Physics 1408-002
Principles of Physics

Lecture 14
– Chapter 8 & 9 –
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Announcement I

Lecture note is on the web
Handout (6 slides/page)
http://highenergy.phys.ttu.edu/~slee/1408/

*** Class attendance is strongly encouraged and will be taken randomly. Also it will be used for extra credits.

HW Assignment #6 will be placed on MateringPHYSICS today, and is due by 11:59pm on Wendseday, 3/4

Announcement II

SI session by
Reginald Tuvilla

SI sessions will be at the following times and location.

Monday 4:30 - 6:00pm - Holden Hall 106
Thursday 4:00 - 5:30pm - Holden Hall 106

Chapter 8

Conservation of Energy

- Conservative and Non-conservative Forces
- Potential Energy
- Mechanical Energy and Its Conservation
- Problem Solving Using Conservation of Mechanical Energy
- The Law of Conservation of Energy
- Energy Conservation with Dissipative Forces: Solving Problems
- Gravitational Potential Energy and Escape Velocity
- Power

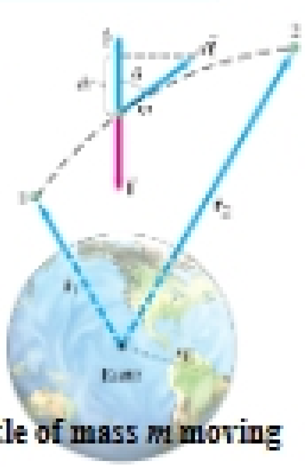
8-7 Gravitational Potential Energy and Escape Velocity

Far from the surface of the Earth, the force of gravity is not constant:

$$\vec{F} = -G\frac{mM_E}{r^2}\hat{r}.$$

The work done on an object moving in the Earth's gravitational field is given by:

$$W = \int_1^2 \vec{F}\cdot d\vec{\ell} = -GmM_E\int_1^2 \frac{\hat{r}\cdot d\vec{\ell}}{r^2}.$$



Arbitrary path of particle of mass m moving from point 1 to point 2.

8-7 Gravitational P.E. and Escape Velocity

$$W = \int_1^2 \vec{F}\cdot d\vec{\ell} = -GmM_E\int_1^2 \frac{\hat{r}\cdot d\vec{\ell}}{r^2}.$$

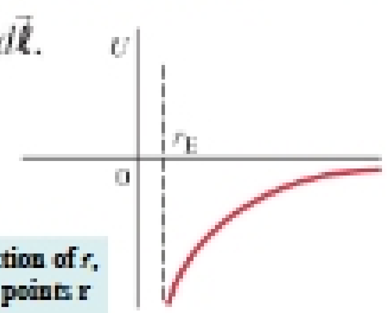
Solving the integral gives:

$$W = \frac{GmM_E}{r_2} - \frac{GmM_E}{r_1}.$$

We can define gravitational potential energy:

$$\Delta U = -W_G = -\int_1^2 \vec{F}_G\cdot d\vec{\ell}.$$

$$U(r) = -\frac{GmM_E}{r}.$$



Gravitational potential energy plotted as a function of r, the distance from Earth's center. Valid only for points $r > r_E$, the radius of the Earth.

8-7 Gravitational Potential Energy and Escape Velocity

Example: Package dropped from high-speed rocket.

A box of empty film canisters is allowed to fall from a rocket traveling outward from Earth at a speed of 1800 m/s when 1600 km above the Earth's surface. The package eventually falls to the Earth. Estimate its speed just before impact. Ignore air resistance.

$$\frac{1}{2}mv_1^2 - G\frac{mM_E}{r_1} = \frac{1}{2}mv_2^2 - G\frac{mM_E}{r_2}$$

$$v_2 = \sqrt{v_1^2 - 2GM_E(\frac{1}{r_1} - \frac{1}{r_2})} = 5320 \text{ m/s}$$

8-7 Gravitational Potential Energy and Escape Velocity

If an object's initial kinetic energy is equal to the potential energy at the Earth's surface, its total energy will be zero. The velocity at which this is true is called the escape velocity; for Earth:

$$v_{esc} = \sqrt{2GM_E/r_E} = 1.12 \times 10^4 \text{ m/s}.$$

8.8 Power

- The time rate of energy transfer
- The average power is given by $\overline{P} = \frac{W}{\Delta t}$

Instantaneous Power

- The instantaneous power is the limiting value of the average power as Δt approaches zero

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

- This can also be written $P = \frac{dW}{dt} = \vec{\mathbf{F}} \cdot \frac{d\vec{\ell}}{dt} = \vec{\mathbf{F}} \cdot \vec{\mathbf{v}}.$

Power Generalized

- Power can be related to any type of energy transfer
- In general, power can be expressed as $P = \frac{dE}{dt}$

Units of Power

- The SI unit of power is called the [watt]
  - 1 watt = 1 joule / second = 1 kg · m² / s²
- US Customary system is horsepower: 1 hp = 746 W
- Unit of energy can be defined in terms of units of power.
  - 1 kWh (kilowatt-hour)= (1000 W)(3600 s) = 3.6 x10⁶ J

Summary of Chapter 8

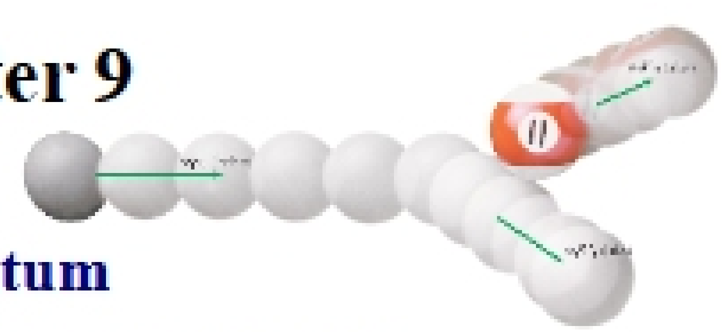
- Gravitational potential energy: $U_{grav} = mgy$.
- Elastic potential energy: $U_{el} = \frac{1}{2} kx^2$.
- For any conservative force:

$$\Delta U = U_2 - U_1 = -\int_1^2 \vec{\mathbf{F}} \cdot d\vec{\ell}.$$

- Total mechanical energy is the sum of kinetic and potential energies.
- Additional types of energy are involved when nonconservative forces act.
- Gravitational potential energy: $U(r) = -\frac{GmM_E}{r}.$
- Power: $P = \frac{dW}{dt} = \frac{dE}{dt}, \quad P = \vec{\mathbf{F}} \cdot \vec{\mathbf{v}}.$

Chapter 9

Linear Momentum



- Conservative Momentum and Its Relation to Force
- Conservation of Momentum
- Collisions and Impulse
- Conservation of Energy and Momentum in Collisions
- Inelastic Collisions
- Collisions in 1-, 2- or 3-Dimensions
- Center of Mass (CM) and Translational Motion
- Systems of Variable Mass; Rocket Propulsion

Momentum and Impulse

Interaction forces between systems can be very complex.

Example: a tennis ball colliding with a racquet

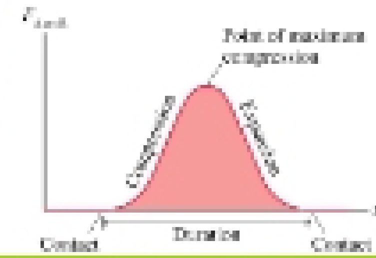
Our goal is to find a relationship between the velocities of the objects before and after the interaction.

A collision is a short-duration interaction b/w 2 objects. Typical collision times are b/w 1 and 10 ms, depending on the materials involved. The harder the objects, the shorter the contact time.

Microscopic view of a "bounce".

During contact the materials compress and a large spring-like force is exerted, called an impulsive force, which repels the object back apart.

Let's write F(t) for the force since it changes with time



Profile of the force during a collision.

9-1 Momentum and Its Relation to Force

Momentum is a vector symbolized by the symbol $\vec{\mathbf{p}}$, and is defined as

$$\vec{\mathbf{p}} = m\vec{\mathbf{v}}.$$

The **rate** of change of momentum is equal to the net **force**:

$$\Sigma\vec{\mathbf{F}} = \frac{d\vec{\mathbf{p}}}{dt}.$$

This can be shown using Newton's **second** law.

$$\Sigma\mathbf{F} = m\mathbf{a} = m\frac{d\mathbf{v}}{dt} = \frac{d(m\mathbf{v})}{dt} = \frac{d\mathbf{p}}{dt}$$

Momentum

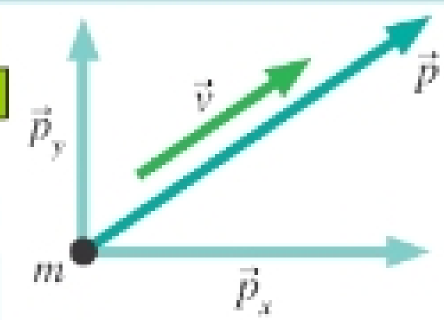
The product of a particle's mass and velocity is called the momentum

Definition: "momentum" $\vec{\mathbf{p}} = m\vec{\mathbf{v}}.$

Momentum is a vector quantity

In terms of components:

$p_x = mv_x;\ p_y = mv_y;\ p_z = mv_z;$



Newton formulated his 2[nd] law in terms of momentum:

2[nd] Law: $\vec{F} = m\vec{a} = m\frac{d\vec{v}}{dt} = \frac{d(m\vec{v})}{dt} = \frac{d\vec{p}}{dt}$

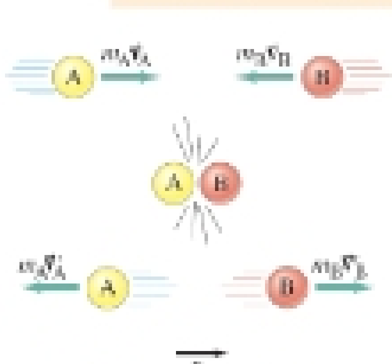
$$\Delta p_x = p_{2x} - p_{1x} = \int_{t_1}^{t_2} F_x(t)\,dt$$

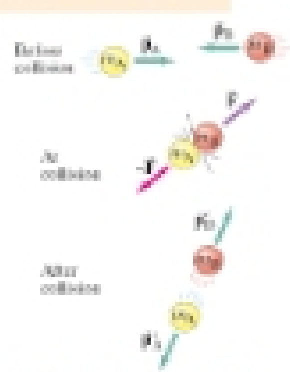
Force changes momentum

9-2 Conservation of Momentum

During a **collision**, measurements show that the total **momentum** does not change:

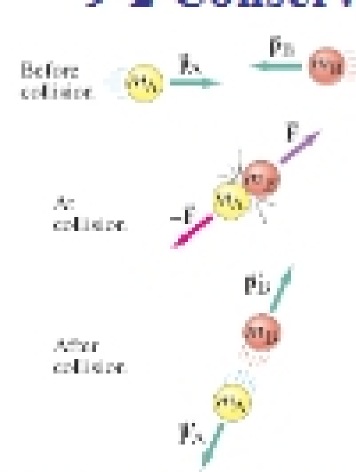
$$m_A\vec{\mathbf{v}}_A + m_B\vec{\mathbf{v}}_B = m_A\vec{\mathbf{v}}'_A + m_B\vec{\mathbf{v}}'_B.$$





Momentum is conserved in a collision of two balls, labeled A and B.

9-2 Conservation of Momentum



Conservation of momentum can also be derived from Newton's laws.

A collision takes a short enough time that we can ignore external forces.

Since the internal forces are equal and opposite, the total momentum is constant.

Collision of two objects. Their momenta before collision are p_A and p_B, and after collision are p_A' and p_B'. At any moment during the collision each exerts a force on the other of equal magnitude but opposite direction.