

Physics 1501

Fall 2008

**Mechanics, Thermodynamics,
Waves, Fluids**

Lecture 7: Force and Motion

Recap: projectile motion

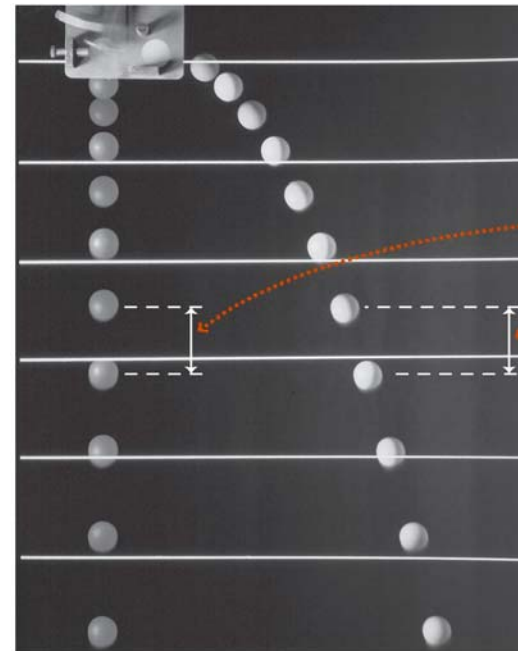
- Motion under the influence of gravity near Earth's surface has essentially constant acceleration $\vec{g}$ whose magnitude is $g = 9.8 \text{ m/s}^2$, and whose direction is downward.
- Such motion is called **projectile motion**.
- Equations for projectile motion, in a coordinate system with y axis vertically upward:
- Horizontal and vertical motions are independent:

$$v_x = v_{x0}$$

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

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

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

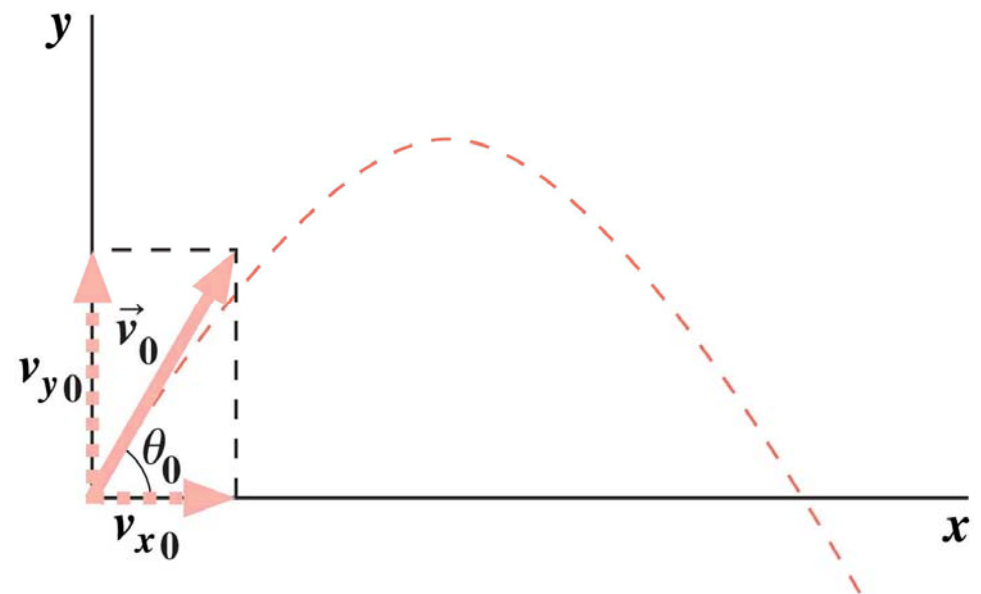
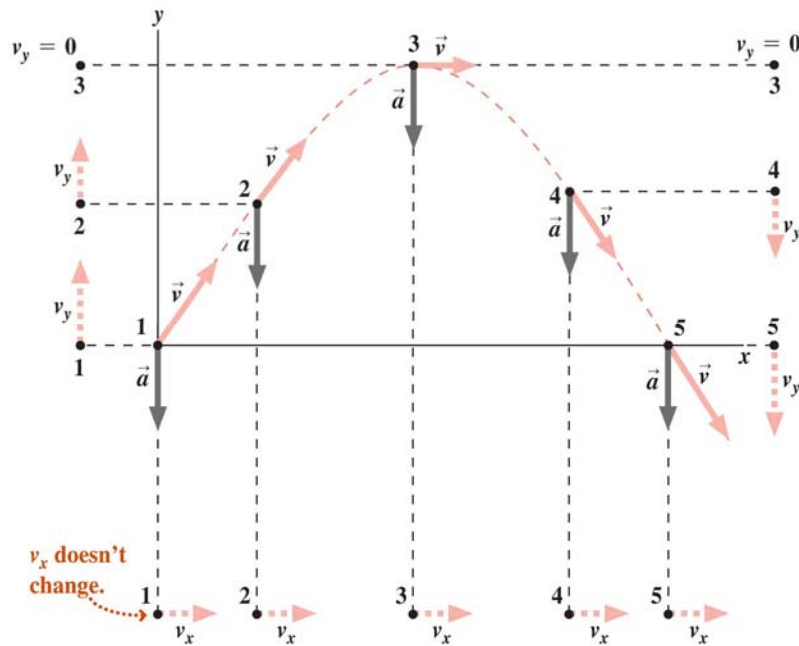


Vertical spacing is the same, showing that vertical and horizontal motion are independent.

Recap: projectile trajectories

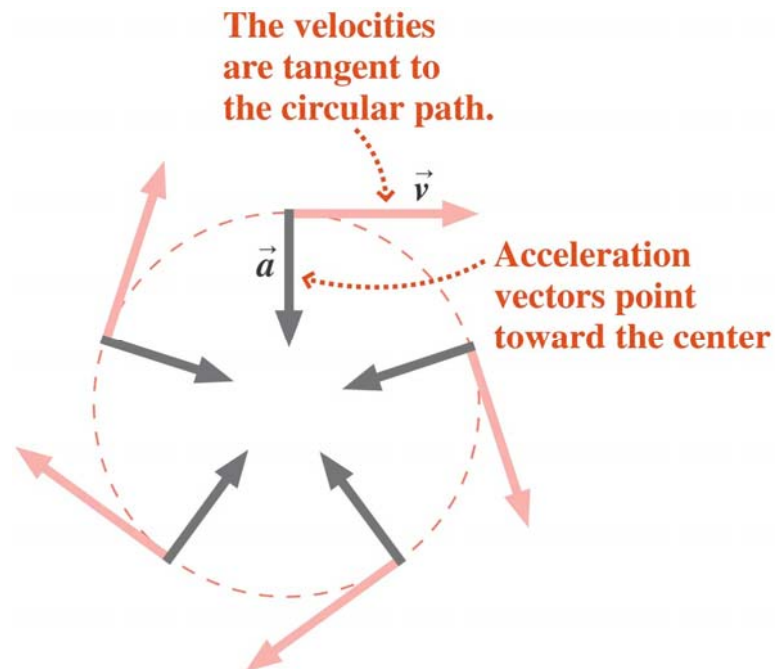
- The trajectory of an object in projectile motion is a parabola, unless the object has no horizontal component of motion.
 - Horizontal motion is unchanged, while vertical motion undergoes downward acceleration:
 - Equation for the trajectory:

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



Recap: 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

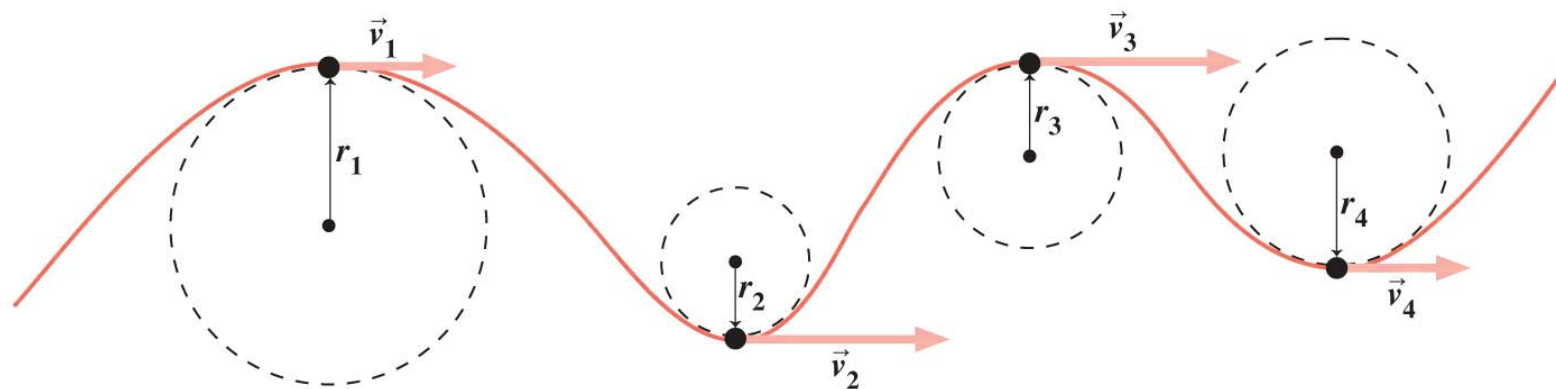
- The figure shows velocity vectors for four points on a noncircular path. Choose the correct order, from smallest to largest, of the centripetal accelerations at these points given $v_1 = v_4$ and $v_2 = v_3$.

A. $a_1 > a_4 > a_3 > a_2$

B. $a_2 > a_3 > a_4 > a_1$

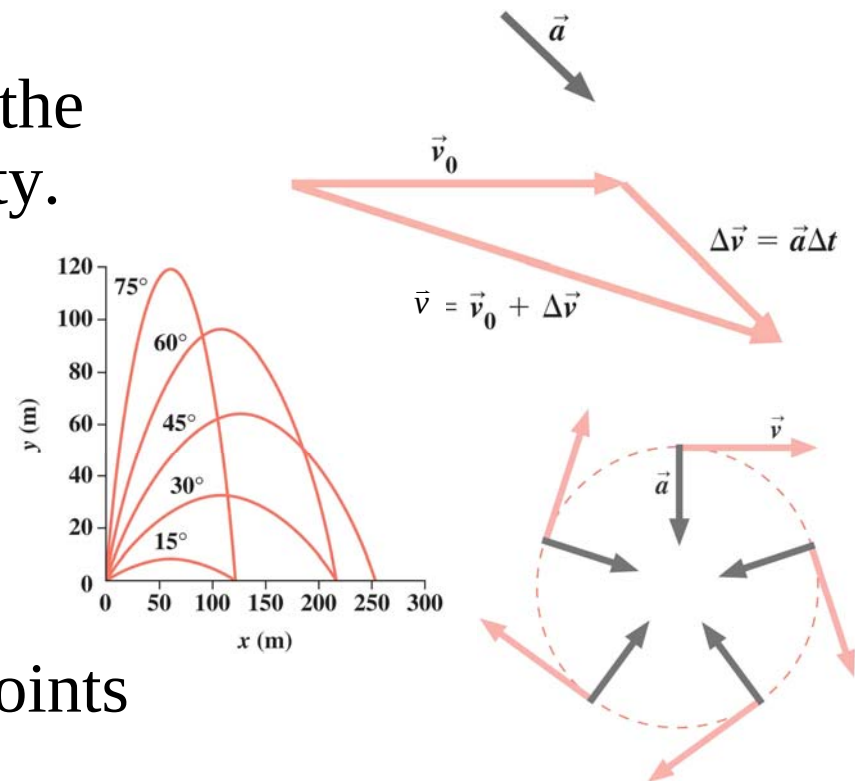
C. $a_3 > a_2 > a_1 > a_4$

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: $\vec{v} = \frac{d\vec{r}}{dt}$
 - Acceleration is the rate of change of velocity: $\vec{a} = \frac{d\vec{v}}{dt}$
- 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

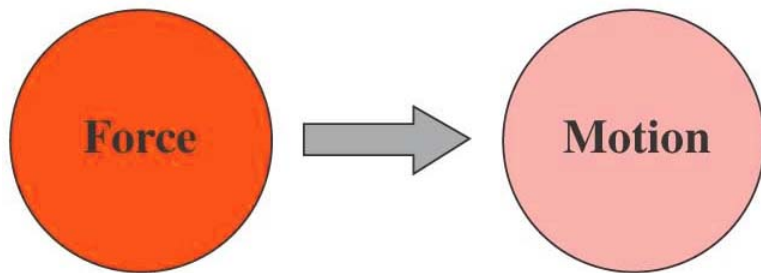
- The concept of force and its role in causing *changes* in motion
- The fundamental forces of physics
- Newton's three laws of motion
- About the force of gravity
 - Including the distinction between mass and weight
- How to apply Newton's laws in one-dimensional motion



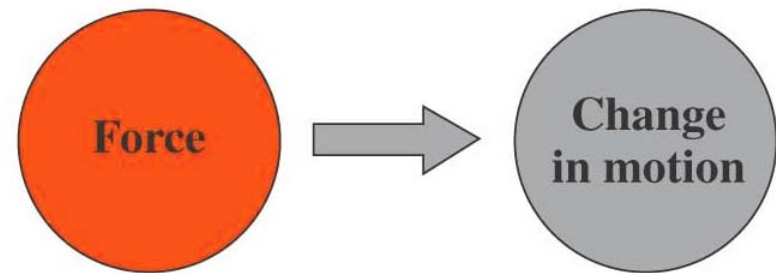
What causes motion?

- 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:

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

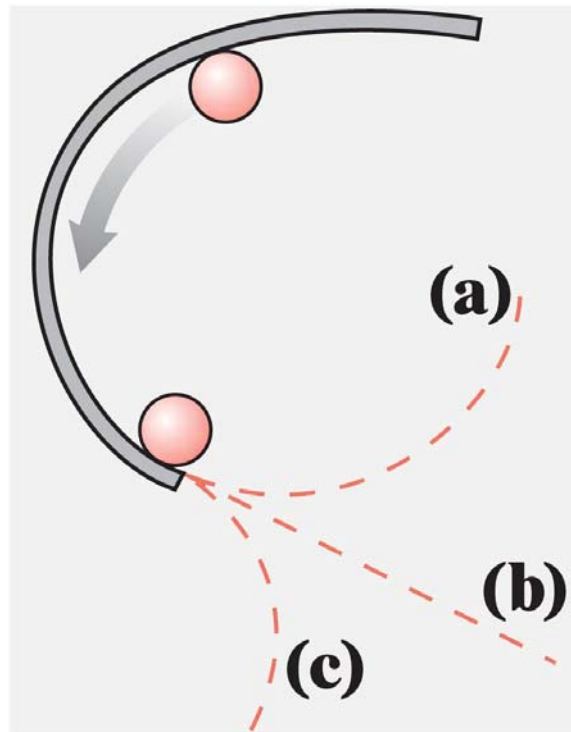
- **Newton's third law of motion:** If object A exerts a force on object B, then object B exerts an oppositely directed force of equal magnitude on A.

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:

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

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

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

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

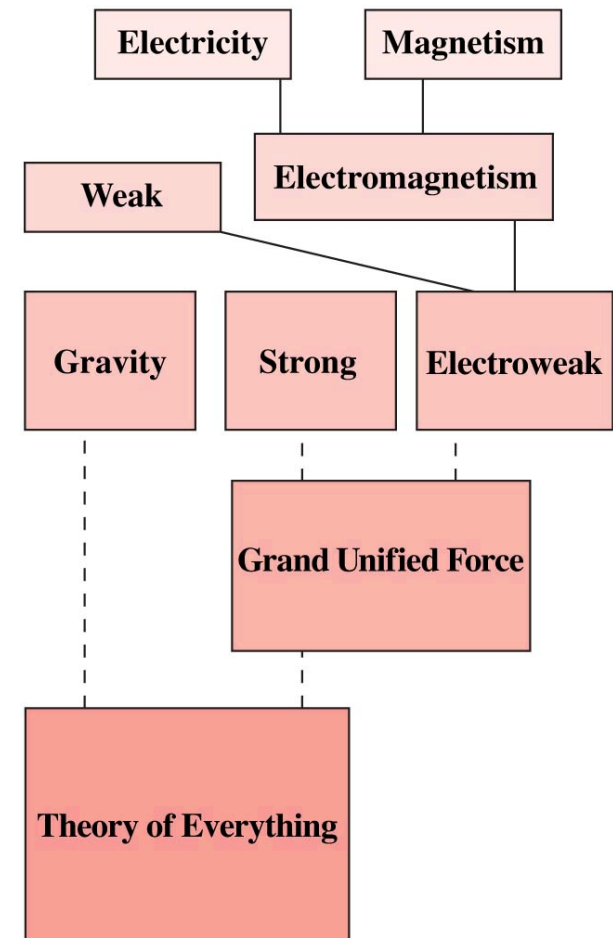
$$\mathbf{F} = \frac{d(m\mathbf{v})}{dt} = m \frac{d\mathbf{v}}{dt} = m\mathbf{a}$$

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

The fundamental forces

- Physicists now recognize three fundamental forces:
 - Gravity
 - The strong force
 - The electroweak force
- All common forces fall under these three categories.
 - Nearly all everyday forces, except gravity, are electromagnetic forces—one aspect of the electroweak force.
- Historically, more forces were once regarded as fundamental, but were later understood to be related.
- A goal of physics is to unify all forces in a “Theory of Everything.”



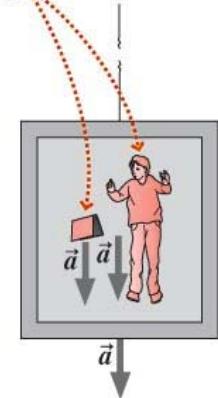
Mass, weight, and gravity

- **Weight** is the force of gravity on an object:

$$\vec{w} = m\vec{g}$$

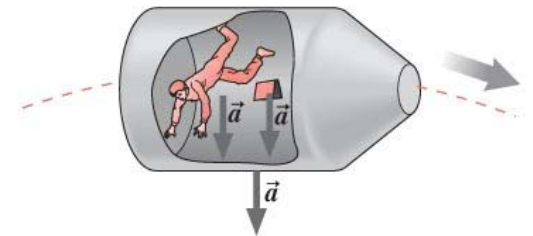
- Mass doesn't depend on the presence or strength of gravity.
- Weight depends on gravity, so varies with location:
 - Weight is different on different planets.
 - Near Earth's surface, $\vec{g}$ has magnitude 9.8 m/s^2 or 9.8 N/kg , and is directed downward.
- All objects experience the same gravitational acceleration, regardless of mass.
 - Therefore objects in **free fall**—under the influence of gravity alone—appear “weightless” because they share a common accelerated motion.
 - This effect is noticeable in orbiting spacecraft
 - because the absence of air resistance means gravity is the only force acting.
 - because the apparent weightlessness continues indefinitely, as the orbit never intersects Earth.

In a freely falling elevator on Earth, the book and person seem weightless because they fall with the same acceleration as the elevator.



Earth
(a)

Like the elevator in (a), an orbiting spacecraft is falling toward Earth, and because its occupants also fall with the same acceleration, they experience apparent weightlessness.



(b)

Example

- A 740-kg elevator accelerates upward at 1.1 m/s^2 , pulled by a cable of negligible mass. Find the tension force in the cable.

- INTERPRET The object of interest is the elevator; the forces are gravity and the cable tension.

- DEVELOP Newton's law reads

$$\vec{F}_{\text{net}} = \vec{T} + \vec{F}_g = m\vec{a}$$

- EVALUATE In a coordinate system with y axis upward, Newton's law reads $T_y + F_{gy} = ma_y$.

Solving gives

$$T = m(a_y + g) = 8.1 \text{ kN}$$

- ASSESS Makes sense; look at some special cases. When $a = 0$, $T = mg$ and the cable tension balances gravity. When $T = 0$, $a = -g$, and the elevator falls freely.

