1. Energy and Energy Conservation

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

- The concept of energy provides a different problem solving approach which can solve problems otherwise difficult to be solved by 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 1.

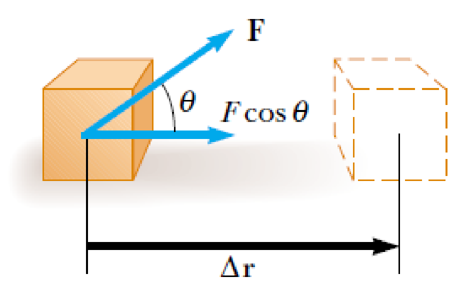
- We shall describe techniques for treating such situations with the help of an important concept called *conservation of energy*.

2. Work Done by a Constant Force

A force F is said to apply a force on an object if the force-object interaction resulted in a finite displacement Δr. Work is then the force-displacement product. If the force is constant, then:

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

Where θ is the angle between the force and the displacement.



Conceptual Example

In which situation below the applied hand force will push the eraser more effectively?

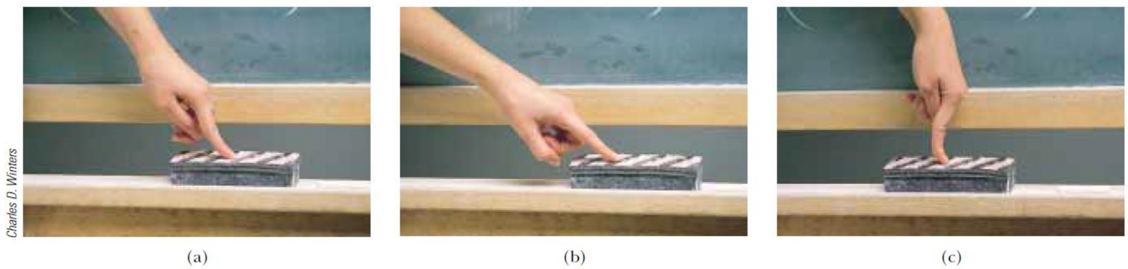
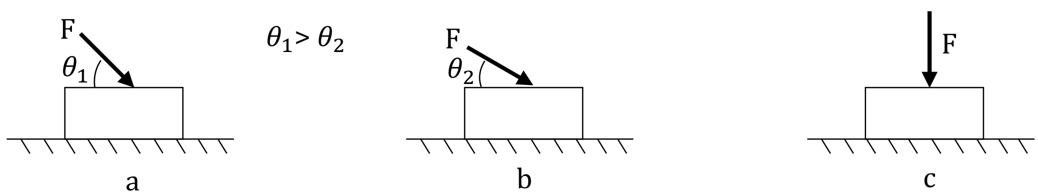
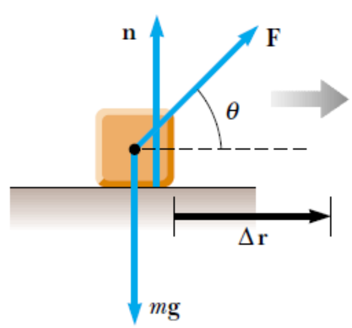


Figure 7.1 An eraser being pushed along a chalkboard tray.



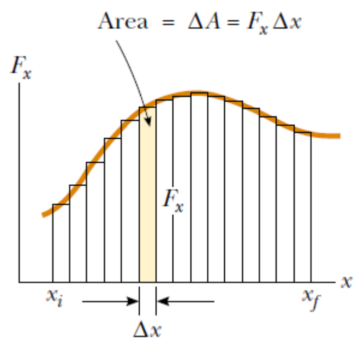
Conceptual Example

Which force in the figure below does a work on the object?

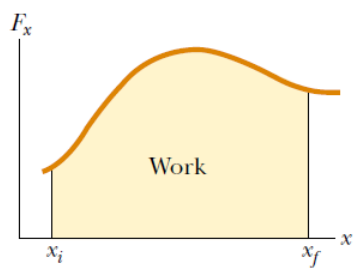


3. Work Done by a Varying Force

The previous expression for the work can only be used when the force is constant in magnitude and direction.
What if a particle is displaced under the action of a force that varies with position as shown in the following figure?



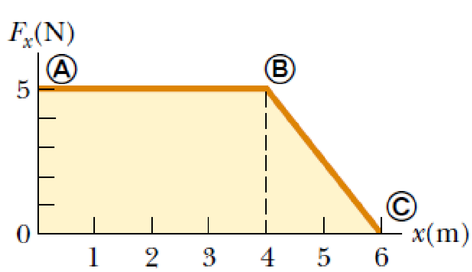
(a)



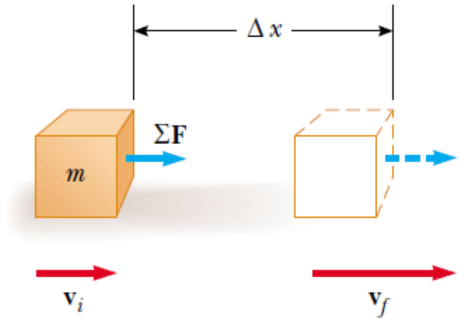
(b)

This graph shows that the work done by the varying force as particle moves from x_i to x_f is equal to *the area under the curve*.

Example 1
A force acting on a particle varies with *x*, as shown in the figure. Calculate the work done by the force as the particle moves from $x = 0$ to $x = 6.0$ m.



4. Kinetic Energy and the Work–Kinetic Energy Theorem



Theorem: The total work done on a particle can be shown (see textbook) to be:

$$\sum W = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

This theorem provides a simplified approach to calculate final velocities without going through calculation of acceleration values (as in Newton's Laws)!

We define *kinetic energy* K: $K = \frac{1}{2}mv^2$

$$\Rightarrow \sum W = K_f - K_i$$

$$\therefore \quad \Delta K = \sum W$$

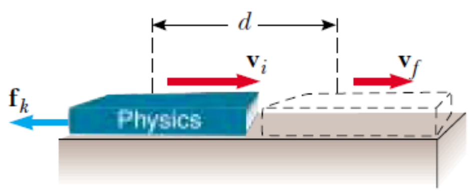
Example 2

A 6.0-kg block initially at rest is pulled to the right along a horizontal, frictionless surface by a constant horizontal force of 12 N. Find the speed of the block after it has moved 3.0 m.

5. Internal Energy and Friction

- The internal energy is the energy associated with an object's <u>temperature</u>.

- In the figure below, a book slides on a frictional surface. The moving object applies work *on the surface*, by which the internal energy of the system increases (i.e. the surface heats up).



6. Situations Involving Kinetic Friction

If there are a friction force and other forces acting on an object, it can be shown that:

$$\Delta K = -f_k d + \sum W_{other}$$

Or:

$$\sum W_{other} = \Delta K + f_k d$$

where d is the length of the friction path followed by the object, and W_{other} is the total work of other forces acting on the system.

- The result of a friction force is to transform kinetic energy of the object into internal energy (heat), and the increase in this internal energy is equal to the decrease in kinetic energy.

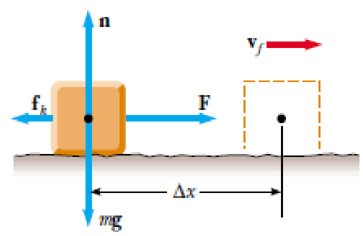
- So, the energy gained by the object (by the work of other forces) will be partially transferred to internal energy of the surface thus reducing the object's kinetic energy.

- In other words, the total work (of other forces applied on the object) will be distributed between increasing the kinetic energy of the object and increasing the internal energy of the frictional surface.

Example 3

6.0-kg block initially at rest is pulled to the right along a horizontal surface by a constant horizontal force of 12 N.

Find the speed of the block after it has moved 3.0 m if the surfaces in contact have a coefficient of kinetic friction of 0.15. (This is the same previous example, modified so that the surface is no longer frictionless.)



Conceptual Example

A car traveling at an initial speed *v* slides a distance *d* to a halt after its brakes lock. Assuming that the car's initial speed is instead 2*v* at the moment the brakes lock, estimate the distance it slides.

7. Gravitational Potential Energy - Work Done by Gravity

Potential energy is a special kind of energy can only be associated with specific types of forces called conservative forces. One example of these forces is the gravitational force between two objects.

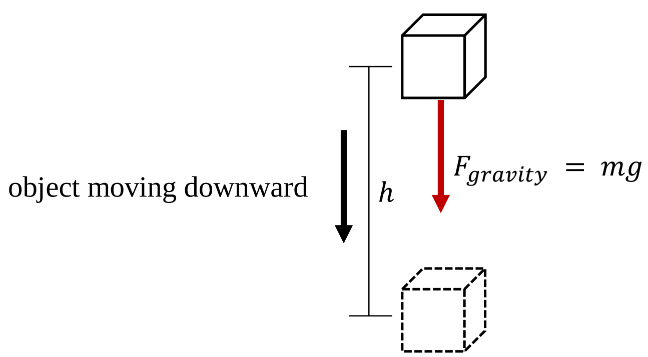
If an abject of mass m moves under gravity (either upward or downward) from an initial height y_i above the surface of the Earth to a final height y_f, the work done by the gravitational force on the object is:

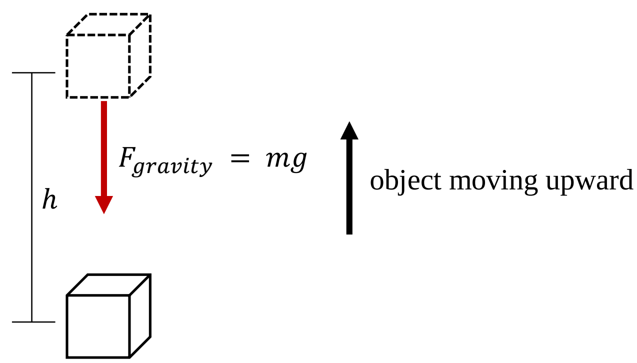
$$W_{gravity} = F_{gravity}\Delta r \cos\theta \;=\; mg\left(y_f - y_i\right)\cos\theta$$

Definition: the quantity mgy is identified as the *gravitational potential energy* U_g .

Defining the positive y-axis to be upward, we get:

$$\Delta U = \begin{cases} mgh\text{, if the object is moving upward} \\ -mgh\text{, if the object is moving downward} \end{cases}$$





$$W_{gravity} = F_{gravity} h \cos 0 \;=\; mgh$$

$$W_{gravity} = F_{gravity} h \cos 180 \;=\; -mgh$$

$$\therefore\; W_{gravity} = -\,\Delta U_g$$

This means that the work done on the system appears as a change in its gravitational potential energy which depends only on the vertical height of the object above the surface of the Earth.

8. Problem Solving Strategy

We have:

$$\Delta K = -f_k d + \sum W_{other} = -f_k d + W_g + \sum W_{other}$$
$$= -f_k d - \Delta U_g + \sum W_{other}$$

Or:

$$\Delta K + \Delta U_g = -f_k d + \sum W_{other}$$

$$\Delta K = \frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2$$

$$\Delta U = \begin{cases} mgh, & \text{if the object is moving upward} \\ -mgh, & \text{if the object is moving downward} \end{cases}$$

$$f_k = \mu_k N$$

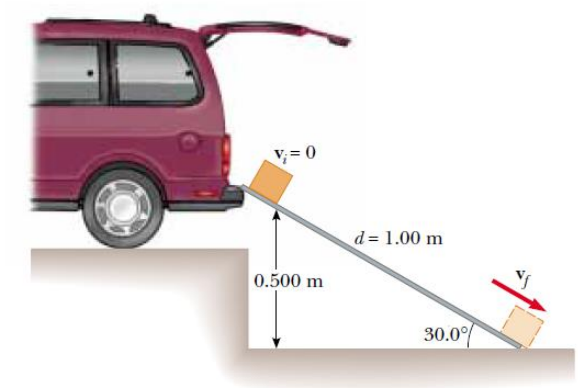
To find N: analyze the forces along the surface normal

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

θ is the angle between the force and displacement.

Example 4

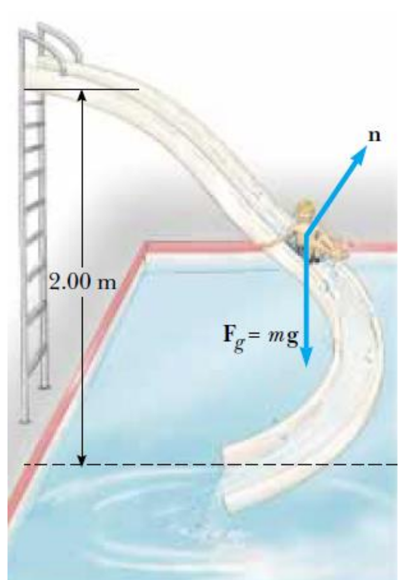
A 3.00-kg crate slides down a ramp as shown in the following figure. The crate experiences a constant friction force of magnitude 5.00 N. Determine the speed of the crate at the bottom of the ramp.



This example can also be solved with energy methods or Newton's laws.

Some problems cannot be solved easily with Newton's laws; thus, we need the energy methods to solve them (see the following example).

Example 5



The child in the picture above with mass (m) starts from rest at the top of the slid

A) Determine his speed at the bottom, assuming no friction is present.

B) If a force of kinetic friction acts on the child, how much mechanical energy does the system lose? Assume that v_f= 3 m/s and m= 20 kg.

9. Power

The time rate of energy transfer = power

If the work done by a force in a time interval Δt is W, then the average power is:

$$\overline{\mathrm{P}} = \frac{W}{\Delta t}$$

The instantaneous power P is:

$$\mathrm{P} = \lim_{\Delta t \to 0} \frac{W}{\Delta t} = \frac{dW}{dt}$$

In general, for any type of energy transfer

$$P = \frac{dE}{dt}$$

We know $dW = \mathbf{F} \cdot d\mathbf{r}$;thus,

$$\mathrm{P} = \frac{dW}{dt} = \mathbf{F} \cdot \frac{dr}{dt} = \mathbf{F} \cdot \mathbf{v}$$

- The SI unit of power is joules per second (J/s), also called the watt (W)
- the horsepower (hp)= 746 W
- 1kWh = (10^3W)(3600 s) = 3.60 x 10^6 J (kWh = a unit of energy, not power) (why)