Recap: relative motion

- An object moves with velocity $\vec{v}'$ relative to one frame of reference.
- That frame moves at $\vec{V}$ relative to a second reference frame.
- Then the velocity of the object relative to the second frame is $\vec{v} = \vec{v}' + \vec{V}$.
- Example:
  - A jetliner flies at 960 km/h relative to the air, heading northward. There’s a wind blowing eastward at 190 km/h. In what direction should the plane fly?
  - The vector diagram identifies the quantities in the equation, and shows that the angle is 11°.
Recap: constant acceleration

• With constant acceleration, the equations for one-dimensional motion apply independently in each direction.
  • The equations take a compact form in vector notation.
  • Each equation stands for two or three separate equations.

\[
\begin{align*}
\vec{v} &= \vec{v}_0 + \vec{a} \cdot t \\
\vec{r} &= \vec{r}_0 + \vec{v}_0 \cdot t + \frac{1}{2} \vec{a} \cdot t^2
\end{align*}
\]
Recap: projectile motion

- Motion under the influence of gravity near Earth’s surface has essentially constant acceleration \( \ddot{g} \) whose magnitude is \( g = 9.8 \text{ m/s}^2 \), and whose direction is downward.

- Such motion is called **projectile motion**.

- Equations for projectile motion, in a coordinate system with \( y \) axis vertically upward:

  \[
  \begin{align*}
  v_x &= v_{x0} \\
  v_y &= v_{y0} - gt \\
  x &= x_0 + v_{x0} t \\
  y &= y_0 + v_{y0} t - \frac{1}{2} gt^2
  \end{align*}
  \]

- Horizontal and vertical motions are independent:

  Vertical spacing is the same, showing that vertical and horizontal motion are independent.
Projectile trajectories

- The trajectory of an object in projectile motion is a parabola, unless the object has no horizontal component of motion.

- Horizontal motion is unchanged, while vertical motion undergoes downward acceleration:

- Equation for the trajectory:

\[ y = x \tan \theta_0 - \frac{g}{2v_0^2 \cos^2 \theta_0} x^2 \]
Uniform circular motion

- When an object moves in a circular path of radius $r$ at constant speed $v$, its acceleration has magnitude
  $$ a = \frac{v^2}{r} $$
- The acceleration vector points toward the center of the circle.
- Since the direction of the acceleration keeps changing, this is *not* constant acceleration.
The figure shows velocity vectors for four points on a noncircular path. Choose the correct order, from smallest to largest, of the centripetal accelerations at these points given $v_1 = v_4$ and $v_2 = v_3$.

A. $a_1 > a_4 > a_3 > a_2$

B. $a_2 > a_3 > a_4 > a_1$

C. $a_3 > a_2 > a_1 > a_4$

D. $a_2 > a_3 > a_1 > a_4$
Summary

- In two and three dimensions, position, velocity, and acceleration become vector quantities.
  - Velocity is the rate of change of position: \( \dot{r} = \frac{dr}{dt} \)
  - Acceleration is the rate of change of velocity: \( \ddot{r} = \frac{d\dot{r}}{dt} \)
- In general, acceleration changes both the magnitude and direction of the velocity.
- Projectile motion results from the acceleration of gravity.
- In uniform circular motion, the acceleration has magnitude \( v^2/r \) and points toward the center of the circular path.
In this lecture you’ll learn

- The concept of force and its role in causing *changes* in motion
- The fundamental forces of physics
- Newton’s three laws of motion
- About the force of gravity
  - Including the distinction between mass and weight
- How to apply Newton’s laws in one-dimensional motion
What causes motion?

- That’s the wrong question!
  - The ancient Greek philosopher Aristotle believed that forces—pushes and pulls—caused motion.
    - The Aristotelian view prevailed for some 2000 years.
  - Galileo and Newton discovered the correct relation between force and motion.
    - Force causes not motion itself but change in motion.

The Aristotelian view

![Diagram: Force -> Motion]

The Newtonian view

![Diagram: Force -> Change in motion]
Newton’s laws of motion

- **Newton’s first law of motion:** 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.

- **Newton’s second law of motion:** The rate at which a body’s momentum changes is equal to the net force acting on the body:

  \[
  \vec{F}_{\text{net}} = \frac{dp}{dt} \quad \text{(Newton’s 2\textsuperscript{nd} Law)}
  \]

- **Newton’s third law of motion:** If object A exerts a force on object B, then object B exerts an oppositely directed force of equal magnitude on A.
The first law

- The first law is a special case of the second law, when there’s no net force acting on an object.
  - In that case the object’s motion doesn’t change.
  - If at rest it remains at rest.
  - If in motion, it remains in uniform motion.
    - Uniform motion is motion at constant speed in a straight line.
    - Thus the first law shows that uniform motion is a natural state, requiring no explanation.
• On a horizontal tabletop is a curved barrier that exerts a force on a ball, guiding its motion in a circular path as shown. After the ball leaves the barrier, which of the dashed paths shown does it follow?
The second law

• The second law tells quantitatively how force causes changes in an object’s “quantity of motion.”
  • Newton defined “quantity of motion,” now called momentum, as the product of an object’s mass and velocity:
    \[ \dot{p} = mv \]

• Newton’s second law equates the rate of change of momentum to the net force on an object:
  \[ F = \frac{dp}{dt} \]

• When mass is constant, Newton’s second law becomes
  \[ F = \frac{d(mv)}{dt} = m\frac{dv}{dt} = ma \]
A nonzero net force acts on an object. Does that mean the object necessarily moves in the same direction as the net force?

A. Yes
B. No