Physics 1501

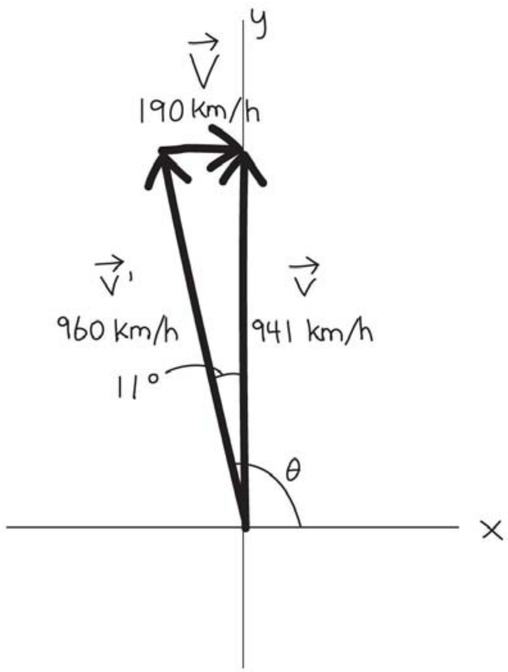
Fall 2008

Mechanics, Thermodynamics, Waves, Fluids

Lecture 6: motion in two and three dimensions III

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.

$$\vec{v} = \vec{v}_0 + \vec{a}\,t$$
$$\vec{r} = \vec{r}_0 + \vec{v}_0 t + \tfrac{1}{2}\vec{a}t^2$$

Recap: projectile motion

- Motion under the influence of gravity near Earth's surface has essentially constant acceleration $\vec{g}$ whose magnitude is g = 9.8 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:

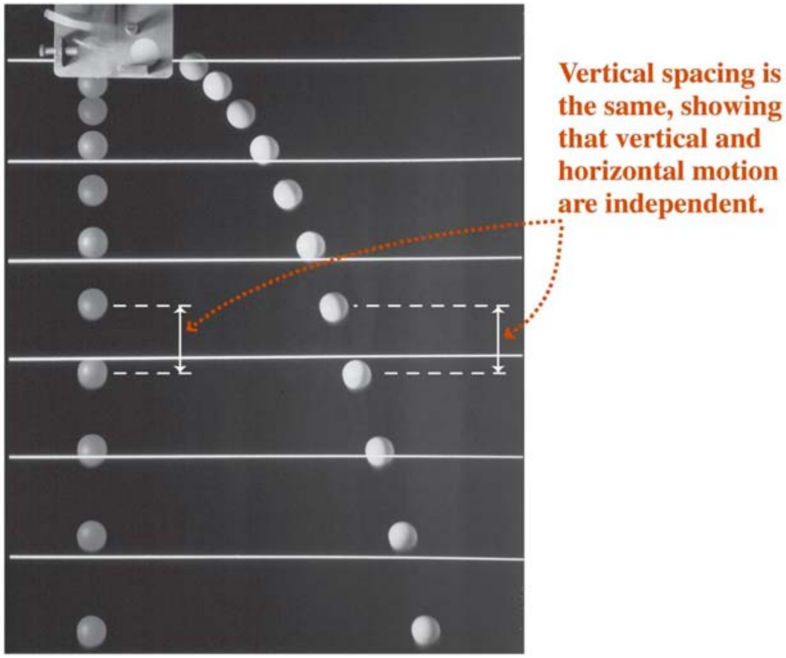
$$v_x = v_{x0}$$

$$v_y = v_{y0} - gt$$

$$x = x_0 + v_{x0}t$$

$$y = y_0 + v_{y0}t - \tfrac{1}{2}gt^2$$

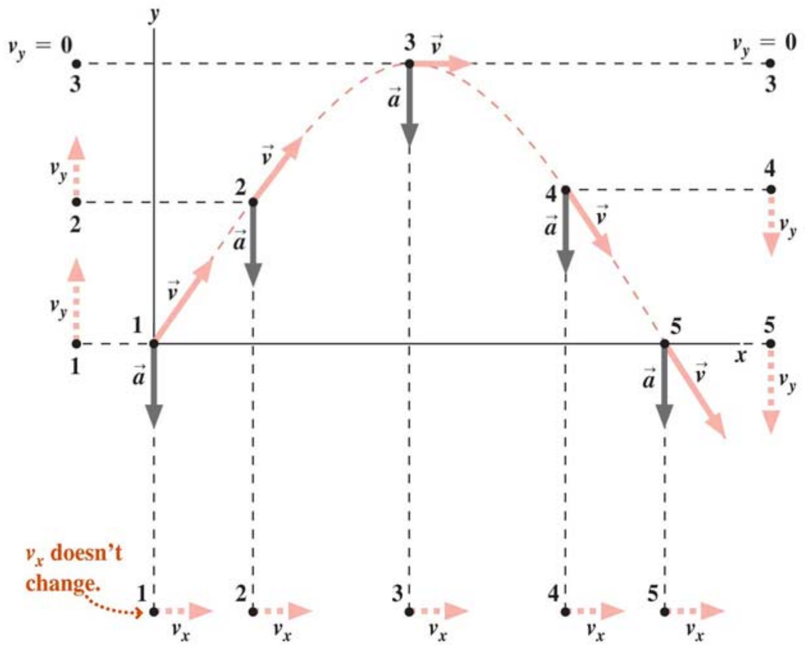
  - Horizontal and vertical motions are independent:

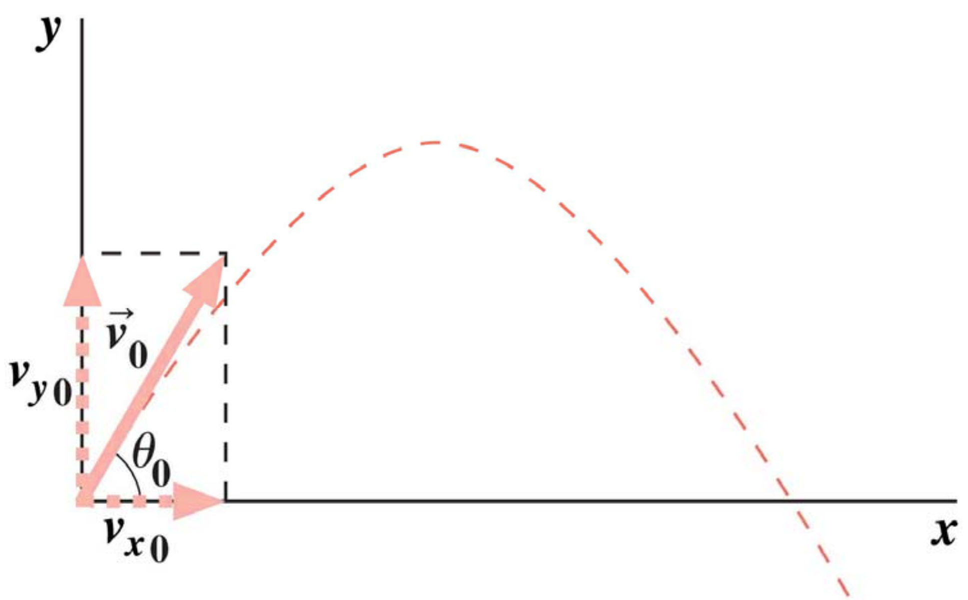


Projectile trajectories

- 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:

$$y = x\tan\theta_0 - \frac{g}{2v_0^2\cos^2\theta_0}x^2$$



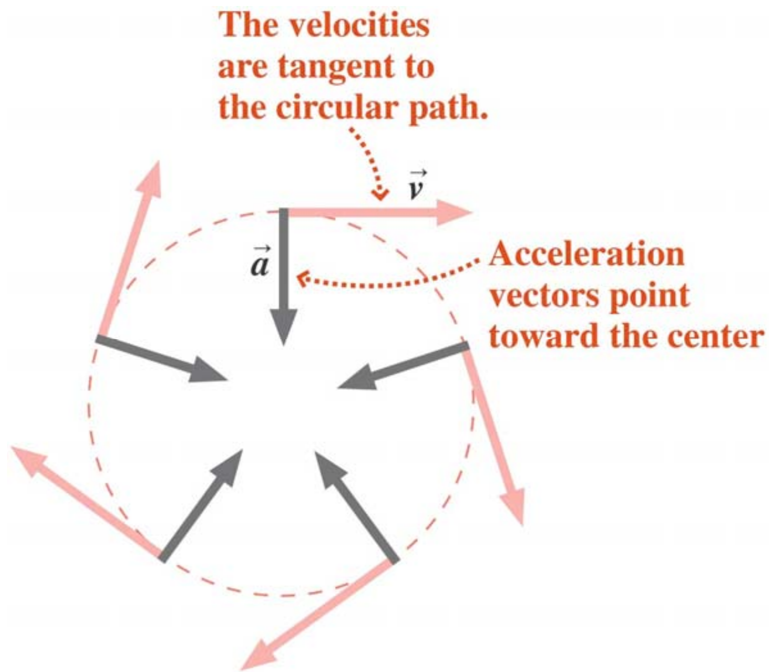


Uniform circular motion

- 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.



question

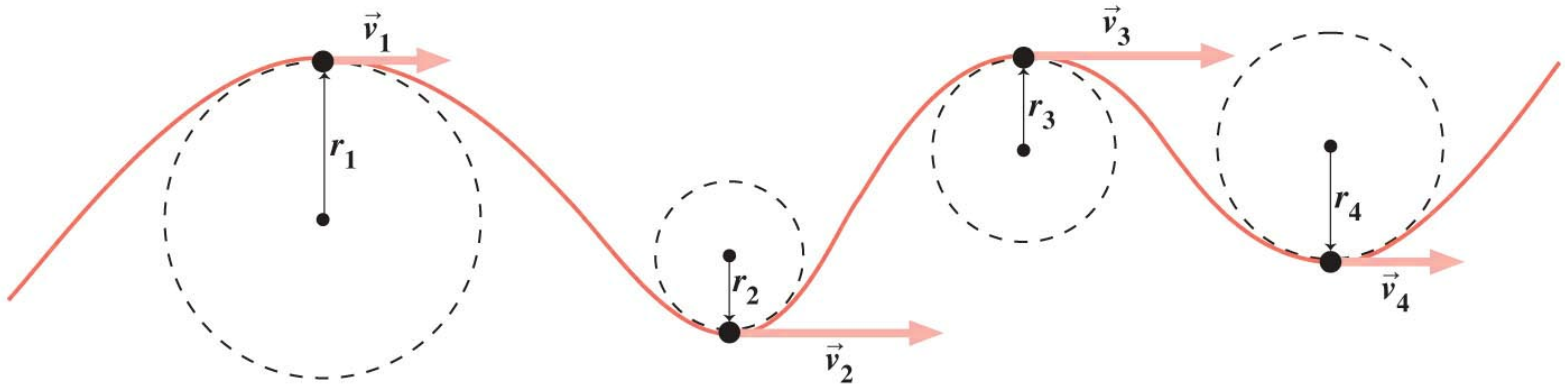
- The figure shows velocity vectors for four points on a noncircular path. Choose the correct order, from smallest to largest, of the centripetal accelerations at these points given $v_1 = v_4$ and $v_2 = v_3$.

  A. $a_1 > a_4 > a_3 > a_2$

  B. $a_2 > a_3 > a_4 > a_1$

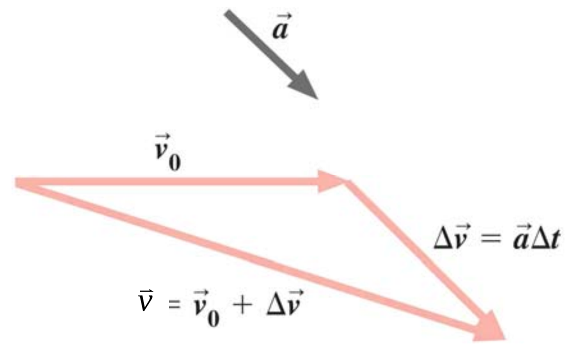
  C. $a_3 > a_2 > a_1 > a_4$

  D. $a_2 > a_3 > a_1 > a_4$

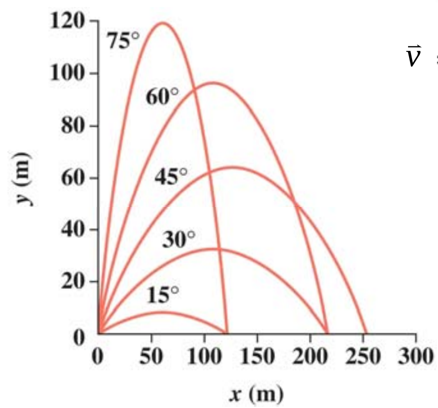


Summary

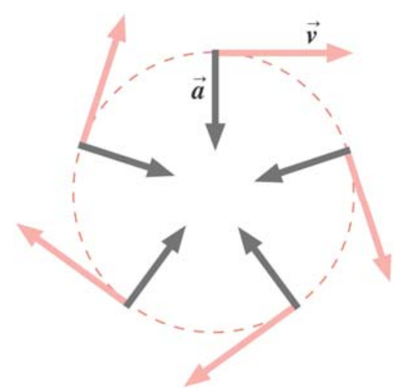
- In two and three dimensions, position, velocity, and acceleration become vector quantities.
  - Velocity is the rate of change of position: $\vec{v} = \dfrac{d\vec{r}}{dt}$
  - Acceleration is the rate of change of velocity: $\vec{a} = \dfrac{d\vec{v}}{dt}$



- 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.

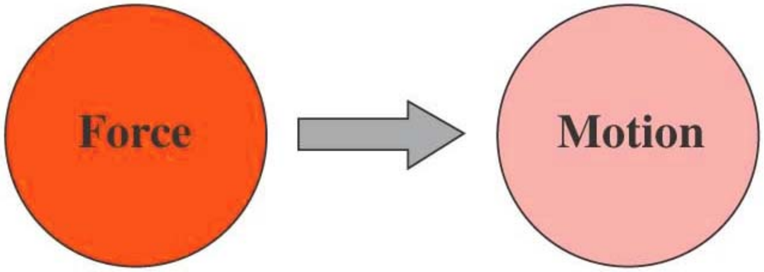
In this lecture you'll learn

- 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

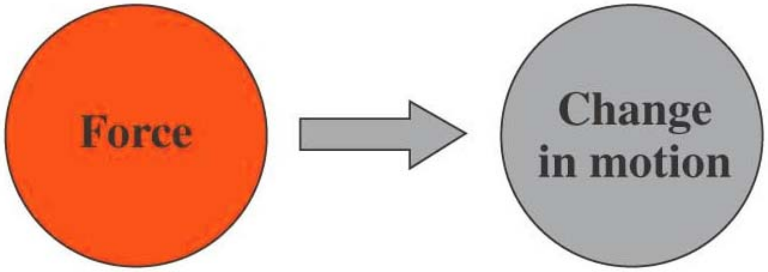
What causes motion?

- 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



The Newtonian view



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:

$$\vec{F}_{\text{net}} = \frac{d\vec{p}}{dt} \quad \text{(Newton's 2}^{\text{nd}}\text{ Law)}$$

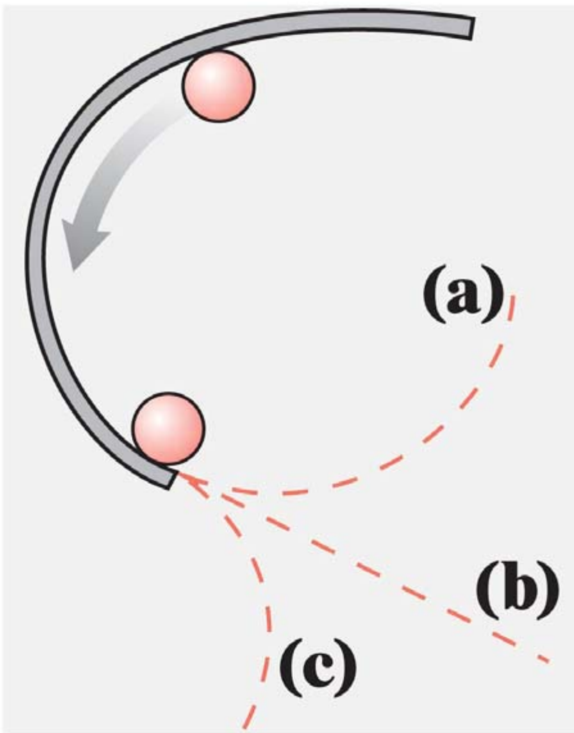
- **Newton's third law of motion:** If object A exerts a force on object B, then object B exerts an oppositely directed force of equal magnitude on A.

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.

question

- 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:

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

  - Newton's second law equates the rate of change of momentum to the net force on an object:

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

  - When mass is constant, Newton's second law becomes

$$\vec{F} = \frac{d\left(m\vec{v}\right)}{dt} = m\frac{d\vec{v}}{dt} = m\vec{a}$$

question

- 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