# PHYS 1443 – Section 004
# Lecture #14

*Thursday, Oct. 9, 2014*

*Dr. Jaehoon Yu*

- Power
- Linear Momentum and Force
- Linear Momentum Conservation
- Collisions and Impulse

# Announcements

- Mid-term comprehensive exam
  - In class 9:30 – 10:50am, Tuesday, Oct. 21
  - Covers CH 1.1 through what we finish Thursday, Oct. 16 plus the math refresher
  - Mixture of multiple choice and free response problems
  - Bring your calculator but DO NOT input formula into it!
    - Your phones or portable computers are NOT allowed as a replacement!
  - You can prepare a one 8.5x11.5 sheet (front and back) of **handwritten** formulae and values of constants for the exam
    - None of the parts of the solutions of any problems
    - No derived formulae, derivations of equations or word definitions!
  - Do NOT Miss the exam!

# Special Project #5

- Make a list of the ***rated power*** of all electric and electronic devices at your home and compiled them in a table. (2 points each for the first 10 items and 1 point for each additional item.)
  - What is an item?
    - Similar electric devices count as one item.
      - All light bulbs make up one item, computers another, refrigerators, TVs, dryers (hair and clothes), electric cooktops, heaters, microwave ovens, electric ovens, dishwashers, etc.
      - All you have to do is to count add all wattages of the light bulbs together as the power of the item
- Estimate the **cost of electricity** for each of the items (taking into account the number of hours you use the device) on the table using the electricity cost per kWh of the power company that serves you and put them in a separate column in the above table for each of the items. (2 points each for the first 10 items and 1 point each additional items). Clearly write down what the unit cost of the power is per kWh above the table.
- Estimate the the total amount of energy in Joules and the total electricity cost ***per month*** and ***per year*** for your home. (5 points)
- Due: Beginning of the class Thursday, Oct. 16

# Special Project Spread Sheet

**PHYS1444-004, Fall14, Special Project #5**

Download this spread sheet from: http://www-hep.uta.edu/~yu/teaching/fall14-1443-004/sp5-spreadsheet.xlsx

| Item Names | Rated power (W) | Number of devices | Average usage: Number of Hours per day | Daily | | | Monthly | | | Yearly | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Power Consumption (kWh) | Energy Usage (J) | Energy cost ($) | Power Consumption (kWh) | Energy Usage (J) | Energy cost ($) | Power Consumption (kWh) | Energy Usage (J) | Energy cost ($) |
| Light Bulbs | 30, 40, 60, 100, etc | 40 | | | | | | | | | | |
| Heaters | | | | | | | | | | | | |
| Fans | | | | | | | | | | | | |
| Air Conditioner | | | | | | | | | | | | |
| Fridgers, Freezers | | | | | | | | | | | | |
| Computers | | | | | | | | | | | | |
| Game consoles | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **Total** | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# Power

- Rate at which the work is done or the energy is transferred
  - What is the difference for the same car with two different engines (4 cylinder and 8 cylinder) climbing the same hill?
  - ➔ The time… 8 cylinder car climbs up the hill faster!

Is the total amount of work done by the engines different? NO

Then what is different? The rate at which the same amount of work performed is higher for 8 cylinders than 4.

Average power $\boxed{\bar{P} \equiv \frac{\Delta W}{\Delta t}}$

Instantaneous power $P \equiv \lim_{\Delta t \to 0} \frac{\Delta W}{\Delta t} = \frac{dW}{dt} = \lim_{\Delta t \to 0} \left(\sum \vec{F}\right) \cdot \frac{\Delta \vec{s}}{\Delta t} = \left(\sum \vec{F}\right) \cdot \vec{v} = \left|\sum \vec{F}\right| \left|\vec{v}\right| \cos\theta$

Unit? $\boxed{J/s = Watts}$ $\boxed{1HP \equiv 746Watts}$

What do power companies sell? $1kWH = 1000Watts \times 3600s = 3.6 \times 10^6 J$

**Energy**

# Energy Loss in Automobile

*Automobile uses only 13% of its fuel to propel the vehicle.*

*Why?*

67% in the engine:
- Incomplete burning
- Heat
- Sound

*16% in friction in mechanical parts*

*4% in operating other crucial parts such as oil and fuel pumps, etc*

*13% used for balancing energy loss related to moving vehicle, like air resistance and road friction to tire, etc*

*Two frictional forces involved in moving vehicles*

$$m_{car}=1450kg \quad Weight=mg=14200N$$

*Coefficient of Rolling Friction; μ=0.016*

$$\mu n=\mu mg=227N$$

*Air Drag*

$$f_a=\frac{1}{2}D\rho Av^2=\frac{1}{2}\times 0.5\times 1.293\times 2v^2=0.647v^2$$

*Total Resistance*

$$f_t=f_r+f_a$$

*Total power to keep speed v=26.8m/s=60mi/h*

$$P=f_t v=(691N)\cdot 26.8=18.5kW$$

*Power to overcome each component of resistance*

$$P_r=f_r v=(227)\cdot 26.8=6.08kW$$

$$P_a=f_a v=(464.7)\cdot 26.8=12.5kW$$

# Linear Momentum

*The principle of energy conservation can be used to solve problems that are harder to solve just using Newton's laws. It is used to describe the motion of an object or a system of objects.*

A new concept of linear momentum can also be used to solve physical problems, especially the problems involving collisions of objects.

*Linear momentum of an object whose mass is m and is moving at the velocity of **v** is defined as*

$$\boxed{\vec{p} \equiv m\vec{v}}$$

What can you tell from this definition about momentum?

1. *Momentum is a vector quantity.*
2. *The heavier the object the higher the momentum*
3. *The higher the velocity the higher the momentum*
4. *Its unit is kg.m/s*

*What else can use see from the definition? Do you see force?*

*The change of momentum in a given time interval*

$$\frac{\Delta\vec{p}}{\Delta t} = \frac{m\vec{v} - m\vec{v}_0}{\Delta t} = \frac{m\left(\vec{v} - \vec{v}_0\right)}{\Delta t} = m\frac{\Delta\vec{v}}{\Delta t} = m\vec{a} = \sum\vec{F}$$

# Linear Momentum and Forces

$$\sum \vec{F} = \lim_{\Delta t \to 0} \frac{\Delta \vec{p}}{\Delta t} = \frac{d\vec{p}}{dt}$$

What can we learn from this force-momentum relationship?

- The rate of the change of particle's momentum is the same as the net force exerted on it.
- When the net force is 0, the particle's linear momentum is a constant as a function of time.
- If a particle is isolated, the particle experiences no net force. Therefore its momentum does not change and is conserved.

Something else we can do with this relationship. What do you think it is?

*The relationship can be used to study the case where the mass changes as a function of time.*

Can you think of a few cases like this?

$$\sum \vec{F} = \frac{d\vec{p}}{dt} = \frac{d\left(m\vec{v}\right)}{dt} = \frac{dm}{dt}\vec{v} + m\frac{d\vec{v}}{dt}$$

*Motion of a meteorite*

*Motion of a rocket*

# Conservation of Linear Momentum in a Two Particle System

Consider an isolated system with two particles that do not have any external forces exerting on it. What is the impact of Newton's 3rd Law?

*If particle #1 exerts force on particle #2, there must be another force that the particle #2 exerts on #1 as the reaction force. Both the forces are internal forces, and the net force in the entire SYSTEM is* ***still 0.***

Now how would the momenta of these particles look like?

*Let say that the particle #1 has momentum* $\mathbf{p_1}$ *and #2 has* $\mathbf{p_2}$ *at some point of time.*

*Using momentum-force relationship*

$$\vec{F}_{21} = \frac{d\vec{p}_1}{dt} \quad \text{and} \quad \vec{F}_{12} = \frac{d\vec{p}_2}{dt}$$

*And since net force of this system is 0*

$$\sum \vec{F} = \vec{F}_{12} + \vec{F}_{21} = \frac{d\vec{p}_2}{dt} + \frac{d\vec{p}_1}{dt} = \frac{d}{dt}\left(\vec{p}_2 + \vec{p}_1\right) = 0$$

*Therefore* $\vec{p}_2 + \vec{p}_1 = const$ *The total linear momentum of the system is conserved!!!*

# More on Conservation of Linear Momentum in a Two Body System

*From the previous slide we've learned that the total momentum of the system is conserved if no external forces are exerted on the system.*

$$\sum \vec{p} = \vec{p}_2 + \vec{p}_1 = const$$

What does this mean?

*As in the case of energy conservation, this means that the total vector sum of all momenta in the system is the same before and after any interactions*

*Mathematically this statement can be written as*

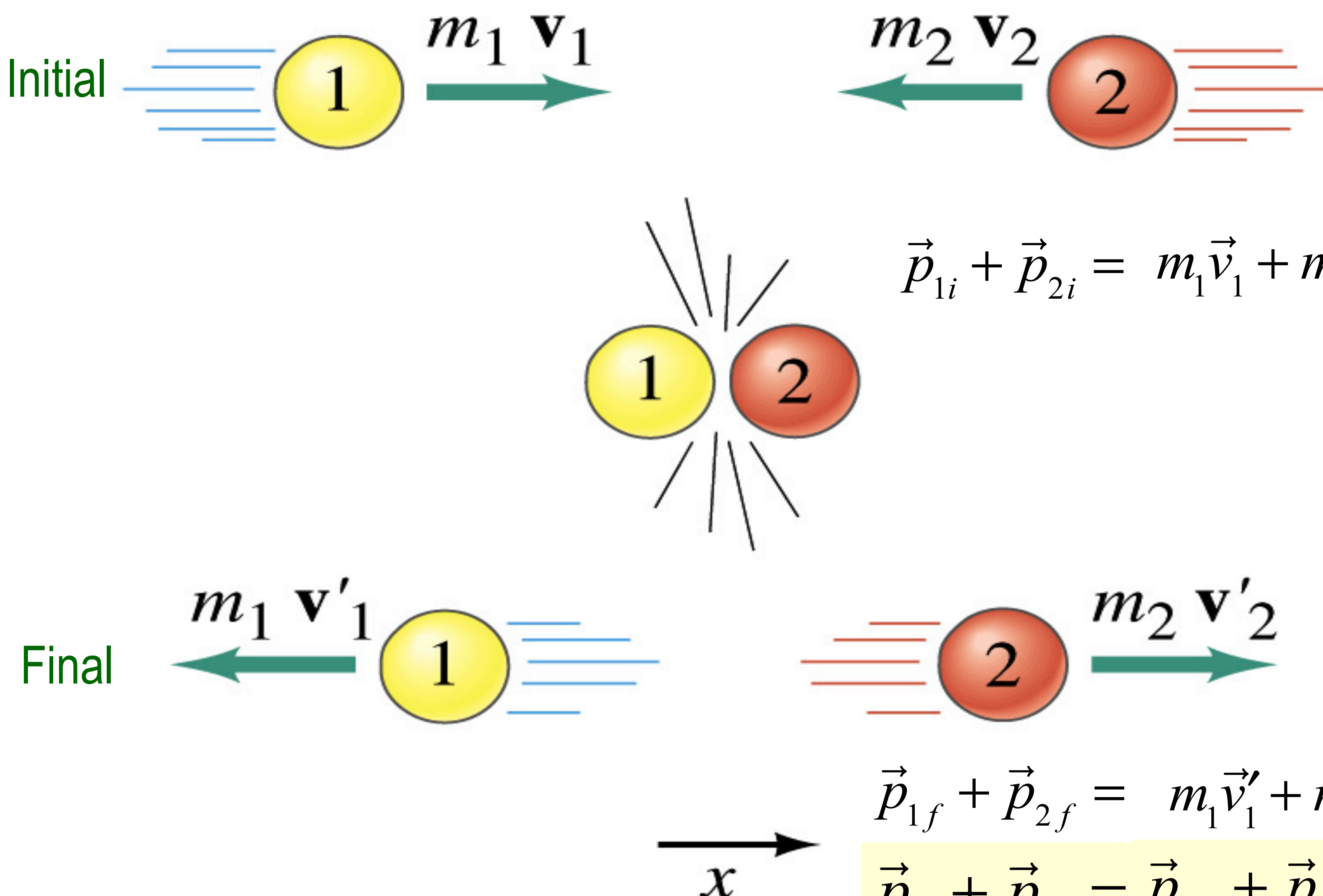
$$\vec{p}_{2i} + \vec{p}_{1i} = \vec{p}_{2f} + \vec{p}_{1f}$$

$$\sum_{system} P_{xi} = \sum_{system} P_{xf} \quad \sum_{system} P_{yi} = \sum_{system} P_{yf} \quad \sum_{system} P_{zi} = \sum_{system} P_{zf}$$

This can be generalized into conservation of linear momentum in many particle systems.

*Whenever two or more particles in an* ***isolated system*** *interact, the total momentum of the system remains constant.*

# Linear Momentum Conservation



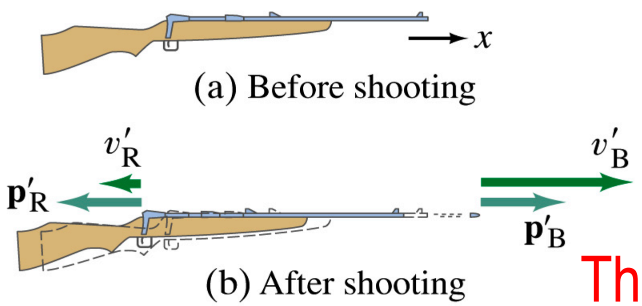

$$\vec{p}_{1i} + \vec{p}_{2i} = m_1\vec{v}_1 + m_2\vec{v}_2$$

$$\vec{p}_{1f} + \vec{p}_{2f} = m_1\vec{v}'_1 + m_2\vec{v}'_2$$

$$\vec{p}_{1i} + \vec{p}_{2i} = \vec{p}_{1f} + \vec{p}_{2f}$$

# Example: Rifle Recoil

Calculate the recoil velocity of a 5.0kg rifle that shoots a 0.020kg bullet at a speed of 620m/s.




From momentum conservation, we can write

$$\vec{p}_i = 0 = \vec{p}_f = \vec{P}_R + \vec{P}_B = m_R \vec{v}_R + m_B \vec{v}_B$$

The x-comp $P_R + P_B = m_R v_R + m_B v_B = 0$

Solving the above for $v_R$ and using the rifle's mass and the bullet's mass, we obtain

$$v_R = \frac{m_B}{m_R} v_B = \frac{0.020}{5.0} \cdot 620 = -2.5 m/s$$

$$\vec{v}_R = -2.5\vec{i}\,(m/s)$$

# Example for Linear Momentum Conservation

Estimate an astronaut's (M=70kg) resulting velocity after he throws his book (m=1kg) to a direction in the space to move to another direction.


From momentum conservation, we can write

$$\vec{p}_i = 0 = \vec{p}_f = m_A \vec{v}_A + m_B \vec{v}_B$$

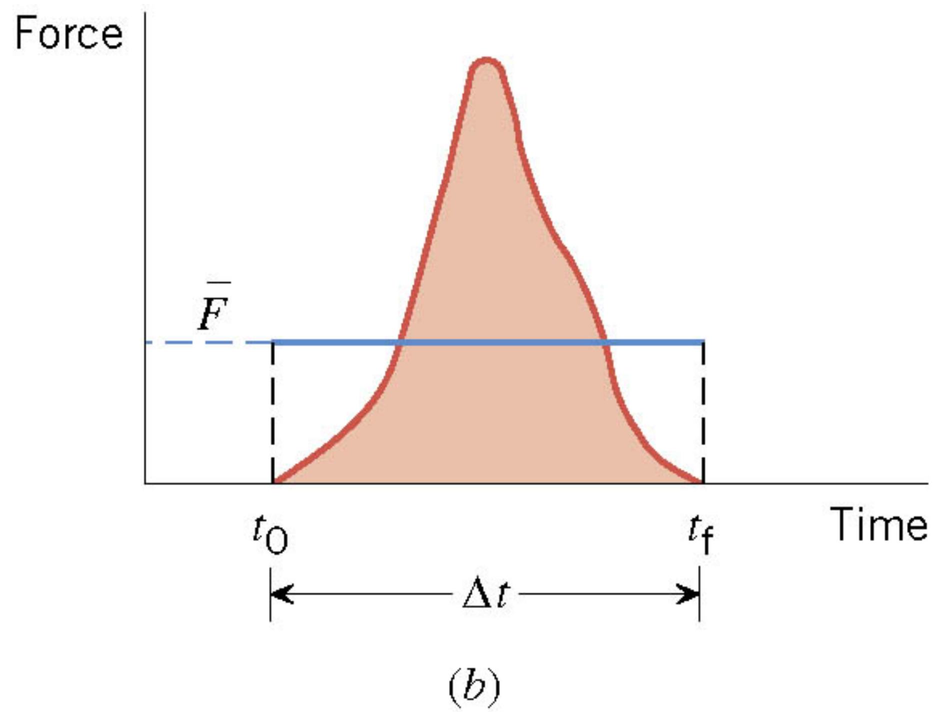
Assuming the astronaut's mass is 70kg, and the book's mass is 1kg and using linear momentum conservation

$$v_A = -\frac{m_B v_B}{m_A} = -\frac{1}{70} v_{\mathbf{B}}$$

Now if the book gained a velocity of 20 m/s in +x-direction, the Astronaut's velocity is

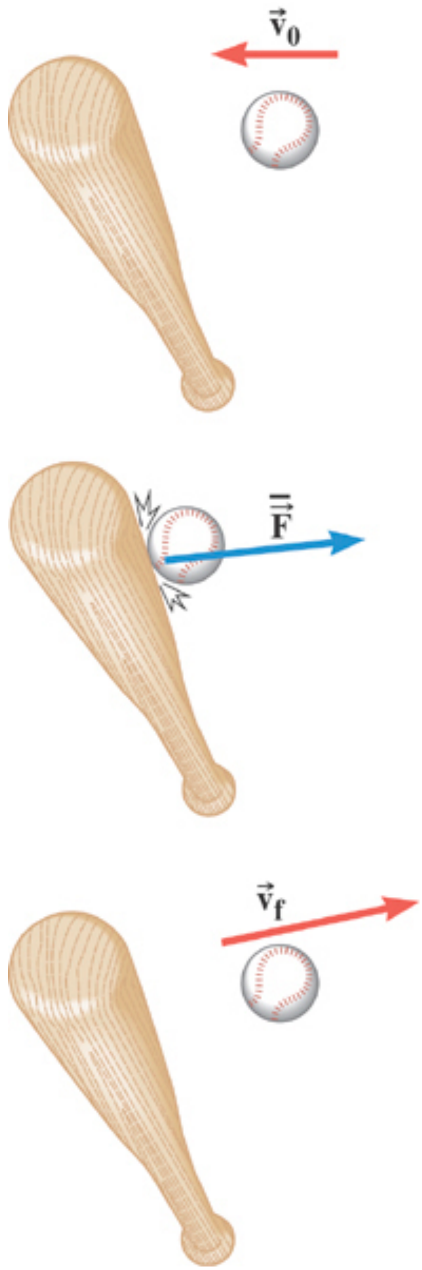
$$\vec{v}_A = -\frac{1}{70}\left(20\vec{i}\right) = -0.3\vec{i} \ (m/s)$$

# Impulse


There are many situations when the force on an object is not constant and in fact quite complicated!!

# Ball Hit by a Bat




$$\vec{\mathbf{a}} = \frac{\vec{\mathbf{v}}_f - \vec{\mathbf{v}}_o}{\Delta t}$$

$$\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$$

$$\sum \vec{\mathbf{F}} = \frac{m\vec{\mathbf{v}}_f - m\vec{\mathbf{v}}_o}{\Delta t}$$

**Multiply either side by Δt**

$$\left(\sum \vec{\mathbf{F}}\right)\Delta t = m\vec{\mathbf{v}}_f - m\vec{\mathbf{v}}_o = \vec{J}$$

# Impulse and Linear Momentum

*Net force causes change of momentum → Newton's second law*

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

By integrating the above equation in a time interval $t_i$ to $t_f$, one can obtain impulse $I$.

$$\int_{t_i}^{t_f} d\vec{p} = \vec{p}_f - \vec{p}_i = \Delta\vec{p} = \int_{t_i}^{t_f} \vec{F}\,dt = \vec{J}$$

So what do you think an impulse is?

*Effect of the force $F$ acting on an object over the time interval $\Delta t = t_f - t_i$ is equal to the change of the momentum of the object caused by that force. Impulse is the degree of which an external force changes an object's momentum.*

*The above statement is called the impulse-momentum theorem and is equivalent to Newton's second law.*

What are the dimension and unit of Impulse? What is the direction of an impulse vector?

*Defining a time-averaged force*

$$\overline{\vec{F}} \equiv \frac{1}{\Delta t}\sum_i \vec{F}_i \Delta t$$

*Impulse can be rewritten*

$$\vec{J} \equiv \overline{\vec{F}}\Delta t$$

*If force is constant*

$$\vec{J} \equiv \vec{F}\Delta t$$

*It is generally assumed that the impulse force acts on a short time but much greater than any other forces present.*