Fundamentals Physics

Tenth Edition

Halliday

Chapter 7

Kinetic Energy and Work

7-1 Kinetic Energy (2 of 5)

- Energy is required for any sort of motion
- Energy:
  - Is a scalar quantity assigned to an object or a system of objects
  - Can be changed from one form to another
  - Is conserved in a closed system, that is the total amount of energy of all types is always the same
- In this chapter we discuss kinetic energy
- We also discuss one method of transferring energy (work)

7-1 Kinetic Energy (3 of 5)

- **Kinetic energy:**
  - The faster an object moves, the greater its kinetic energy
  - Kinetic energy is zero for a stationary object
- For an object with v well below the speed of light:

$$K = \frac{1}{2}mv^2$$ **Equation (7-1)**

- The unit of kinetic energy is a **joule** (J)

$$1\ \text{joule} = 1\ \text{J} = 1\ \text{kg} \cdot \text{m}^2/\text{s}^2.$$ **Equation (7-2)**

7-1 Kinetic Energy (4 of 5) Sample Problem 7.01

Example Energy released by 2 colliding trains (allowed them to crash head-on at full speed) with given weight (1.2 x 10^6 N), acceleration (0.26 m/s^2) from rest and 6.4-km-long track, total kinetic energy of the two locomotives just before the collision?

- Find the final velocity of each locomotive:

$$v^2 = v_0^2 + 2a\left(x - x_0\right).$$

$$v^2 = 0 + 2\left(0.26 \text{ m/s}^2\right)\left(3.2\times10^3\,\text{m}\right),$$ Half of the track

$$v = 40.8 \text{ m/s} = 147\,\text{km/h}.$$

- Convert weight to mass (m=F/a):

$$m = \frac{1.2\times10^6 \text{ N}}{9.8\,\text{m/s}^2} = 1.22\times10^5\,\text{kg}.$$

7-1 Kinetic Energy (5 of 5)

- The kinetic energy:

$$\begin{aligned} K &= 2\left(\frac{1}{2}mv^2\right) = \left(1.22\times10^5\ \text{kg}\right)\left(40.8\ \text{m/s}\right)^2 \\ &= 2.0\times10^8\,\text{J.} \quad \left(\text{Answer}\right) \end{aligned}$$

7-1 Kinetic Energy (5 of 5) Extra example

- An object is constrained by a cord to move in a circular path of radius 0.5m on a horizontal frictionless surface. The cord will break if its tension exceeds 16N. What is the maximum kinetic energy the object can have?

A very simple calculation requiring

$$K = \tfrac{1}{2} m v^2 \text{ and } a_r = v^2 / r = F_r / m \qquad (\Rightarrow mv^2 = r\, F_r)$$

$$K = \frac{1}{2} r \times F_r = \frac{1}{2}(0.5m)\times(16N) = 4N \cdot m = \boxed{4J}$$

7-2 Work and Kinetic Energy (2 of 11)

Work W is energy transferred to or from an object by means of a force acting on the object. Energy transferred to the object is positive work, and energy transferred from the object is negative work.

7-2 Work and Kinetic Energy (3 of 11)

- This is not the common meaning of the word “work”
  - To do work on an object, energy must be transferred
  - Throwing a baseball does work
  - Pushing an immovable wall does not do work

7-2 Work and Kinetic Energy

- Start from force equation and 1-dimensional velocity:

$$F_x = ma_x,$$ **Equation (7-3)**

$$v^2 = v_0^2 + 2a_x d.$$ **Equation (7-4)**

- Rearrange into kinetic energies:

$$\frac{1}{2}mv^2 - \frac{1}{2}mv_0^2 = F_x d.$$ **Equation (7-5)**

- The left side is now the change in energy
- Therefore work is:

$$W = F_x d.$$ **Equation (7-6)**

7-2 Work and Kinetic Energy (5 of 11)

To calculate the work **we use only the force component along the object's displacement.** The force component perpendicular to the displacement does zero work.

- For an angle ϕ between force and displacement:

$$W = Fd\,\cos\phi$$ **Equation (7-7)**

- As vectors we can write:

$$W = \vec{F} \cdot \vec{d}$$ **Equation (7-8)**

7-2 Work and Kinetic Energy (6 of 11)

- Notes on these equations:
  - Force is constant
  - Object is particle-like (rigid)
  - Work can be positive or negative

7-2 Work and Kinetic Energy (7 of 11)

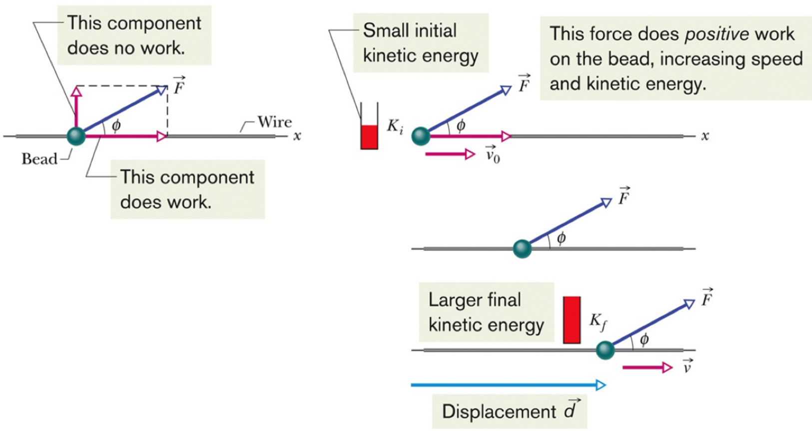


Figure 7-2

- Work has the SI unit of joules (J), the same as energy
- In the British system, the unit is foot-pound (ft lb)

7-2 Work and Kinetic Energy (8 of 11)

A force does negative work when it has a vector component in the opposite direction as the displacement. It does zero work when it has no such vector component.

- For two or more forces, the **net work** is the sum of the works done by all the individual forces
- Two methods to calculate net work:
  - We can sum the individual work terms.
  - We can take the vector sum of forces (F_{net}) and calculate the net work once.

7-2 Work and Kinetic Energy

- The **work-kinetic energy theorem** states:

$$\Delta K = K_f - K_i = W, \qquad \textbf{Equation (7-10)}$$

- (change in kinetic energy) = (the net work done)
- Or we can write it as:

$$K_f = K_i + W, \qquad \textbf{Equation (7-11)}$$

- (final *KE*) = (initial *KE*) + (net work)

7-2 Work and Kinetic Energy (10 of 11)

- The work-kinetic energy theorem holds for positive and negative work

Example If the kinetic energy of a particle is initially 5 J:

- A net transfer of 2 J to the particle (positive work)
    - Final $KE = 7$ J
- A net transfer of 2 J from the particle (negative work)
    - Final $KE = 3$ J

Checkpoint 1

A particle moves along an x axis. Does the kinetic energy of the particle increase, decrease, or remain the same if the particle's velocity changes (a) from −3 m/s to −2 m/s and (b) from −2 m/s to 2 m/s? (c) In each situation, is the work done on the particle positive, negative, or zero?

Answer:

(a) energy decreases (v^2)

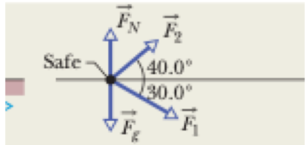
(b) energy remains the same (v^2)

(c) work is negative for (a), and work is zero for (b) $(\Delta K = K_f - K_i = W)$

Sample Problem 7.02

Two spies, sliding a 225 kg safe, displacement $|\vec{d}|$=8.50m, $\vec{F}_1$ by spy 001 =12.0N at 30° downward from horizontal, $\vec{F}_2$ is a pull from spy 002 =10.0N at 40° above horizontal. (a) What is the net work done on the safe by forces during the displacement?

Only force components parallel to the displacement do work.



$$W_1 = F_1 d \cos\phi_1 = (12.0\text{ N})(8.50\text{ m})(\cos 30.0°) = 88.33\text{ J},$$

$$W_2 = F_2 d \cos\phi_2 = (10.0\text{ N})(8.50\text{ m})(\cos 40.0°) = 65.11\text{ J}.$$

Net work:

$$W = W_1 + W_2 = 88.33\text{ J} + 65.11\text{ J} = 153.4\text{ J} \approx 153\text{ J}.$$

The spies transfer 153 J of energy to the kinetic energy of the safe.

(b)What is the work done on the safe by the gravitational force and by the normal force ?

$$W_g = mgd\cos 90^\circ = mgd(0) = 0$$
$$W_N = F_N d\cos 90^\circ = F_N d(0) = 0.$$

(c) The safe is initially stationary. What is its speed *vf* at the end of the 8.50 m displacement?

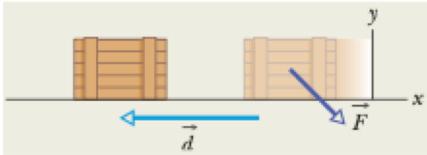
$$W = K_f - K_i = \tfrac{1}{2}mv_f^2 - \tfrac{1}{2}mv_i^2.$$

$$v_f = \sqrt{\frac{2W}{m}} = \sqrt{\frac{2(153.4\text{ J})}{225\text{ kg}}} = 1.17\text{ m/s}.$$

Sample Problem 7.03

A crate is sliding, $\vec{d} = (-3.0\text{ m})\hat{i}$, and wind pushes with $\vec{F} = (2.0\text{ N})\hat{i} + (-6.0\text{ N})\hat{j}$

The parallel force component does *negative* work, slowing the crate.



How much work does this force do on the crate during the displacement?

$$W = \vec{F}\cdot\vec{d} = [(2.0\text{ N})\hat{i} + (-6.0\text{ N})\hat{j}]\cdot[(-3.0\text{ m})\hat{i}]$$

$$\begin{aligned} W &= (2.0\text{ N})(-3.0\text{ m})\hat{i}\cdot\hat{i} + (-6.0\text{ N})(-3.0\text{ m})\hat{j}\cdot\hat{i} \\ &= (-6.0\text{ J})(1) + 0 = -6.0\text{ J}. \qquad \text{(Answer)} \end{aligned}$$

7-3 Work Done by the Gravitational Force (2 of 7)

- We calculate the work as we would for any force
- Our equation is:

$$W_g = mgd \cos \phi$$ **Equation (7-12)**

- For a rising object:

$$W_g = mgd \cos 180^\circ = mgd(-1) = -mgd.$$ **Equation (7-13)**

- For a falling object:

$$W_g = mgd \cos 0^\circ = mgd(+1) = +mgd.$$ **Equation (7-14)**

7-3 Work Done by the Gravitational Force (3 of 7)

- Work done in lifting or lowering an object, **apply**ing an upwards **force**:

$$\Delta K = K_f - K_i = W_a + W_g,$$ **Equation (7-15)**

- For a stationary object:
  - Kinetic energies are zero
  - We find:

$$W_a + W_g = 0$$
$$W_a = -W_g.$$ **Equation (7-16)**

7-3 Work Done by the Gravitational Force (4 of 7)

- In other words, for an applied lifting force:

$$W_a = -mgd\cos\phi \quad \left(\text{work done in lifting and lowering; } K_f = K_i\right), \quad \textbf{Equation (7-17)}$$

- Applies regardless of path

7-3 Work Done by the Gravitational Force (5 of 7)

- Figure 7-7 shows the orientations of forces and their associated works for upward and downward displacement
- Note that the works (in 7-16) need not be equal, they are only equal if the initial and final kinetic energies are equal
- If the works are unequal, you will need to know the difference between initial and final kinetic energy to solve for the work

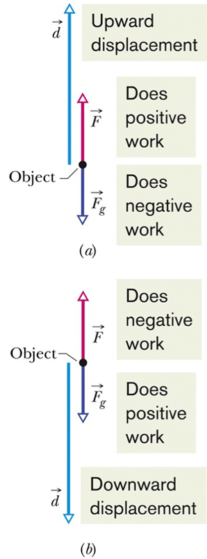


Figure 7-7

7-3 Work Done by the Gravitational Force

(6 of 7) Sample Problem 7.04

Examples 200 kg sleigh, θ=30˚, pulled through distance d= 20 m, How much work is done by each force acting on the sleigh? (Tension does positive work, gravity does negative work)

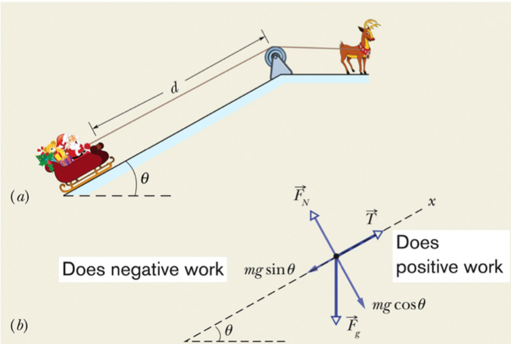


Figure 7-8

Work by the normal force:

$$W_N = F_N d \cos 90^\circ = 0.$$

Work by the gravitational force:

$$F_{gx} = mg \sin\theta = (200\text{ kg})(9.8\text{ m/s}^2)\sin 30^\circ = 980\text{ N}.$$

$$W_g = F_{gx} d \cos 180^\circ = (980\text{ N})(20\text{ m})(-1) = -1.96\times 10^4\text{ J}. \quad \text{(Answer)}$$

Or use the full gravitational force instead of a component and angle between *Fg* and *d* is 120˚

Work W_T by the rope's force:

Use the work–kinetic energy theorem of Eq. 7-10 ($\Delta K = W$), where the net work W done by the forces is $W_N + W_g + W_T$ and the change ΔK in the kinetic energy is just zero (because the initial and final kinetic energies are the same—namely, zero).

$$0 = W_N + W_g + W_T = 0 - 1.96 \times 10^4\,\mathrm{J} + W_T$$

$$W_T = 1.96 \times 10^4\,\mathrm{J}. \qquad \text{(Answer)}$$