PHYS 1441 – Section 001
Lecture #9

Wednesday, June 24, 2015
Dr. Jaehoon Yu

- Newton's Laws Recap
- Application of Newton's Laws
- Force of Friction
- Uniform Circular Motion

Today's homework is homework #6, due 11pm, Tuesday, June 30!!

Announcements

- Reading Assignments: CH5.4 and 5.9
- Mid-term grade discussion
  - Tomorrow in my office (CPB342) during the class time
  - Organized by the last names
    - A – G: 10:30 – 11:00am
    - H – M: 11:00 – 11:30am
    - N – R: 11:30 – 12:00pm
    - S – Z: 12:00 – 12:30pm
- In class next Thursday, July 2
  - Non-comprehensive exam
  - Covers CH 4.6 to what we finish next Wednesday, July 1
  - 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 ➔ no solutions, derivations, word definitions or key methods for solutions
    - No additional formulae or values of constants will be provided!

Announcements II

- Quiz 3
  - Beginning of the class next Tuesday, June 30
  - Covers CH4.6 through what we finish Monday, June 29
  - BYOF
- Quiz 2 results
  - Class average: 24.5/49
    - Equivalent to: 50/100
    - Previous quiz: 75/100
  - Class top score: 49/49
- Mid-term exam results
  - Class average: 59.4/109
    - Equivalent to: 54.5/100
    - Previous quiz: 65/100
  - Class top score: 95/109

Special Project #3

- Using the fact that $g=9.80m/s^2$ on the Earth's surface, find the average density of the Earth.
  – Use ONLY the following information but without computing the value of the volume explicitly
    - The gravitational constant $G = 6.67\times10^{-11}\ N\cdot m^2/kg^2$
    - The radius of the Earth $R_E = 6.37\times10^3\,km$
- 20 point extra credit
- Due: Tuesday, June 30
- You must show your OWN, detailed work to obtain any credit!!

Newton's Three Laws Motion

1st law of motion (Law of Inertia): *In the absence of external forces, an object at rest remains at rest and an object in motion continues in motion with a constant velocity.*

2nd law of motion: *The acceleration of an object is directly proportional to the net force exerted on it and is inversely proportional to the object's mass.*

$$\sum_i \vec{F}_i = m\vec{a}$$

3rd law of motion: *If two objects interact, the force F_{21} that object 2 exerts on object 1 is equal in magnitude and opposite in direction to the force F_{12} object 1 exerts on object 2.*

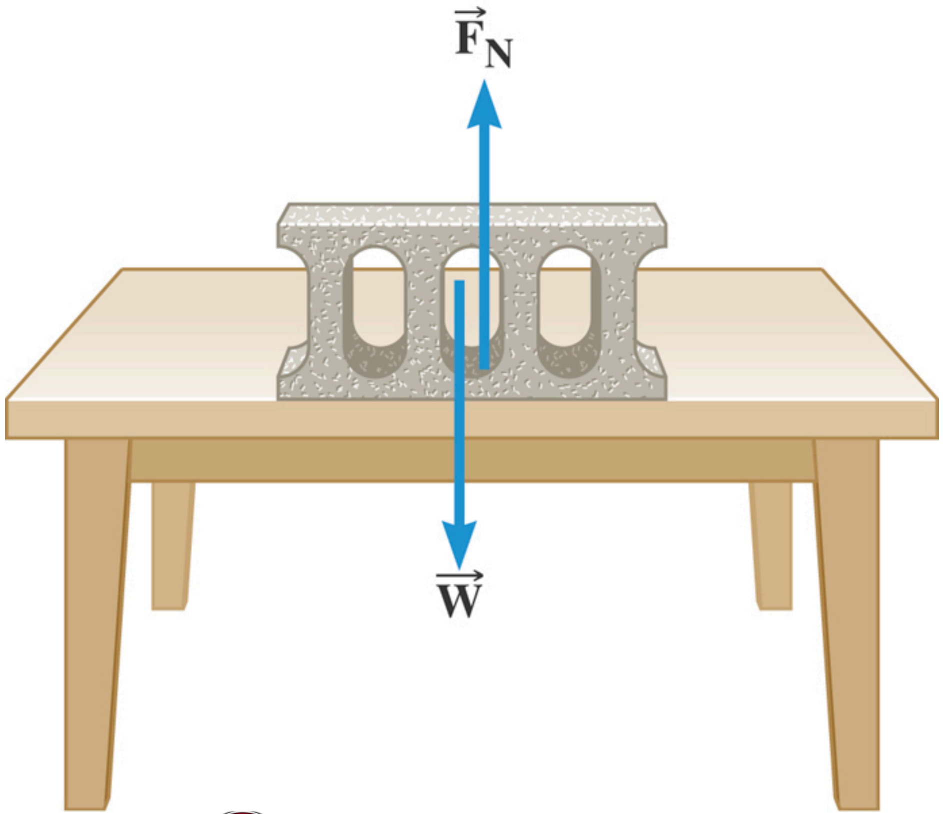
$$\vec{F}_{12} = -\vec{F}_{21}$$

Categories of Forces

- Fundamental Forces: Truly unique forces that cannot be derived from any other forces
  - Total of four fundamental forces
    - Gravitational Force
    - Electromagnetic Force
    - Weak Nuclear Force
    - Strong Nuclear Force
- Non-fundamental forces: Forces that are derived from the fundamental forces
  - Friction
  - Tension in a rope
  - Normal or support forces

The Normal Force

The normal force is one component of the force that a surface exerts on an object with which it is in contact – namely, the force component that is **perpendicular to the surface**.

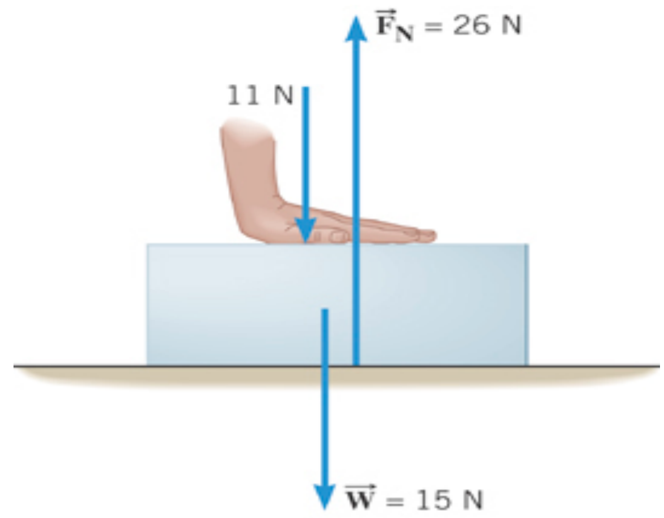


Some normal force exercises

Case 1: Hand pushing down on the book

$$F_N - 11\text{ N} - 15\text{ N} = 0$$

$$F_N = 26\text{ N}$$

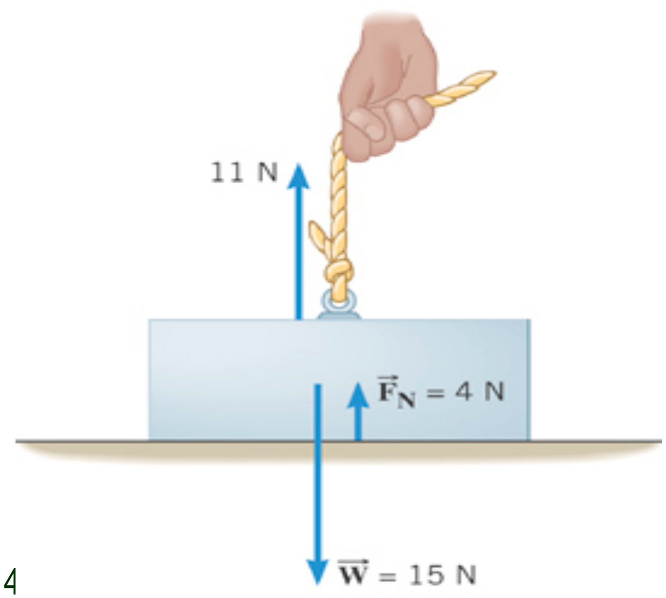


(a)

Case 2: Hand pulling up the book

$$F_N + 11\text{ N} - 15\text{ N} = 0$$

$$F_N = 4\text{ N}$$



(b)

Some Basic Information

When Newton's laws are applied, *external forces* are only of interest!!

Why?

Because, as described in Newton's first law, an object will keep its current motion unless non-zero net external force is applied.

Normal Force, ***n***:

The force that reacts to action forces due to the surface structure of an object. Its direction is always perpendicular to the surface.

Tension, ***T***:

The reactionary force by a stringy object against an external force exerted on it.

Free-body diagram

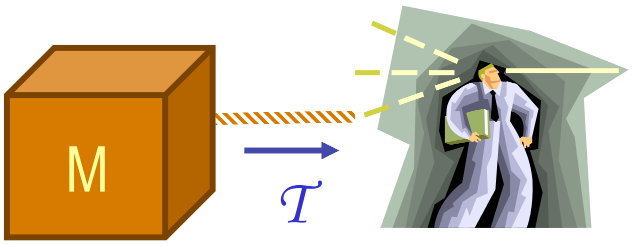
*A graphical tool which is a **diagram of external forces on an object** and is extremely useful analyzing forces and motion!! Drawn only on an object.*

Solving a problem using Newton's Laws

1. Identify all the forces acting on the object we are trying to figure out the motion!
2. Draw a free body diagram of all the forces with proper directions indicated
3. Write down the vector equation with all the forces
4. Establish force equations for each component of the forces
5. Solve for the quantities asked using force equations and the relevant kinematic equations

Applications of Newton's Laws

Suppose you are pulling a box on frictionless ice, using a rope.



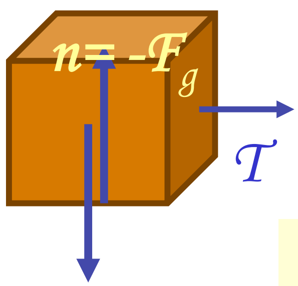
What are the forces being exerted on the box?

Gravitational force: $\boldsymbol{F_g}$

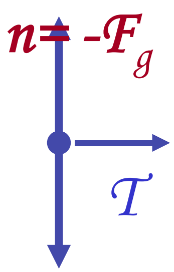
Normal force: $\boldsymbol{n}$

Tension force: $\boldsymbol{T}$

Free-body diagram



$F_g = -Mg$



$F_g = -Mg$

Total vector force:
$\boldsymbol{F = F_g + n + T = T}$

$$\sum F_x = T = Ma_x \qquad a_x = \frac{T}{M}$$

$$\sum F_y = -F_g + n = Ma_y = 0 \qquad a_y = 0$$

If T is a constant force, a_x, is constant

$$v_{xf} = v_{xi} + a_x t = v_{xi} + \left(\frac{T}{M}\right)t$$

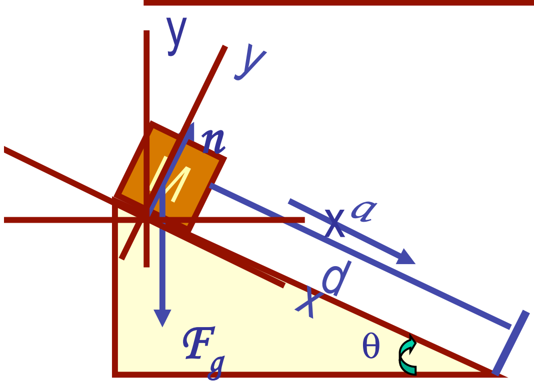
$$\Delta x = x_f - x_i = v_{xi}t + \frac{1}{2}\left(\frac{T}{M}\right)t^2$$

What happened to the motion in y-direction?

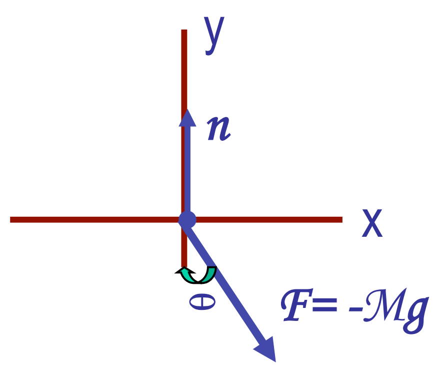
Example w/o Friction

A crate of mass M is placed on a frictionless inclined plane of angle θ.

a) Determine the acceleration of the crate after it is released.



Free-body Diagram



$$\vec{F} = \vec{F}_g + \vec{n} = m\vec{a}$$

$$F_x = Ma_x = F_{gx} = Mg\sin\theta$$

$$a_x = g\sin\theta$$

$$F_y = Ma_y = n - F_{gy} = n - mg\cos\theta = 0$$

Supposed the crate was released at the top of the incline, and the length of the incline is d. How long does it take for the crate to reach the bottom and what is its speed at the bottom?

$$d = v_{ix}t + \frac{1}{2}a_x t^2 = \frac{1}{2}g\sin\theta\, t^2$$

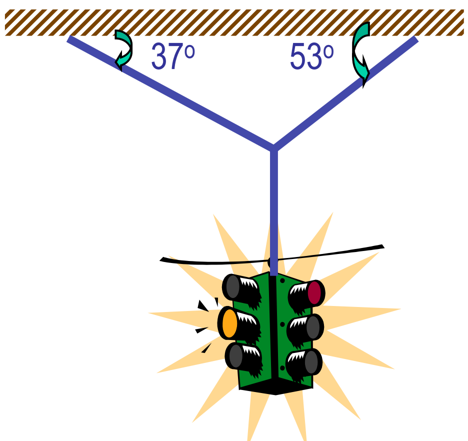
$$\therefore t = \sqrt{\frac{2d}{g\sin\theta}}$$

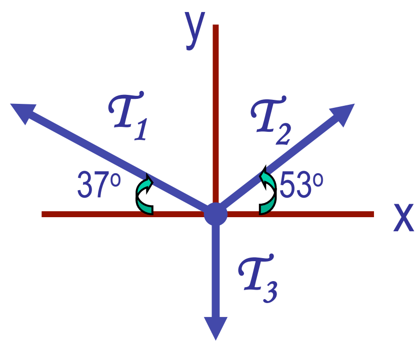
$$v_{xf} = v_{ix} + a_x t = g\sin\theta\sqrt{\frac{2d}{g\sin\theta}} = \sqrt{2dg\sin\theta}$$

$$\therefore v_{xf} = \sqrt{2dg\sin\theta}$$

Example for Using Newton's Laws

A traffic light weighing 125 N hangs from a cable tied to two other cables fastened to a support. The upper cables make angles of 37.0° and 53.0° with the horizontal. Find the tension in the three cables.





$$\vec{F} = \vec{T}_1 + \vec{T}_2 + \vec{T}_3 = m\vec{a} = 0$$ Newton's 2nd law

x-comp. of net force

$$F_x = \sum_{i=1}^{i=3} T_{ix} = 0 \quad -T_1\cos(37^\circ) + T_2\cos(53^\circ) = 0 \therefore T_1 = \frac{\cos(53^\circ)}{\cos(37^\circ)} T_2 = 0.754T_2$$

y-comp. of net force

$$F_y = \sum_{i=1}^{i=3} T_{iy} = 0$$

$$T_1\sin(37^\circ) + T_2\sin(53^\circ) - mg = 0$$

$$T_2\left[\sin(53^\circ) + 0.754 \times \sin(37^\circ)\right] = 1.25T_2 = 125N$$

$$T_2 = 100N;\ T_1 = 0.754T_2 = 75.4N$$

Force of Friction

Resistive force exerted on a moving object due to viscosity or other types frictional property of the medium in or surface on which the object moves.

These forces are either proportional to the velocity or the normal force.

Force of static friction, f_s: *The resistive force exerted on the object until just before the beginning of its movement*

Empirical Formula

$$\left|\vec{f}_s\right| \le \mu_s \left|\vec{n}\right|$$

What does this formula tell you?

Static friction force increases till it reaches the limit!!

Beyond the limit, the object moves, and there is **NO MORE** static friction but the kinetic friction takes it over.

Force of kinetic friction, f_k

The resistive force exerted on the object during its movement

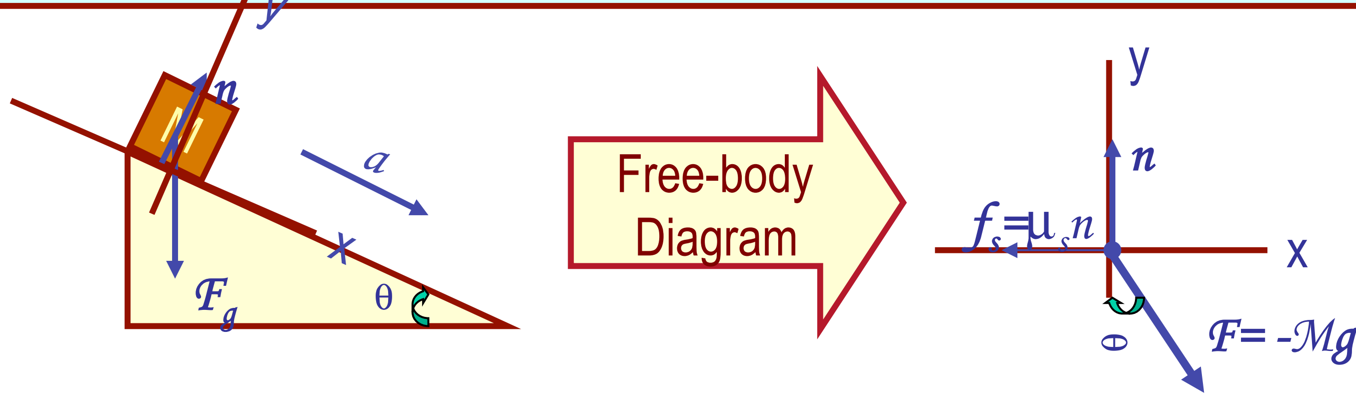
$$\left|\vec{f}_k\right| = \mu_k \left|\vec{n}\right|$$

Which direction does kinetic friction apply?

Opposite to the motion!

Example w/ Friction

Suppose a block is placed on a rough surface inclined relative to the horizontal. The inclination angle is increased till the block starts to move. Show that by measuring this critical angle, θ_c, one can determine coefficient of static friction, μ_s.



Net force $\vec{F} = M\vec{a} = \vec{F}_g + \vec{n} + \vec{f}_s$

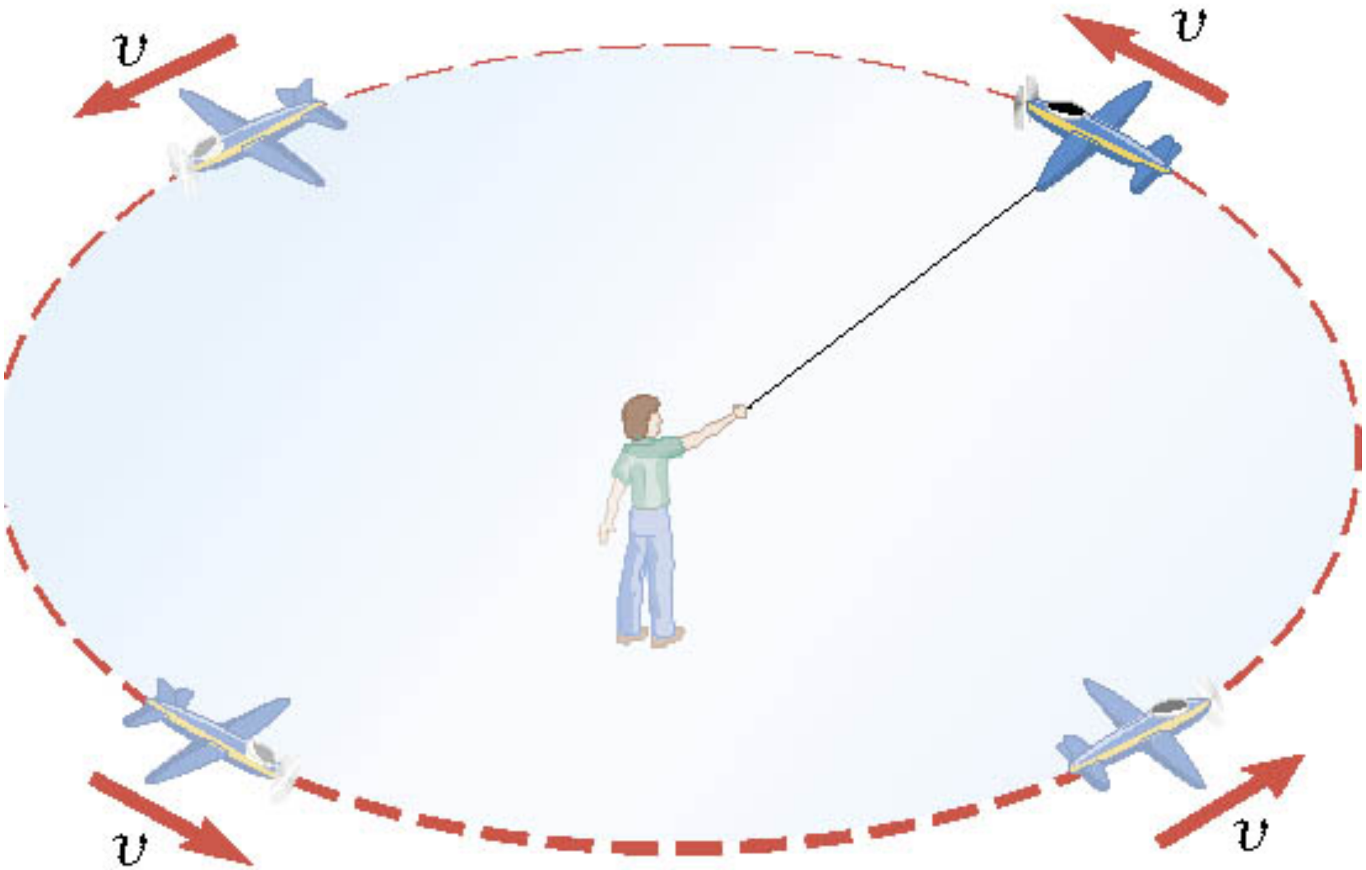
x comp. $F_x = F_{gx} - f_s = Mg\sin\theta - f_s = 0 \quad f_s = \mu_s n = Mg\sin\theta_c$

y comp. $F_y = Ma_y = n - F_{gy} = n - Mg\cos\theta_c = 0 \quad n = F_{gy} = Mg\cos\theta_c$

$$\mu_s = \frac{Mg\sin\theta_c}{n} = \frac{Mg\sin\theta_c}{Mg\cos\theta_c} = \tan\theta_c$$

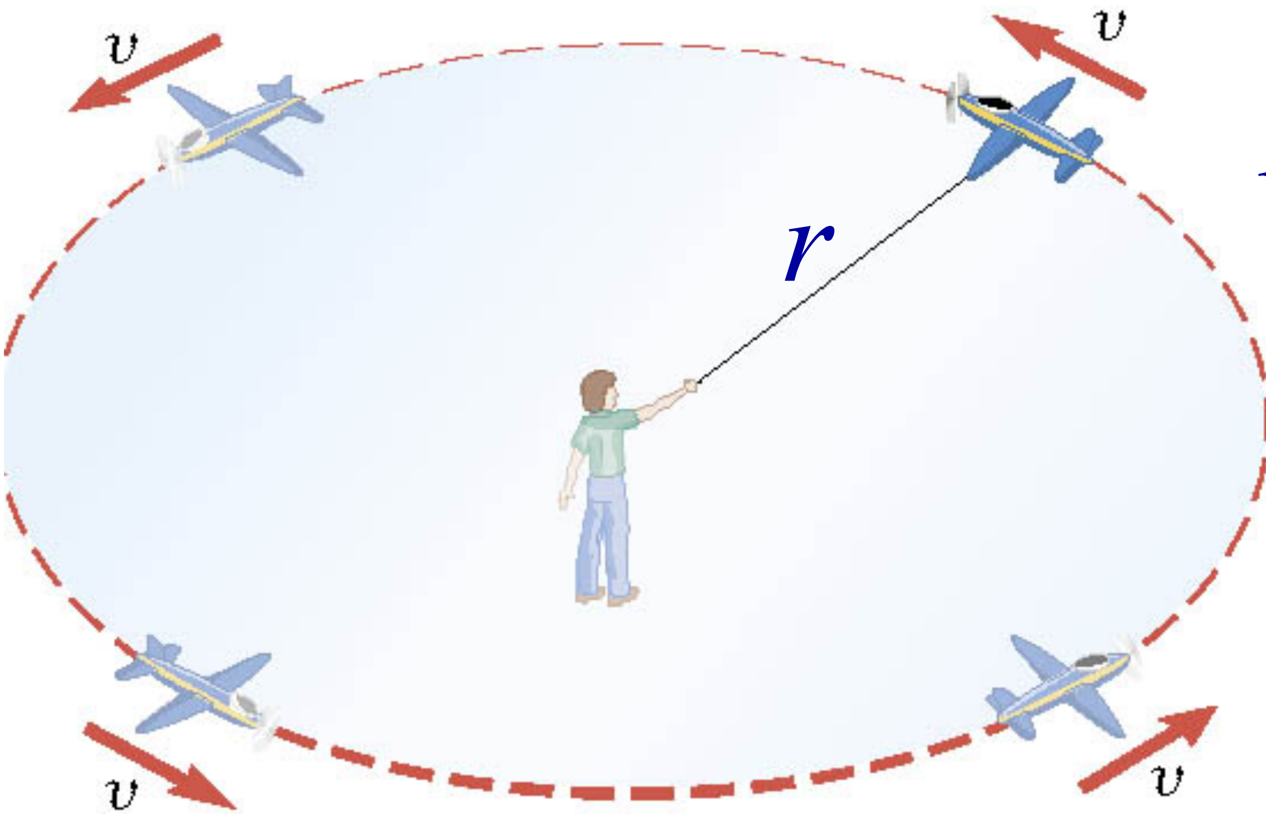
Definition of the Uniform Circular Motion

Uniform circular motion is the motion of an object traveling at a constant **speed** on a circular path.



Speed of a uniform circular motion?

Let *T* be the period of this motion, the time it takes for the object to travel once around the complete circle whose radius is r.



$$v = \frac{\text{distance}}{\text{time}} = \frac{2\pi r}{T}$$

Ex. : A Tire-Balancing Machine

The wheel of a car has a radius of 0.29m and is being rotated at 830 revolutions per minute on a tire-balancing machine. Determine the speed at which the outer edge of the wheel is moving.

$$\frac{1}{830\,\text{revolutions/min}} = 1.2\times10^{-3}\ \text{min/revolution}$$

$$T = 1.2\times10^{-3}\ \text{min} = 0.072\ \text{s}$$

$$v = \frac{2\pi r}{T} = \frac{2\pi(0.29\ \text{m})}{0.072\ \text{s}} = 25\,\text{m/s}$$