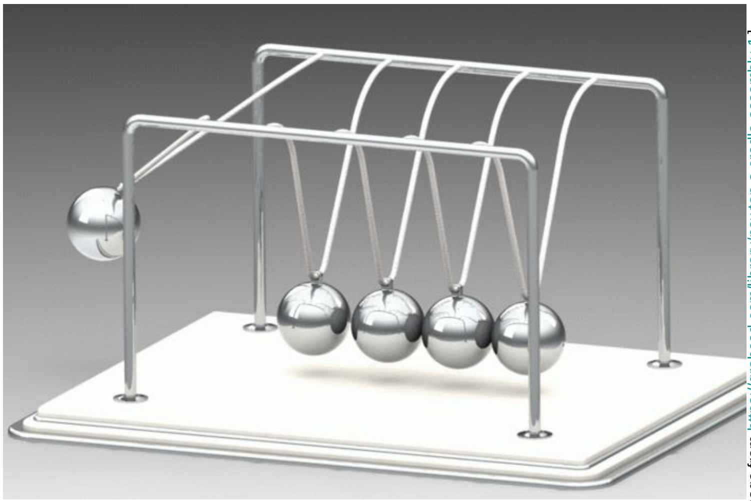
PHY131H1F - Class 21



[image from https://grabcad.com/library/newton-s-cradle-assembly-1]

Today:

7.6 Skills for analyzing processes using the work-energy principle

7.7 Collisions

Learning Catalytics Question

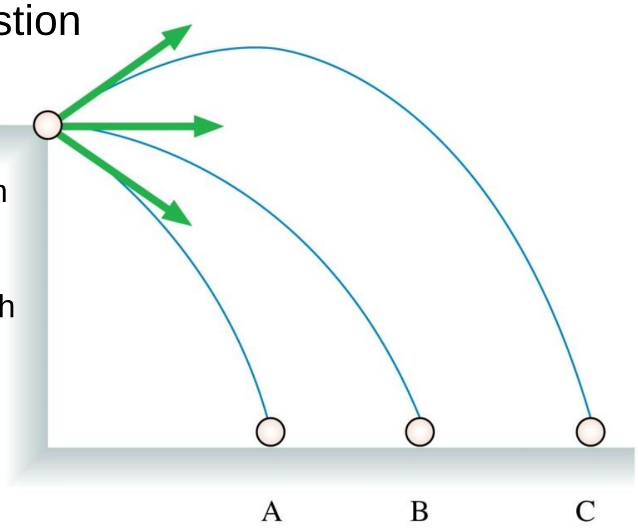
Three balls are thrown from a cliff with the same speed but at different angles. Which ball has the greatest speed just before it hits the ground?

A. Ball A.

B. Ball B.

C. Ball C.

D. All balls have the same speed.



Learning Catalytics Question

A hockey puck sliding on smooth ice at 4 m/s comes to a 1-m-high hill. Will it make it to the top of the hill?

A. Yes.

B. No.

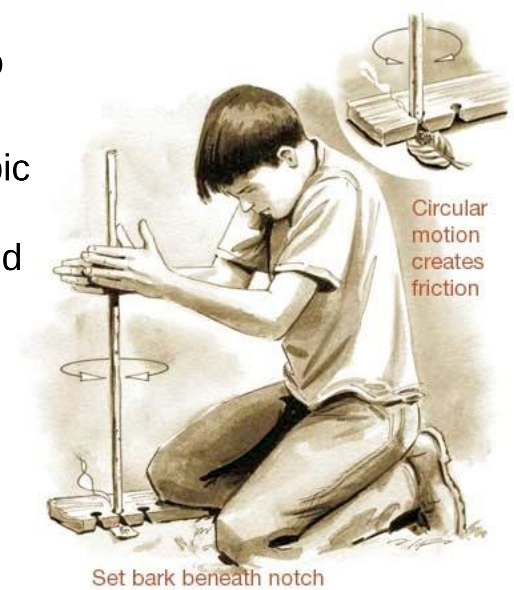
C. Can't answer without knowing the mass of the puck.

D. Can't say without knowing the angle of the hill.

Internal Energy

- Dissipative forces transform macroscopic energy (kinetic), into internal thermal energy.
- Internal energy is the microscopic energy due to random vibrational and rotational motion of atoms and molecules.
- For kinetic friction:

$$\Delta U_{\text{int}} = f_k \, d$$



Conservation of Energy

- If no external work is done on the system, and no heat is exchanged between the system and its environment, then:

$$K_i + U_i = K_f + U_f + \Delta U_{int}$$

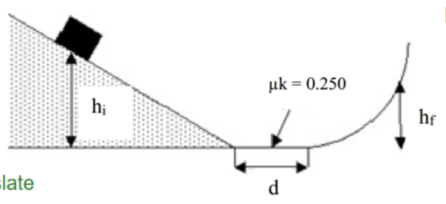
- K is the kinetic energy of the system.
- U is the total potential energy of the system, (recall ΔU is $-1\times$ the work done by conservative forces)
- ΔU_{int} is the increase internal thermal energy of the system due to kinetic friction.

[Doc Cam Examples]

- **From a past PHY131 Final exam:**
- A small box of mass m = 10.0 kg is released from rest at an initial height of h_i = 2.00 meters on a frictionless incline as shown. At the bottom of the ramp, it encounters a rough surface with length d = 1.00 m and $\mu_k = 2.50 \times 10^{-1}$, and then a **frictionless** circular rise.
- At what height h_f does the box stop on the circular rise?

Simplify and diagram

Represent mathematically



Sketch and translate

Solve and Evaluate

▪ **Ch.7 Example:** A box of mass, m, starts sliding with initial speed v up an incline of angle θ above the horizontal. The coefficient of kinetic friction between the incline and the box is μ_k. How far along the incline does the box go before it stops?

Sketch and translate

Represent mathematically

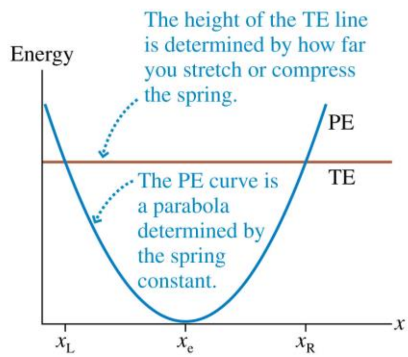
Simplify and diagram

Solve and Evaluate

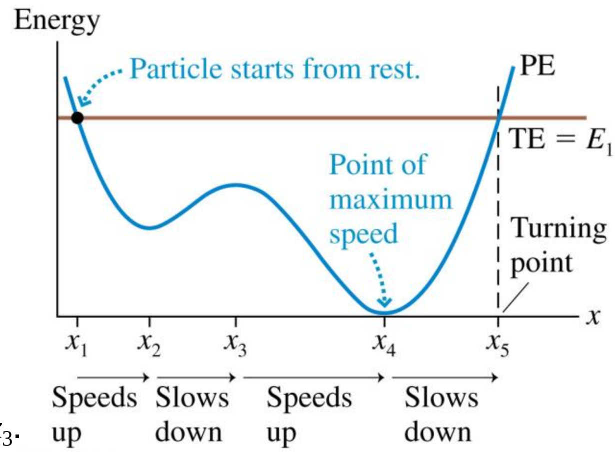
- Shown is the energy diagram of a mass on a horizontal spring.
- The potential energy (PE) is the parabola:

$$U_s = ½k(x - x_e)^2$$

- The PE curve is determined by the spring constant; you can't change it.
- You can set the total energy (TE) to any height you wish simply by stretching the spring to the proper length at the beginning of the motion.



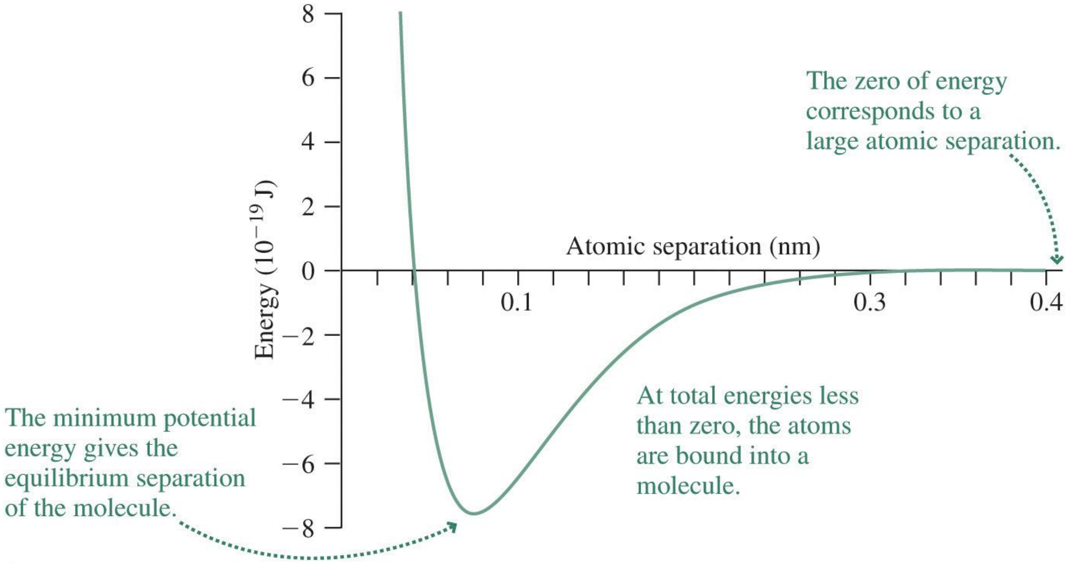
- Shown is a more general energy diagram.
- The particle is released from rest at position x_1.
- Since K at x_1 is zero, the total energy $\mathrm{TE} = U$ at that point.
- The particle speeds up from x_1 to x_2.
- Then it slows down from x_2 to x_3.



- The particle reaches maximum speed as it passes x_4.
- When the particle reaches x_5, it turns around and reverses the motion.

Potential-Energy Curve for an H_2 Molecule

- The potential-energy curve for a pair of hydrogen atoms shows potential energy of the **covalent bond** as a function of atomic separation.



Quick LC Question 1 of 3:

- Two objects collide. All external forces on the objects are negligible.
- If the collision is “elastic”, that means it conserves

A. Momentum $p=mv$

B. Kinetic energy $E = ½\, mv^2$

C. Both

D. Neither

Quick LC Question 2 of 3:

- Two objects collide. All external forces on the objects are negligible.
- If the collision is “inelastic”, that means it conserves

A. Momentum $p=mv$

B. Kinetic energy $E = ½\, mv^2$

C. Both

D. Neither

Quick LC Question 3 of 3:

- Two objects collide. All external forces on the objects are negligible.
- If the collision is "totally inelastic", that means

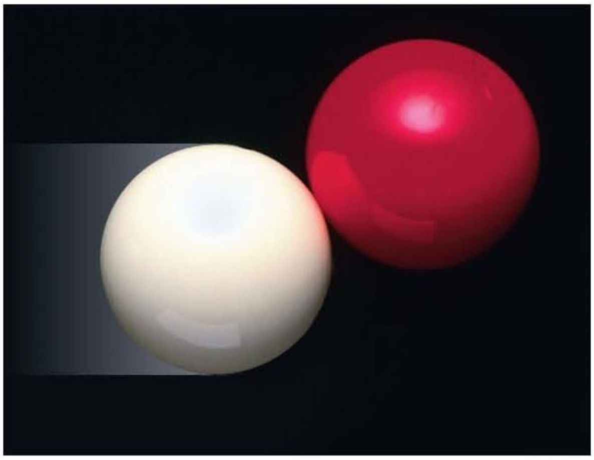
A. momentum is not conserved.

B. the final kinetic energy is zero.

C. the objects stick together.

D. one of the objects ends with zero velocity.

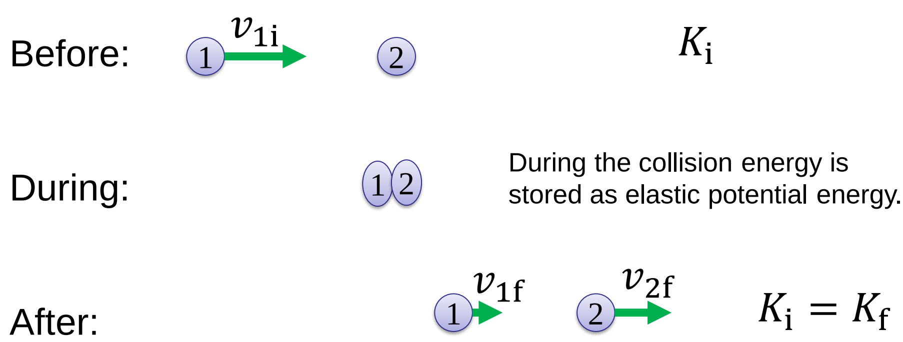
Elastic Collisions



A perfectly elastic collision conserves both momentum and mechanical energy.

Elastic Collision in 1 Dimension when ball 2 is initially at rest.

Consider a head-on, perfectly elastic collision of a ball of mass m_1 having initial velocity v_{1i}, with a ball of mass m_2 that is initially at rest.



The balls' velocities after the collision are v_{1f} and v_{2f}.

Elastic Collision in 1 Dimension when ball 2 is initially at rest.

Momentum conservation: $m_1 v_{1f} + m_2 v_{2f} = m_1 v_{1i}$

Kinetic energy conservation: $\frac{1}{2} m_1 {v_{1f}}^2 + \frac{1}{2} m_2 {v_{2f}}^2 = \frac{1}{2} m_1 {v_{1i}}^2$

There are two equations, and two unknowns: v_{1f} and v_{2f}. Solving for the unknowns gives:

$$v_{1f} = \frac{m_1 - m_2}{m_1 + m_2} v_{1i}$$

$$v_{2f} = \frac{2m_1}{m_1 + m_2} v_{1i}$$

(Elastic collision with ball 2 initially at rest.)

Elastic Collision in 1 Dimension when ball 2 is initially at rest.

$$v_{1\mathrm{f}} = \frac{m_1 - m_2}{m_1 + m_2} v_{1\mathrm{i}}$$

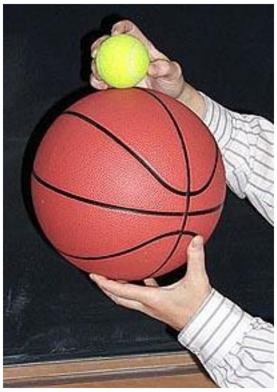
$$v_{2\mathrm{f}} = \frac{2m_1}{m_1 + m_2} v_{1\mathrm{i}}$$

(Elastic collision with ball 2 initially at rest.)

These equations come in especially handy, because you can always switch into an inertial reference frame in which ball 2 is initially at rest!

Demonstration and Example

- A 0.50 kg basketball and a 0.05 kg tennis ball are stacked on top of each other, and then dropped from a height of 0.82 m above the floor.
- How high does the tennis ball bounce?
- Assume all perfectly elastic collisions.

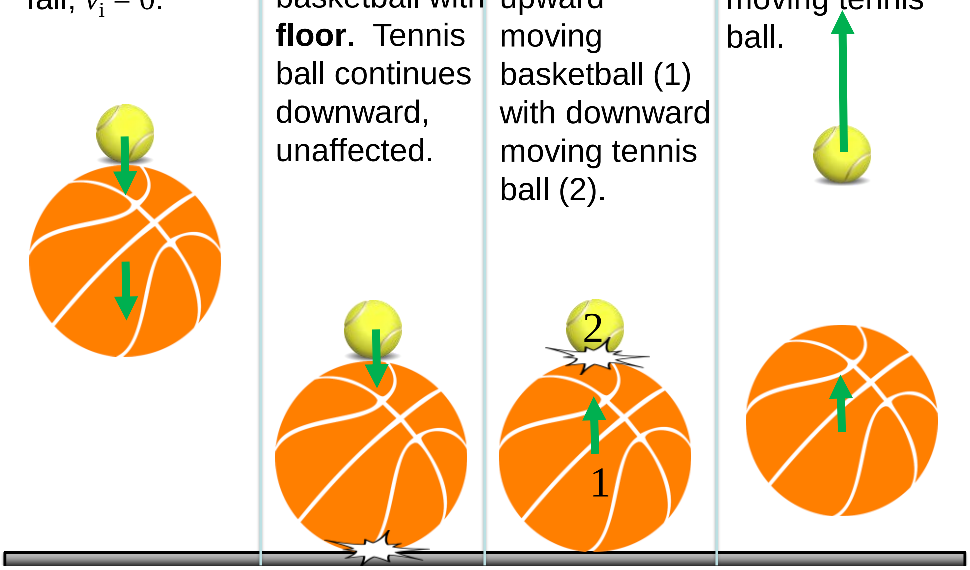


Segment 1: freefall of both balls as they fall, $v_i = 0$.

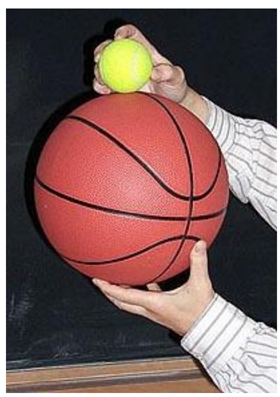
Segment 2: Elastic collision of basketball with **floor**. Tennis ball continues downward, unaffected.

Segment 3: Elastic collision of upward moving basketball (1) with downward moving tennis ball (2).

Segment 4: freefall of upward moving tennis ball.



Demonstration and Example



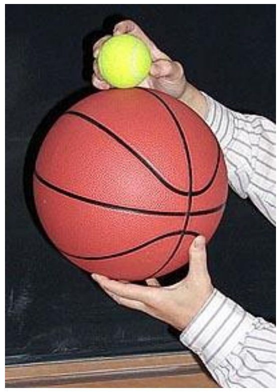
- Divide motion into segments.
- **Segment 1:** free-fall of both balls from a height of h = 0.82 m. Use conservation of energy: $K_i + U_{gi} = K_f + U_{gf}$

$$0 + mgh = \frac{1}{2} m v_f^2 + 0$$

$v_f = \pm[2gh]^{1/2} = -4.0$ m/s, for both balls.

- **Segment 2:** basketball bounces elastically with the floor, so its new velocity is +4.0 m/s.

Demonstration and Example



- **Segment 3:** A 0.50 kg basketball moving upward at 4.0 m/s strikes a 0.05 kg tennis ball, initially moving downward at 4.0 m/s.
- Their collision is perfectly elastic.
- What is the speed of the tennis ball immediately after the collision?

[Doc Cam Notes]

- A 0.50 kg basketball moving upward at 4.0 m/s strikes a 0.05 kg tennis ball, initially moving downward at 4.0 m/s. Their collision is perfectly elastic. What is the speed of the tennis ball immediately after the collision?

$$v_{1f} = \frac{m_1 - m_2}{m_1 + m_2} v_{1i} \qquad v_{2f} = \frac{2m_1}{m_1 + m_2} v_{1i}$$

(Elastic collision with ball 2 initially at rest.)

Sketch and translate

Simplify and diagram

Represent mathematically

Solve and Evaluate

Demonstration and Example

- **Segment 4:** freefall of tennis ball on the way up. $v_{i2} = +10.5$ m/s.
- Use conservation of energy:

$K_i + U_{gi} = K_f + U_{gf}$

$\frac{1}{2} m v_i^2 + 0 = 0 + mgh$

$h = v_i^2/(2g) = 5.6$ m.

- So the balls were dropped from 0.82 m, but the tennis ball rebounds up to 5.6 m! (Assuming no energy losses.)