Motion in many dimensions: Circular motion.

Newton’s Laws of Motion.
Laws that answer “why” questions about motion.
Forces. Inertia. Momentum.

Uniform Circular Motion

- Uniform circular motion – the motion of an object describing a circular path at constant speed.
- The motion is accelerated because the direction of the velocity is changing.
- The velocity vectors are tangent to the circular path.
- Acceleration vector is always perpendicular to the velocity.
- When acceleration is always perpendicular to velocity, then only the direction of velocity changes and not the magnitude.
Uniform Circular Motion

- This acceleration is known as radial acceleration, $a_r$, or centripetal acceleration, $a_c$.

- “Centripetal” = “center-seeking.”

- The magnitude of centripetal acceleration is given by

\[ a = \frac{v^2}{r} \]

while the direction of centripetal acceleration is always toward the center of the circular motion.
Nonuniform circular motion

- An object moving in a curved path with varying speed is in nonuniform circular motion.
- Both direction and magnitude of the velocity are changing
  \( \Rightarrow \) acceleration cannot be strictly \( \parallel \) or \( \perp \) to the velocity.
  \[
  \vec{a} = \vec{a}_r + \vec{a}_t
  \]
  \( \vec{a}_r \) changes only the direction of the velocity
  \( \vec{a}_t \) changes only the magnitude of the velocity.
- Uniform circular motion: \( a_t = 0 \); 1D motion: \( a_r = 0 \)

Clicker Question

An object moves outward along a spiral path shown. If the magnitude of its radial acceleration is to remain constant, which of the following is true?

A) its speed must increase.
B) its speed must decrease.
C) its speed must remain the same.
D) the magnitude of its radial acceleration will remain constant regardless of whether or not its speed is changing.
E) the magnitude of its radial acceleration cannot remain constant for the type of motion shown.
Dynamics

- **Kinematics**: the study of motion without reference to its causes
  - Key concepts: displacement, velocity, acceleration

- **Dynamics**: study of the causes of changes in motion (starting, stopping, speeding up, slowing down, changing direction)
  - New Concepts: Force, Mass

Newton’s Three Laws of Motion:
- Obtained from first principles => fundamental;
- Based on experimental observations of motion, not product of math derivation

How would you define a force?

- **The Moon has been circling Earth for billions of yrs, not moving away. Why?**
  - Earth’s gravity “pulls” on the Moon.

- **You stand on the 2nd floor of a building and don’t fall through. Why?**
  - The floor “pushes” upward, counters the downward “pull” of gravity.

- Force is a push or a pull on an object.
- Is force a vector or a scalar?
  - Force is a vector (magnitude and direction).
Contact Forces vs. Field Forces

- At the microscopic level, what we call contact forces involve action-at-a-distance electric forces between the particles composing macroscopic objects.

Typical force magnitudes

<table>
<thead>
<tr>
<th>Force Description</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravitational pull of the Sun on Earth</td>
<td>$3.5 \times 10^{22}$ N</td>
</tr>
<tr>
<td>Thrust of a large jet engine</td>
<td>$7.7 \times 10^5$ N</td>
</tr>
<tr>
<td>Pull of a large locomotive</td>
<td>$5 \times 10^5$ N</td>
</tr>
<tr>
<td>Gravitational pull of Earth on a person</td>
<td>$7.3 \times 10^2$ N</td>
</tr>
<tr>
<td>Weight of a medium sized apple</td>
<td>1 N</td>
</tr>
<tr>
<td>Gravitational pull of Earth on a 5 cent coin</td>
<td>$5.1 \times 10^{-2}$ N</td>
</tr>
<tr>
<td>Electric attraction between the proton and the electron</td>
<td>$8.2 \times 10^{-8}$ N</td>
</tr>
<tr>
<td>Weight of a small bacterium</td>
<td>$1 \times 10^{-18}$ N</td>
</tr>
<tr>
<td>Gravitational attraction between the proton and the electron</td>
<td>$3.6 \times 10^{-47}$ N</td>
</tr>
</tbody>
</table>
The wrong and the right questions about motion

• Aristotle’s Q: “What keeps things moving?”

• Galileo: a moving object needs no push to keep it moving. Q: “What causes changes in motion?”
  (starting, stopping, speeding up, slowing down, changing direction)

• Newton: Formulated 3 quantitative laws describing how exactly motion changes.

  Introduced the idea of forces for quantitative description of interaction btw an object & its environment.

Newton’s First Law

A body in uniform motion remains in uniform motion, and a body at rest remains at rest, unless acted on by a nonzero net force.

• Uniform motion = unchanging motion (in a straight line at constant speed)

• A net force is a vector sum of all forces on an object ($\Sigma F$).

• The 1st law: it does not take a force to keep something in unchanging motion; force is needed only to change an object’s state of motion.
Clicker Question

The figure is a view looking down on a horizontal tabletop. On the tabletop is a curved barrier that exerts a force on a ball, guiding its motion in a circular path, as shown.

After the ball ceases contact with the barrier, which of the dashed paths shown does it follow?

A  
B  
C

Force diagrams (=“free-body diagrams”)

- In a force diagram:
  1. Represent object of interest as •
  2. Draw all the force vectors acting on that object.

A chair is at rest in the middle of a room:

\[ F_{\text{ground on ch}} \]

\[ F_{\text{Earth on ch}} \]

A flying squirrel is gliding (no wing flaps) from a tree to the ground at constant velocity:

\[ F_{\text{air on sq}} \]

\[ F_{\text{Earth on sq}} \]

By Newton’s 1st Law: \( \Sigma F = 0 \)
1st law = the law of inertia

• 1st law: it takes a force to change an object’s motion. => objects naturally resist a change in motion.

• In the absence of a net force, i.e., when \( \Sigma F = 0 \), objects tend to keep on doing what they’re doing.

• Inertia = the resistance an object has to a change in its state of motion.

Inertia

• Some objects are hard to start moving - or hard to stop once started. (stop a baseball vs. a bowling ball thrown at you)

• Inertia describes the resistance to changes in motion. NOTE: inertia is not a force, it is a tendency.

• A measure of an object’s inertia: its mass.

• Inertia is often masked by friction (quickly brings moving objects to rest) => misled Aristotle who believed objects moved only so long as force was being applied to them.
Momentum

• Newton: the best measure of an object’s “quantity of motion” is momentum.

• Momentum vector:

\[ \vec{p} = m\vec{v} \]

- takes into account inertia, speed, and the direction of motion.

• How does the momentum vector of an object change throughout the object’s motion?

⇒ Newton’s 2nd law.

Newton’s Second Law

The rate at which a body’s momentum changes is equal to the net force acting on the body:

\[ \sum \vec{F} = \frac{d\vec{p}}{dt} \]

• It’s the net force (\( \sum \vec{F} \)) that is important in determining the change in the object’s motion.

• When a body’s mass remains constant ⇒

\[ \sum \vec{F} = \frac{d\vec{p}}{dt} = \frac{d(m\vec{v})}{dt} = m\frac{d\vec{v}}{dt} = ma \]

\[ \sum \vec{F} = m\vec{a} \]

• SI unit of force is the newton N = (kg)(m/s²)
For Next Time:

- Read Chapter 3
- Finish up homework for Chapter 3
- Study for Quiz 2 (Ch. 3)
- These clickers have NOT been registered by the deadline (April 15).