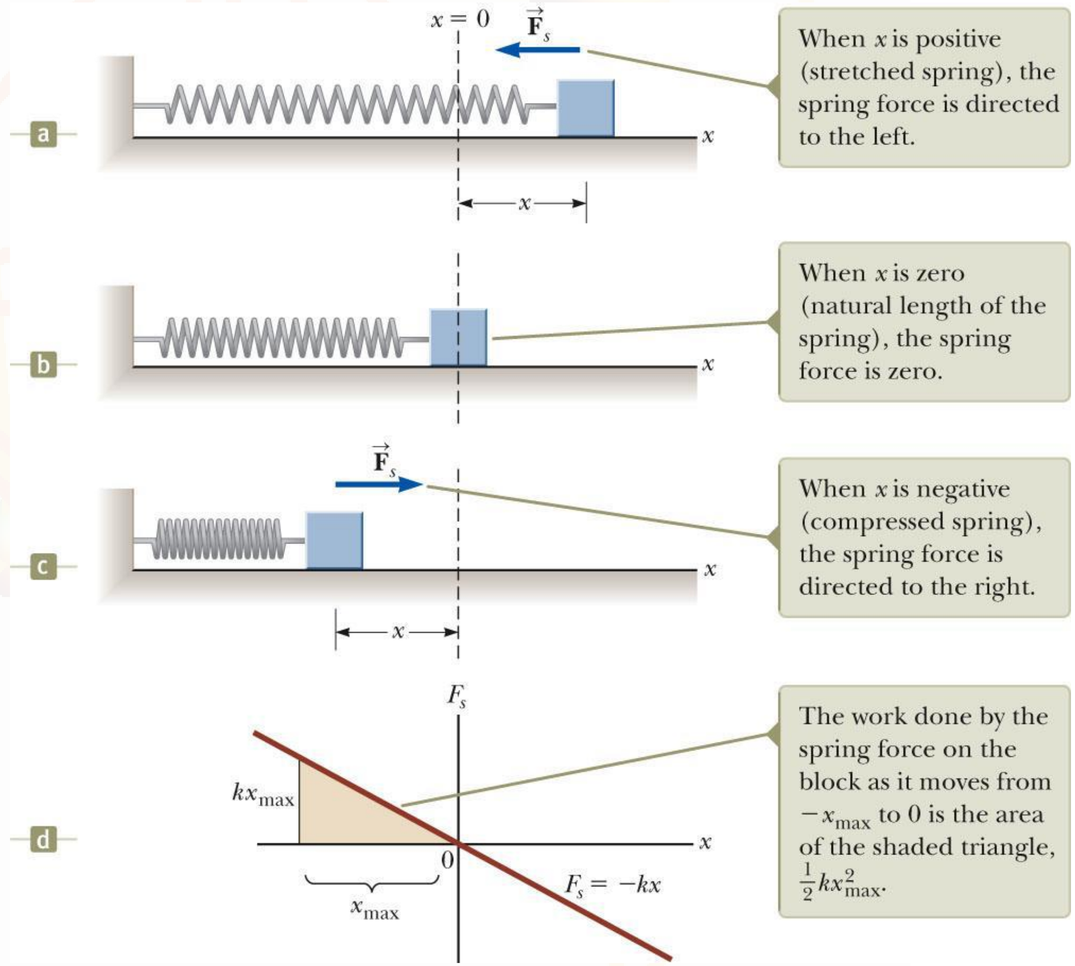
This theorem indicates that the speed of a particle will **increase** if the net work done on it is **positive**, because the final kinetic energy will be greater than the initial kinetic energy. The speed will **decrease** if the net work is **negative.**

Remember work is a scalar, so this is the algebraic sum.

7.5 Kinetic Energy and the Work–Kinetic Energy Theorem

Work Done By A Spring

A model of a common physical system for which the force varies with position. The block is on a horizontal, frictionless surface. Observe the motion of the block with various values of the spring constant.



7.5 Kinetic Energy and the Work–Kinetic Energy Theorem

Spring Force (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.

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

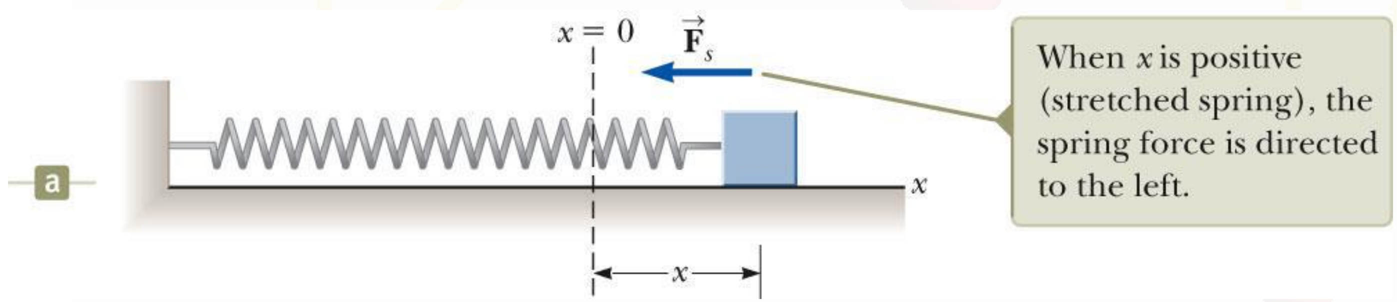
When x is 0 (at the equilibrium position), F is 0

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

The force exerted by the spring is always directed opposite to the displacement from equilibrium.

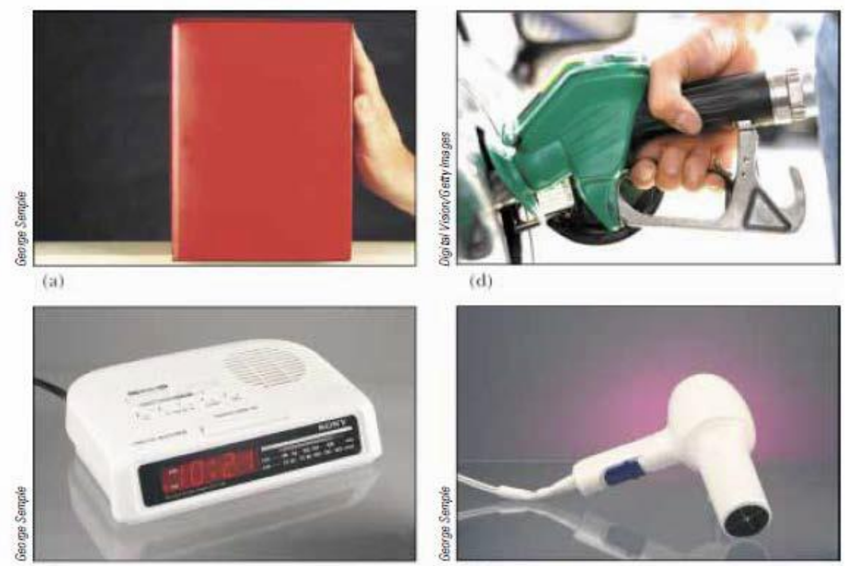
The spring force is sometimes called the restoring force.

If the block is released it will oscillate back and forth between –x and x.



7.6 The Nonisolated System-Conservation of Energy

- A particle, that is acted on by various forces, resulting in a change in its kinetic energy is an example of nonisolated system.
- Another example: when a body slides on a surface, heat will be generated although kinetic energy of the surface has not changed.
- Methods of Energy Transfer:Work
- Mechanical Waves
- Heat
- Matter transfer
- Electrical Transmission
- Electromagnetic radiation



7.6 The Nonisolated System-Conservation of Energy

We can neither create nor destroy energy—energy is always conserved. Thus, if the total amount of energy in a system changes, it can only be due to the fact that energy has crossedtheboundaryofthesystembyatransfermechanismsuchasoneofthe methodslistedabove. This is a general statement of the principle of conservation of energy.

$$\Delta E_{system} = \sum T$$

Change in the total energy of the system = the amount of energy transferred across the system boundary by some mechanism

7.7 Situations Involving Kinetic Friction

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- Change in Kinetic energy is linked to the work done by a frictional force as:

$$-f_k d = \Delta K \qquad (7.20)$$

or :

$$\Delta E_{\text{int}} = f_k d \qquad (7.22)$$

- *the result of a friction force is to transform kinetic energy into internal energy, and the increase in internal energy is equal to the decrease in kinetic energy*.

7.8 Power

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- Average power is defined as:

$$\bar{p} = \frac{W}{\Delta t} \qquad (7.23)$$

- instantaneous power is:

$$p = \frac{dW}{dt}$$

$$\because dW = \boldsymbol{F}.d\boldsymbol{r}$$

$$\rightarrow p = \frac{\boldsymbol{F}.d\boldsymbol{r}}{dt} = \boldsymbol{F}.\frac{d\boldsymbol{r}}{dt} = \boldsymbol{F}.\boldsymbol{v} \qquad (7.23)$$

- instantaneous power is: *Applied force × velocity*
- The SI unit of power is joules per second (J/s), also called the watt (W)
- *Or horsepower: 1hp = 746 W*

Lecture Summary

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Thank You

ACKNOWLEDGEMENTS