Fundamentals Physics

Tenth Edition

Halliday

Chapter 8_2

Potential Energy and Conservation of Energy

8-3 Reading a Potential Energy Curve (3 of 8)

- For one dimension, force and potential energy are related (by work) as:

$$F(x) = -\frac{dU(x)}{dx} \qquad \textbf{Equation (8-22)}$$

- Therefore we can find the force $F(x)$ from a plot of the potential energy $U(x)$, by taking the derivative (slope)
- If we write the mechanical energy out:

$$U(x) + K(x) = E_{\text{mec}}. \qquad \textbf{Equation (8-23)}$$

- We see how $K(x)$ varies with $U(x)$:

$$K(x) = E_{\text{mec}} - U(x). \qquad \textbf{Equation (8-24)}$$

8-3 Reading a Potential Energy Curve (4 of 8)

- To find $K(x)$ at any place, take the total mechanical energy (constant) and subtract $U(x)$ $K(x) = E_{\text{mec}} - U(x).$
- Places where $K = 0$ are **turning points**
  - There, the particle changes direction (K cannot be negative)
- At equilibrium points, the slope of $U(x)$ is 0
- A particle in **neutral equilibrium** is stationary, with potential energy only, and net force = 0
  - If displaced to one side slightly, it would remain in its new position
  - ***Example: a marble on a flat tabletop***

8-3 Reading a Potential Energy Curve (5 of 8)

- A particle in **unstable equilibrium** is stationary, with potential energy only, and net force = 0
  - If displaced slightly to one direction, it will feel a force propelling it in that direction
  - ***Example: a marble balanced on a bowling ball***
- A particle in **stable equilibrium** is stationary, with potential energy only, and net force = 0
  - If displaced to one side slightly, it will feel a force returning it to its original position
  - ***Example: a marble placed at the bottom of a bowl***

- Plot (a) shows the potential $U(x)$
- Plot (b) shows the force $F(x)$
- If we draw a horizontal line, (c) or (f) for example, we can see the range of possible positions
- $x < x_1$ is forbidden for the E_{mec} in (c): the particle does not have the energy to reach those points

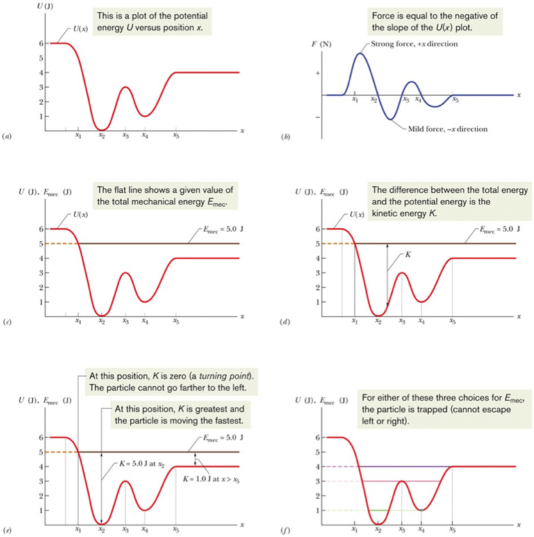
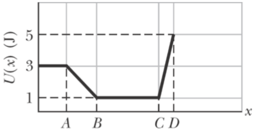


Figure 8-9

8-3 Reading a Potential Energy Curve (8 of 8)

Checkpoint 4

The figure gives the potential energy function $U(x)$ for a system in which a particle is in one dimensional motion. (a) Rank regions AB, BC, and CD according to the magnitude of the force on the particle, greatest first. (b) What is the direction of the force when the particle is in region AB?

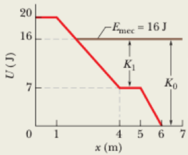


Answer:

(a) CD, AB, BC

(b) to the right

Sample Problem 8.04 Reading a potential energy graph



Kinetic energy is the difference between the total energy and the potential energy.

* 2.00 kg particle, along x axis, a conservative force acts on it, PE as in the figure:

At x = 6.5 m, the particle has velocity, v_0 = (–4.00 m/s)î

(a) From the figure, determine the particle's speed at x_1 = 4.5 m. $K(x) = E_{mec} - U(x)$.

At x = 6.5 m, the particle K:
$$K_0 = \tfrac{1}{2}mv_0^2 = \tfrac{1}{2}(2.00\text{ kg})(4.00\text{ m/s})^2 = 16.0\text{ J}.$$

U = 0 AT 6.5, $E_{mec} = K_0 + U_0 = 16.0\text{ J} + 0 = 16.0\text{ J}$ (plotted as a horizontal line in the figure)

From the figure, at x = 4.5 m, PE is U_1 = 7.0 J, then:

$$K_1 = E_{mec} - U_1 = 16.0\text{ J} - 7.0\text{ J} = 9.0\text{ J}.$$

Because $K_1 = \tfrac{1}{2}mv_1^2$, we find

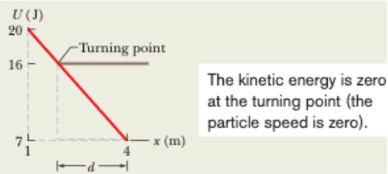
$$v_1 = 3.0\text{ m/s}. \qquad \text{(Answer)}$$

Sample Problem 8.04 Reading a potential energy graph

(b) Where is the particle's turning point located? (it is where the force momentarily stops and then reverses the particle's motion, $v = 0$ and thus $K = 0$)

*we want the point in the figure where the plot of U rises to meet the horizontal line of E_{mec}.

* We can use the proportionality of distances:



$$\frac{16 - 7.0}{d} = \frac{20 - 7.0}{4.0 - 1.0},$$

$d = 2.08$ m. Thus, the turning point is at

$x = 4.0 \text{ m} - d = 1.9$ m.

(c) Evaluate the force acting on the particle when it is in the region $1.9 \text{ m} < x < 4.0$ m. ($F(x) = -dU(x)/dx$, negative of the slope on a graph of $U(x)$)

$$F = -\frac{20\text{ J} - 7.0\text{ J}}{1.0\text{ m} - 4.0\text{ m}} = 4.3\text{ N}$$

8-4 Work Done on a System by an External Force (2 of 6)

- We can extend work on an object to work on a system:

Work is energy transferred to or from a system by means of an external force acting on that system.

- For a system of more than 1 particle, work can change both K and U, or other forms of energy of the system
- For a frictionless system:

$$W = \Delta K + \Delta U,$$

Equation (8-25)

$$W = \Delta E_{\text{mec}}$$

Equation (8-26)

8-4 Work Done on a System by an External Force (3 of 6)

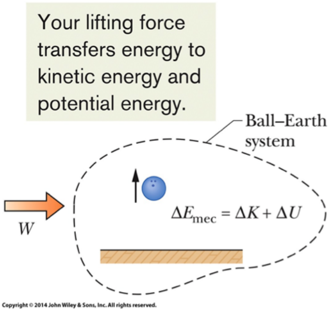


Figure 8-12

8-4 Work Done on a System by an External Force (4 of 6)

- For a system with friction:

$$\Delta E_{\text{th}} = f_k d \quad (\text{increase in thermal energy by sliding}). \qquad \textbf{Equation (8-31)}$$

$$W = \Delta E_{\text{mec}} + \Delta E_{\text{th}} \qquad \textbf{Equation (8-33)}$$

- The thermal energy comes from the forming and breaking of the welds between the sliding surfaces

8-4 Work Done on a System by an External Force (5 of 6)

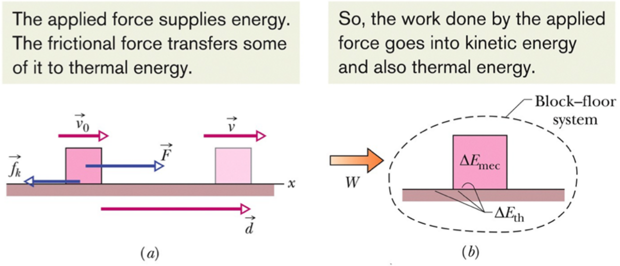


Figure 8-13

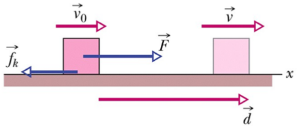
8-4 Work Done on a System by an External Force (6 of 6)

Checkpoint 5

In three trials, a block is pushed by a horizontal applied force across a floor that is not frictionless, as in Figure 8-13*a*.The magnitudes F of the applied force and the results of the pushing on the block's speed are given in the table. In all three trials, the block is pushed through the same distance d. **Rank** the three trials **according to the change in the thermal energy** of the block and floor that occurs in that distance d, greatest first.

Trial	*F*	Result on Block's Speed
a	5.0 N	decreases
b	7.0 N	remains constant
c	8.0 N	increases

The applied force supplies energy. The frictional force transfers some of it to thermal energy.



(*a*)

Answer:

All trials result in **equal thermal energy change**. The value of f_k **is the same in all cases**, since μ_k has only 1 value.

Sample Problem 8.05 Work, friction, change in thermal energy, cabbage heads

Crate, $m = 14$ kg, horizontal force $\vec{F}$ of magnitude 40 N, displacement of magnitude $d = 0.50$ m, speed decreases from $v_0 = 0.60$ m/s to $v = 0.20$ m/s.

(a) How much work is done by force $\vec{F}$, and on what system does it do the work?

$$W = Fd\cos\phi = (40\text{ N})(0.50\text{ m})\cos 0^\circ = 20\text{ J.}$$

The work done is the crate – floor system, if there is no friction, then $\vec{F}$ should be accelerating the crate…

(b) What is the increase ΔE_{th} in the thermal energy of the crate and floor?

$$W = \Delta E_{mec} + \Delta E_{th}.$$

$$\Delta E_{mec} = \Delta K = \tfrac{1}{2}mv^2 - \tfrac{1}{2}mv_0^2.$$

$$\begin{aligned}\Delta E_{th} &= W - \left(\tfrac{1}{2}mv^2 - \tfrac{1}{2}mv_0^2\right) = W - \tfrac{1}{2}m(v^2 - v_0^2)\\ &= 20\text{ J} - \tfrac{1}{2}(14\text{ kg})[(0.20\text{ m/s})^2 - (0.60\text{ m/s})^2]\\ &= 22.2\text{ J} \approx 22\text{ J.} \qquad \text{(Answer)}\end{aligned}$$

8-5 Conservation of Energy (3 of 8)

- Energy transferred between systems can always be accounted for
- The **law of conservation of energy** concerns
  - The **total energy** E of a system
  - Which includes mechanical, thermal, and other internal energy

The total energy E of a system can change only by amounts of energy that are transferred to or from the system.

8-5 Conservation of Energy (4 of 8)

- Considering only energy transfer through work:

$$W = \Delta E = \Delta E_{\text{mec}} + \Delta E_{\text{th}} + \Delta E_{\text{int}}, \qquad \textbf{Equation (8-35)}$$

8-5 Conservation of Energy (5 of 8)

- An isolated system is one for which there can be no external energy transfer

The total energy E of an isolated system cannot change.

- Energy transfers may happen internal to the system
- We can write:

$$\Delta E_{\text{mec}} + \Delta E_{\text{th}} + E_{\text{int}} = 0$$ **Equation (8-36)**

- Or, for two instants of time:

$$E_{\text{mec},2} = E_{\text{mec},1} - \Delta E_{\text{th}} - \Delta E_{\text{int}}.$$ **Equation (8-37)**

8-5 Conservation of Energy (6 of 8)

In an isolated system, we can relate the total energy at one instant to the total energy at another instant without considering the energies at intermediate times.

8-5 Conservation of Energy (7 of 8)

- External forces can act on a system without doing work:

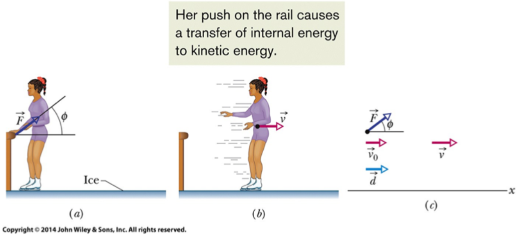


Figure 8-15

- The skater pushes herself away from the wall
- She turns internal chemical energy in her muscles into kinetic energy
- Her K change is caused by the force from the wall, but the wall does not provide her any energy

8-5 Conservation of Energy (8 of 8)

- We can expand the definition of power
- In general, power is the rate at which energy is transferred by a force from one type to another
- If energy ΔE is transferred in time Δt, the **average power** is:

$$P_{\text{avg}} = \frac{\Delta E}{\Delta t}.$$

Equation (8-40)

- And the **instantaneous power** is:

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

Equation (8-41)