PHY131H1F Summer – Class 8

Today:

- Momentum and Impulse
- Conservation of Momentum
- Collisions, Explosions
- Conservation of Energy
- Kinetic Energy
- Gravitational Potential Energy
- Hooke's Law
- Elastic Potential Energy

Pre-class Reading Quiz. (Chapter 9)

A 10 kg cart is moving to the left at 2 m/s. Define positive as "towards the right". The cart suddenly stops. What is the change in momentum of the cart?

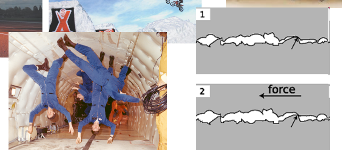
A. –20 kg m/s
B. –10 kg m/s
C. 0 kg m/s
D. 10 kg m/s
E. 20 kg m/s

Pre-class Reading Quiz. (Chapter 10)

According to Knight, energy is a physical quantity with properties somewhat similar to

A. money.
B. heat.
C. a liquid.
D. work.
E. momentum.

- We made it up! It isn't "real", but it's very useful!
- Keeping track of "credits" and "debits" can be interesting, since it doesn't come from nowhere.
- You can't just create it from nothing (it doesn't grow on trees!).

Part I:

Looked at motion in terms of particles and forces.

Chapters 1-4 describe motion with kinematics

Chapters 5-8 explain motion with dynamics: Unbalanced force causes acceleration.

Part II:

Introduces the ideas of ***momentum*** and ***energy***. These concepts give us new useful ways of analyzing motion.

Some quantities stay the same while other things around them change.

For example, when a bomb explodes, if you add up the mass of all the products, it will be the same as the mass of the original bomb. This is "Conservation of Mass": $M_f = M_i$.

Similarly, we have "Conservation of Momentum" ($\vec{p}_f = \vec{p}_i$) and "Conservation of Energy" ($E_f = E_i$) : two new and useful principles which are introduced in chapters 9, 10 and 11.

Last day I asked at the end of class:

- Consider a car accident in which a car, initially traveling at 50 km/hr, collides with a large, massive bridge support.
- The car comes to an abrupt stop. The airbag inflates, saving the driver.
- Why is the force of the hard plastic steering wheel worse than the force of the airbag in stopping the driver?
- ANSWER:
- The driver must reduce his momentum from mv to zero. This requires a force applied over some amount of time. If the time is very short, the force must be very large (ie hitting steering wheel).
- If the driver hits the airbag, this squishes during impact, lengthening the time of the stop. If the stopping process **takes longer**, then the maximum force is **less**.

Momentum

Momentum is the product of a particle's mass and velocity, has units of kg m/s, and is given by

$$\textbf{momentum} = \vec{p} = m\vec{v}$$

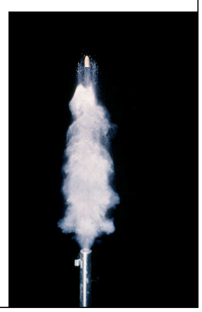
An object can have a larger momentum if it is:

- moving faster or,
- has more mass

Note: Momentum is a vector quantity. It has both x and y components.

Examples

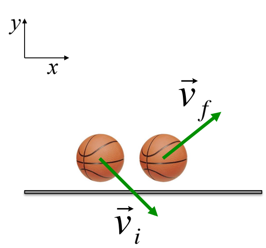
- A 1000 kg car travels west at 25 m/s. What is its momentum?



- A 0.01 kg bullet is fired straight up, and leaves the gun with a muzzle speed of 1000 m/s. What is its momentum?

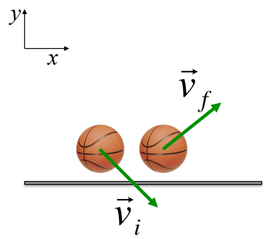
A basketball with mass 0.1 kg is traveling down and to the right with $v_{xi} = +5$ m/s, and $v_{yi} = -5$ m/s. It hits the horizontal ground, and then is traveling up and to the right with $v_{xf} = +5$ m/s, and $v_{yf} = +4$ m/s. What is the change in the x-component of its momentum?

A. +0.5 kg m/s
B. –0.5 kg m/s
C. +0.1 kg m/s
D. +0.9 kg m/s
E. zero



A basketball with mass 0.1 kg is traveling down and to the right with $v_{xi} = +5$ m/s, and $v_{yi} = -5$ m/s. It hits the horizontal ground, and then is traveling up and to the right with $v_{xf} = +5$ m/s, and $v_{yf} = +4$ m/s. What is the change in the y-component of its momentum?

A. +0.5 kg m/s
B. –0.5 kg m/s
C. +0.1 kg m/s
D. +0.9 kg m/s
E. zero

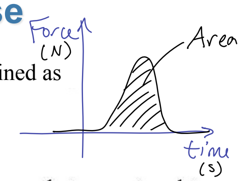


Impulse

The *impulse* upon a particle is defined as

$$\textbf{impulse} = J_x = \int_{t_i}^{t_f} F_x(t)\, dt$$

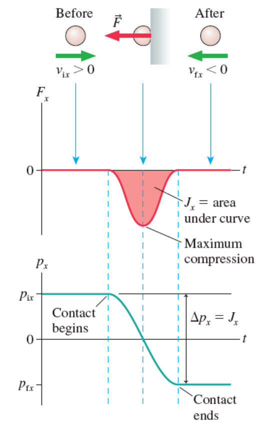
$$= \text{area under the } F_x(t) \text{ curve between } t_i \text{ and } t_f$$



Impulse has units of N s, but you should be able to show that N s are equivalent to kg m/s.
The **impulse-momentum theorem** states that the change in a particle's momentum is equal to the impulse on it. $\Delta\vec{p} = \vec{J}$

Example

- A 0.50 kg cart rolls to the right at +1.2 m/s.
- It collides with a force sensor.
- A plot of force versus time (with positive force defined as towards the right) gives an area of –1.0 N s.
- What is the velocity of the cart immediately after the collision?



A 100 g rubber ball and a 100 g damp cloth are dropped on the floor from the same height. They both are traveling at the same speed just before they hit the floor. The rubber ball bounces, the damp cloth does not. Which object exerts a larger downward impulse on the floor?

A. They exert equal impulses.
B. The damp cloth exerts a larger impulse.
C. The rubber ball exerts a larger impulse.

Chapter 9 big idea:
"Conservation of Momentum"

- A system of particles has a total momentum, $\vec{P}$
- If the system is isolated, meaning that there is no external net-force acting on the system, then:

$$\vec{P}_f = \vec{P}_i$$

- This means the momentum is "conserved"; it doesn't change over time.

Chapter 9 summary:

Law of Conservation of Momentum

The total momentum $\vec{P} = \vec{p}_1 + \vec{p}_2 + \cdots$ of an isolated system is a constant. Thus

$$\vec{P}_f = \vec{P}_i$$

Newton's Second Law

In terms of momentum, Newton's second law is

$$\vec{F} = \frac{d\vec{p}}{dt}$$

- Two particles collide, one of which was initially moving, and the other initially at rest. Is it possible for *both* particles to be at rest after the collision? [Assume no outside forces act on the particles.]

A. Yes

B. No

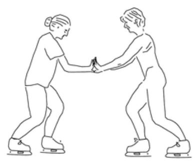
- Two particles collide, one of which was initially moving, and the other initially at rest. Is it possible for *one* particle to be at rest after the collision? [Assume no outside forces act on the particles.]

A. Yes

B. No

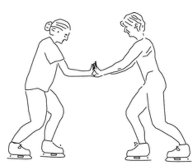
- Two ice skaters, Paula and Ricardo, push off from each other. They were both initially at rest. Ricardo has a greater mass than Paula. Which skater has the greater magnitude of momentum after the push-off?

A. Ricardo
B. Paula
C. neither



- Two ice skaters, Paula and Ricardo, push off from each other. They were both initially at rest. Ricardo has a greater mass than Paula. Which skater has the greater speed after the push-off?

A. Ricardo
B. Paula
C. neither



Chapter 10

What is "energy"?

- Energy is a property of an object, like age or height or mass.
- Every object that is moving has some Kinetic Energy.
- Objects in a gravitational or electric field may also have Potential Energy.
- Energy has units, and can be measured.
- Energy is relative; kinetic energy of car is different for an observer in the car than it is for an observer standing on the side of the road.

Momentum and Energy

- If a net force acts on a system, then, over time, its momentum will change. Impulse describes the change in momentum, and is equal to the integral of $F_{net} \bullet dt$.
- Not only is the momentum changing in time, the system also gains *energy* as it moves.
- If a net force acts on a system, then, over distance, its energy will change. Work describes the change in energy, and is equal to the integral of $F_{net} \bullet ds$. (this is a Chapter 11 concept)
- The SI unit of Work comes from force × distance. 1 N × 1 m = 1 Joule = 1 J.

Kinetic and Potential Energy

Work is a form of energy which gets transferred to an object when a force is acted upon it over a certain distance.

There are many other forms of energy. For examples:

Kinetic energy is an energy of ***motion***:

$$K = \frac{1}{2}mv^2 \qquad \text{(kinetic energy)}$$

Gravitational potential energy is an energy of ***position***:

$$U_g = mgy \qquad \text{(gravitational potential energy)}$$

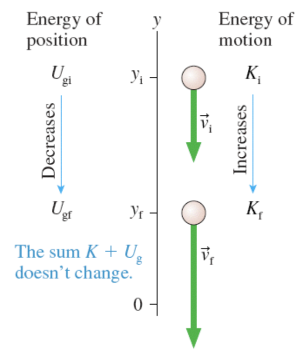
Chapter 10 big idea: "Conservation of Energy"

- A system of particles has a total energy, E.
- If the system is isolated, meaning that there is no work or heat being added or removed from the system, then:

$$E_f = E_i$$

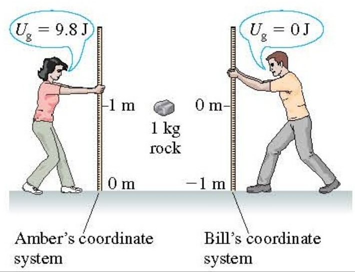
- This means the energy is "conserved"; it doesn't change over time.
- This is also the first law of thermodynamics; "You can't get something for nothing."

FIGURE 10.4 Kinetic energy and gravitational potential energy.



NOTE: The Zero of Potential Energy

- You can place the origin of your coordinate system, and thus the "zero of potential energy," wherever you choose and be assured of getting the correct answer to a problem.
- The reason is that only ΔU has physical significance, not U_g itself.



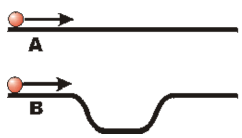
EXAMPLE: The speed of a sled

QUESTION:

Sidra runs forward with her sled at 2.0 m/s. She hops at the top of a very slippery slope. The slope is 7.0° below the horizontal, and extends down a total vertical distance of 5.0 m. What is her speed at the bottom?

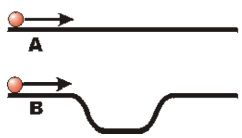
EXAMPLE: The speed of a sled

QUESTION:
Sidra runs forward with her sled at 2.0 m/s. She hops at the top of a very slippery valley. The valley goes down to 5.0 m below her starting position, then back up to the same initial height. What is her speed when she reaches the other side of the valley? [neglect friction]



Two balls are launched along a pair of tracks with equal velocities, as shown. Both balls reach the end of the track. *Predict*: Which ball will reach the end of the track first?

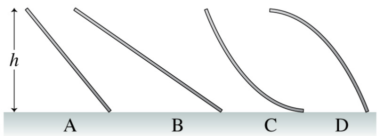
- A
- B
- C: They will reach the end of the track at the same time



Demo: Two balls were launched along a pair of tracks with equal velocities. Both balls reached the end of the track. *Observe*: Which ball reached the end of the track first?

- A
- B
- C: They reached the end of the track at the same time

A small child slides down the four frictionless slides A–D. Each has the same height, and the child always starts from rest. Rank in order, from largest to smallest, her speeds v_A to v_D at the bottom.



A. $v_C > v_A = v_B > v_D$
B. $v_C > v_B > v_A > v_D$
C. $v_D > v_A > v_B > v_C$
D. $v_A = v_B = v_C = v_D$
E. $v_D > v_A = v_B > v_C$

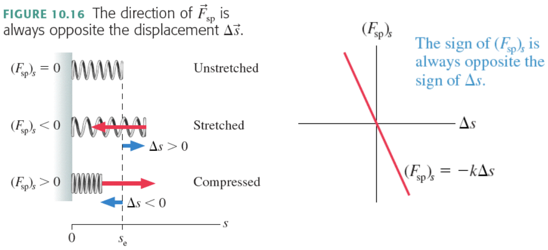
Hooke's Law

- If you stretch a rubber band, bend a ruler or other solid object, a force appears that tries to pull the object back to its equilibrium, or unstretched, state.
- A force that restores a system to an equilibrium position is called a **restoring force**.
- If s is the position, and s_e is the equilibrium position, we define $\Delta s = s - s_e$.

$$(F_{sp})_s = -k\Delta s \qquad \text{(Hooke's law)}$$

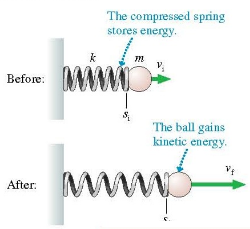
- where $(F_{sp})_s$ is the s-component of the restoring force, and k is the spring constant of the spring.
- The minus sign reminds you that it is a *restoring force*.

FIGURE 10.16 The direction of $\vec{F}_{sp}$ is always opposite the displacement $\Delta\vec{s}$.



Elastic Potential Energy

FIGURE 10.19 Before and after a spring launches a ball.



Consider a before-and-after situation in which a spring launches a ball. The compressed spring has "stored energy," which is then transferred to the kinetic energy of the ball. We define the **elastic potential energy** U_s of a spring to be

$$U_s = \frac{1}{2}k(\Delta s)^2 \qquad \text{(elastic potential energy)}$$

A spring-loaded gun shoots a plastic ball with a speed of 4 m/s. If the spring is compressed twice as far, the ball's speed will be

A. 1 m/s.
B. 2 m/s.
C. 4 m/s.
D. 8 m/s.
E. 16 m/s.

Before Next Class:

- Read Chapter 10 and 11 of Knight.
- Complete MasteringPhysics.com Problem Set 6 due by June 13 at 11:59pm
- Something to think about:
- If one object does work on another object, does energy always get transferred from one object to the other?