PHYS101

Week 2

Motion

- The change in position relative to some “fixed” point.
- There is no such thing as “absolute motion”, only motion relative to “something else”.
  - Examples: Motion of bouncing ball relative to me, my motion relative to train, train’s motion relative to ground (Earth’s surface), Earth’s motion relative to sun and other “fixed stars”, sun’s (and other stars) motion relative to galaxy…
- How do we measure position? How do we measure motion?
  - Example: Speedometer, radar gun, sonic ranger: relative to ground, GPS: relative to satellites (subtract motion of ground relative to satellites to get motion relative to ground)
- What is the “cause” of motion? You don’t always need one!
  - Example: Bicycle coasting, Passenger inside an airplane
- There are some reference systems (called “inertial systems”) where uniform motion in a fixed direction doesn’t require any cause (it’s the “natural” state)
- In such systems, objects at rest tend to stay at rest, and objects in motion tend to continue to move (or “coast”) UNLESS acted upon by a force - NEWTON’S FIRST LAW

Forces

- Push or pull on an object (mass point) due to its interaction with “something else”
- Cause of **changes** in motional state (**acceleration**) - see later...
- Has both a magnitude (strength - “how hard do we push/pull”) and a direction (“which way do we push/pull”) ->
  Force is a **vector**
- [Units: $m\,kg/s^2 = N$]

Examples

- Contact Forces: “Push” (Normal force, pressure), “pull” (tensional force, adhesion), “carry along” (“stickiness”, static and dynamic friction, shear †)
- Forces at a distance: **Gravity** (*mg* near surface of Earth, more complicated form for general case of one mass attracting another).
- Forces at a distance: **Electric** and **magnetic** forces (**Electromagnetism** -> 2nd part of semester)
- On the subatomic level: Weak force, **strong** force (QCD)

† Ultimately all due to **electrostatic** forces!

Principle of Superposition

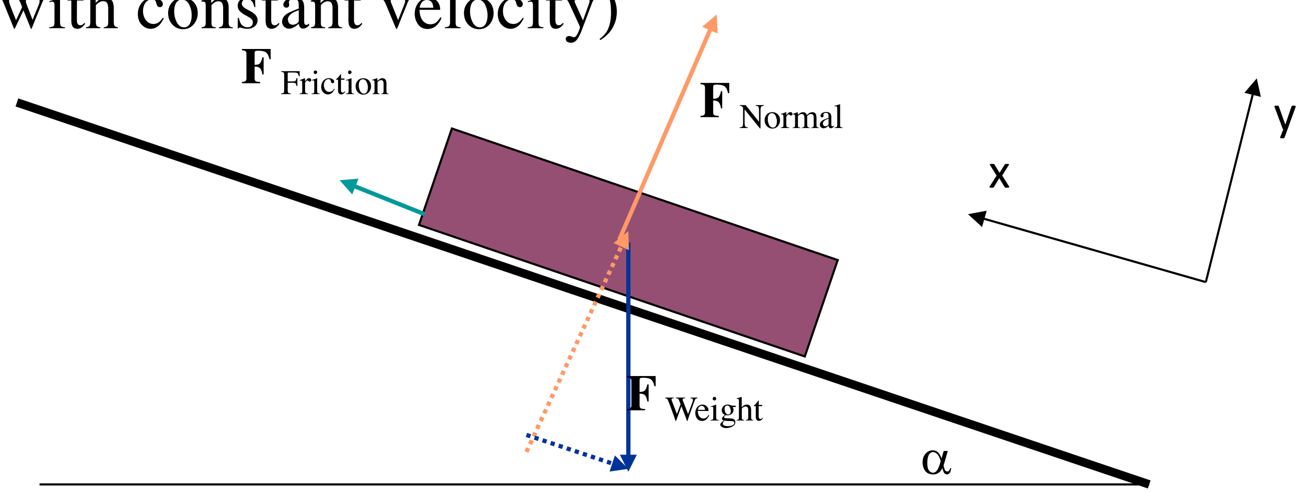
- The effect of several different forces acting on the same (mass) point is equal to that of the single force which is their vector sum
  - Example: Holding up an object - gravity and “normal force” cancel
- Can generalize for many forces:

$$\vec{\mathbf{F}}_{\text{resultant}} = \sum_{\text{all forces i=1...N}} \vec{\mathbf{F}}_{\text{i}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 + \ldots + \vec{\mathbf{F}}_N$$

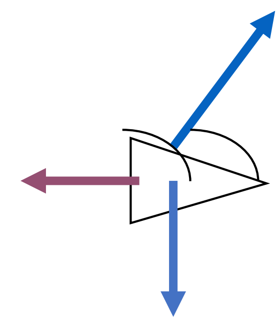
- If all forces add up to zero -> equilibrium = no change in motional state in an inertial system (object remains in its previous state of motion or rest)
  - Another way to determine an unknown force: balance it with known forces

Example: Equilibrium - zero net force

- Equilibrium: All forces acting on an object add up to zero (vectorially).
- Adding vectors pictorially:
  - Move 1st vector around until its **head** touches the 2nd vector's **tail**
  - Draw vector from 1st vector's **tail** to 2nd vector's **head** = sum vector
  - Repeat with additional vectors to get total sum
- Example: Car sitting still on an inclined plane (or moving down with constant velocity)



Equilibrium - Sailboat



Newton's First Law

In an **inertial** coordinate system:

- IF the net force (Σ $\mathbf{F}_i$) acting on an object is zero, its velocity will not change:
  - If it is at rest, it will remain at rest.
  - If it is moving, it will continue to move with constant speed along a straight line.
- => IF the velocity changes, there must be a force acting!
  - Examples: Car on Freeway, Puck on Ice, Spaceship,…
- Remember: Always add up **all** forces to get net force! If an object is in contact with another object, there usually are normal forces and frictional forces between them (including friction in air).
- You don't need any net force to keep on moving - inertia does it!

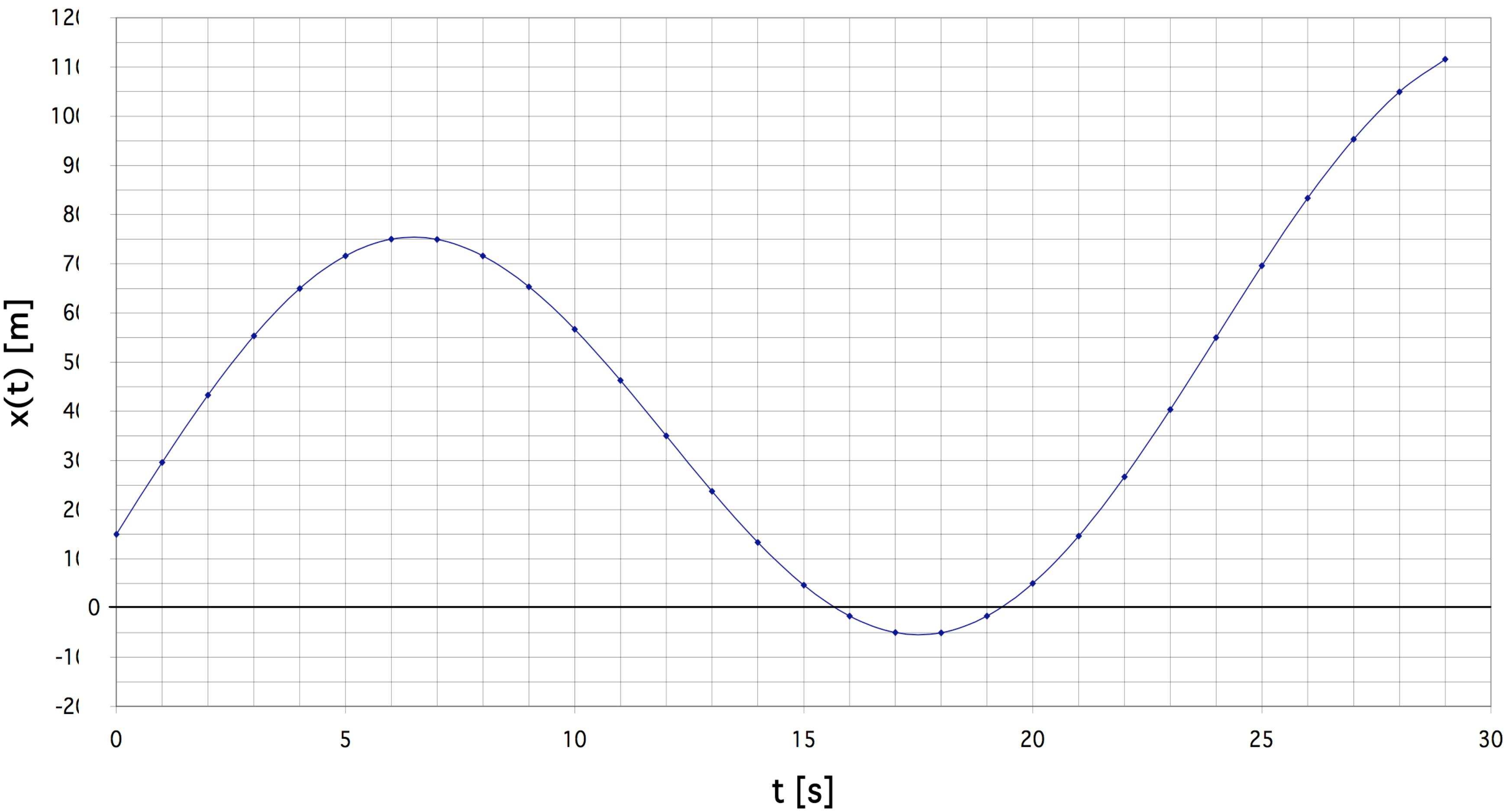
Inertial Frame of Reference

- Newton's First Law is **only** true if you measure velocity, acceleration etc. in a coordinate system that is an Inertial Frame of Reference (= not accelerating itself).
- Examples:
  - Inertial Frames: A spaceship far away from any stars and planets, a fixed frame with respect to the surface of Earth (nearly), any frame that moves with constant velocity with respect to another Inertial Frame of Reference
  - Non-inertial Frames: An accelerating train, a spaceship circling Earth, a falling elevator, a car going around a corner.
- How can you tell? Use Newton's First Law: **If** it is true in **your** reference frame, **then** your frame is an Inertial Frame.

Linear Motion

- Motion in only one dimension $\rightarrow$
  Displacement relative to origin is given by a single number x (positive or negative)
- Example 1:
  Horizontal motion (straight rail etc.) (x can be >0 and <0 !)
- Example 2:
  Vertical motion (free fall, throwing things straight up).

Graph of displacement *x* vs. elapsed time *t*



Average Velocity

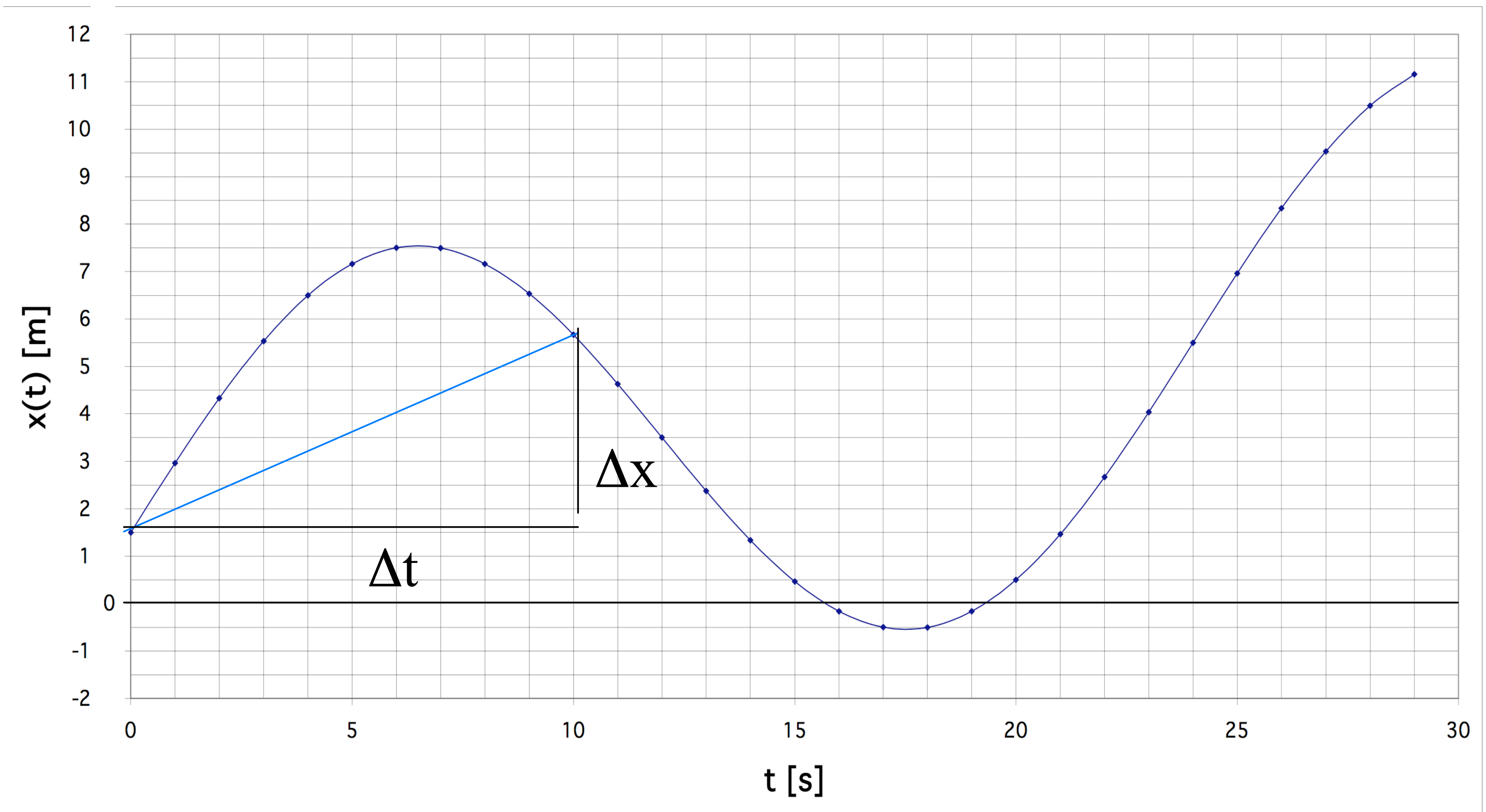
- Motion: Displacement is a function of time!
- Completely specified by giving $x(t)$ (displacement x at time t)
- Average Velocity:

$$v_{av} = \frac{\text{change in position after some time } \Delta t}{\text{elapsed time } \Delta t} =$$

$$= \frac{x(t_2) - x(t_1)}{t_2 - t_1} = \frac{\Delta x}{\Delta t}$$

- All velocities are completely specified by **magnitude** (called **speed**) $v_{\text{av}} = |\Delta x|/\Delta t$ and **sign** (direction).

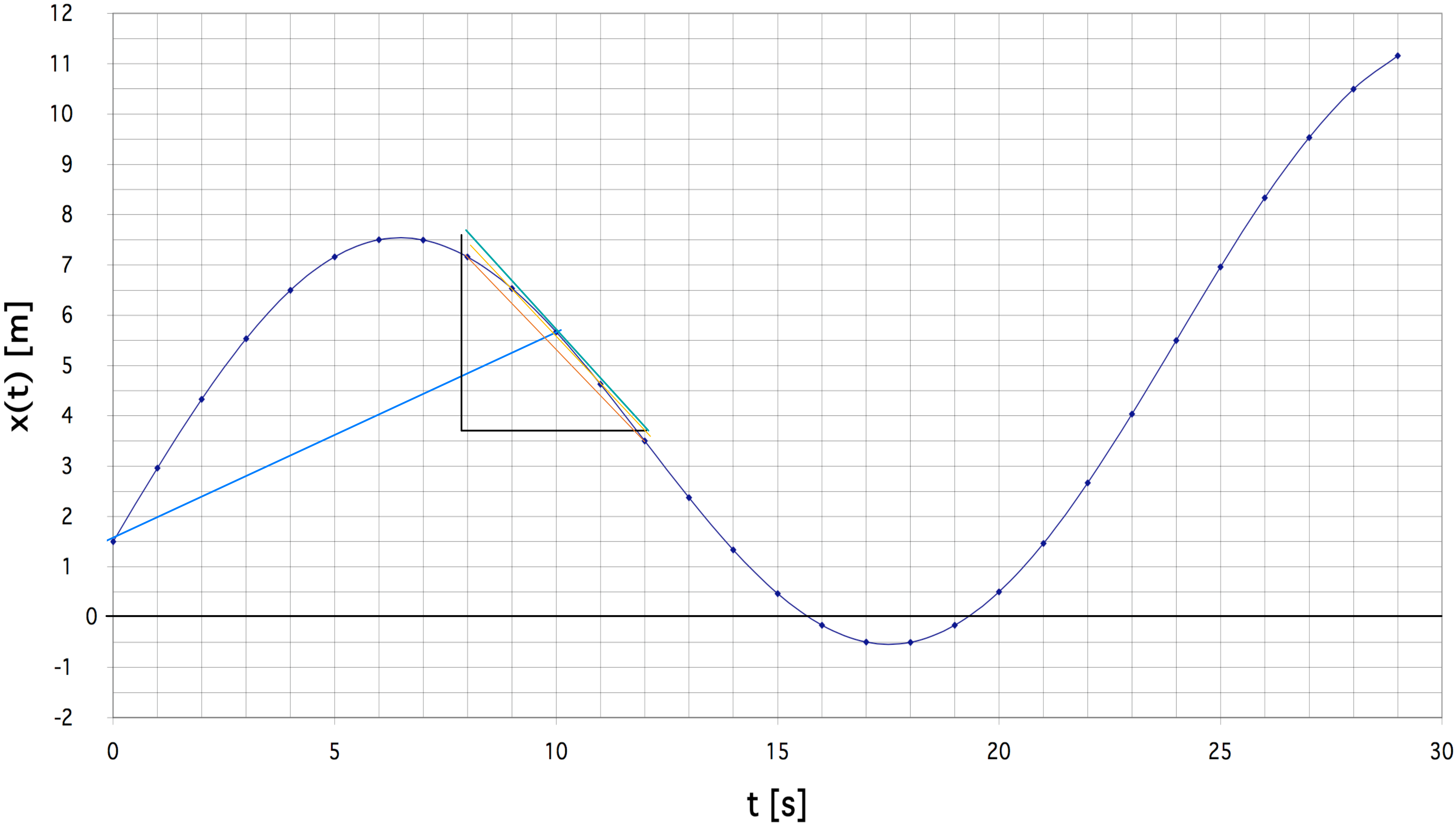
Graph of displacement *x* vs. elapsed time *t* – Average Velocity



Instantaneous Velocity

- If you go with constant velocity for some time interval, the average velocity for that time interval is equal to your instantaneous velocity at any point during that time interval.
- If you measure your average velocity for a VERY short time interval, you approximate your instantaneous velocity.
- Odometer plus watch measure average speed.
  Distance on the map divided by elapsed time measures average velocity.
  Speedometer plus compass measure instantaneous velocity.
  (Note: Average speed is **NOT** the magnitude of average velocity)
  - Example: Motorboat vs. Sailboat

Graph of displacement x vs. elapsed time t – Instantaneous velocity



Velocity cont'd

- Remember: Velocity is always *relative* to something else (a coordinate system)
- Relative velocities add: if you move with 2 miles/hour relative to ship, and ship moves 15 miles/hour relative to river water, and river water moves 3 miles/hour relative to shore, then you move 20 miles/hour relative to shore
- Don't confuse displacement, velocity, speed, average velocity
- You can have constant speed but non-constant velocity (e.g., going in a circle) -> NOT an inertial system

New way to formulate Newton’s First Law:

- IF you are measuring the instantaneous velocity of an object RELATIVE TO AN INERTIAL FRAME OF REFERENCE
- AND the net force (total sum of all forces acting) is ZERO
- THEN the object will continue to move with the SAME instantaneous velocity (direction and magnitude are constant) relative to that same reference frame
- An object at rest is just a special case of this: Instantaneous velocity is zero.

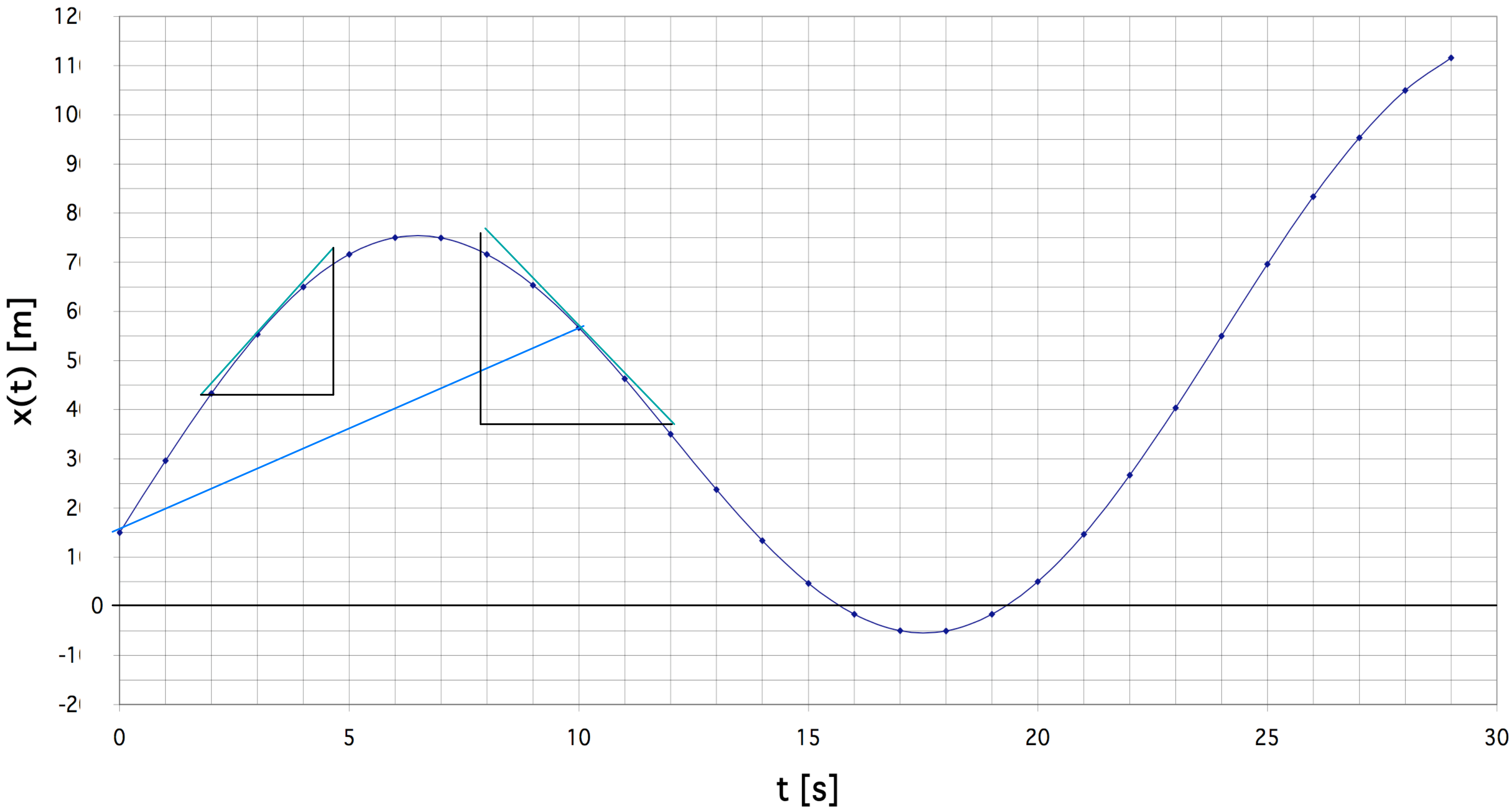
Acceleration

- Same general idea:

$$a = \frac{\text{change in velocity during time } \Delta t}{\text{elapsed time interval } \Delta t} = \frac{\Delta \mathbf{v}}{\Delta t}$$

- Can again be specified by giving magnitude $a_{av} = |\Delta v|/\Delta t$ and sign.
- Positive velocity, increasing speed => positive acceleration $a > 0$
- Positive velocity, decreasing speed (slowing down) => negative acceleration (deceleration) $a < 0$
- Negative velocity, increasing speed => negative acceleration $a < 0$
- Negative velocity, slowing down => positive acceleration $a > 0$
- NOTE: Acceleration in an inertial system must have a cause! (Force)

Graph of displacement *x* vs. elapsed time *t* – average acceleration

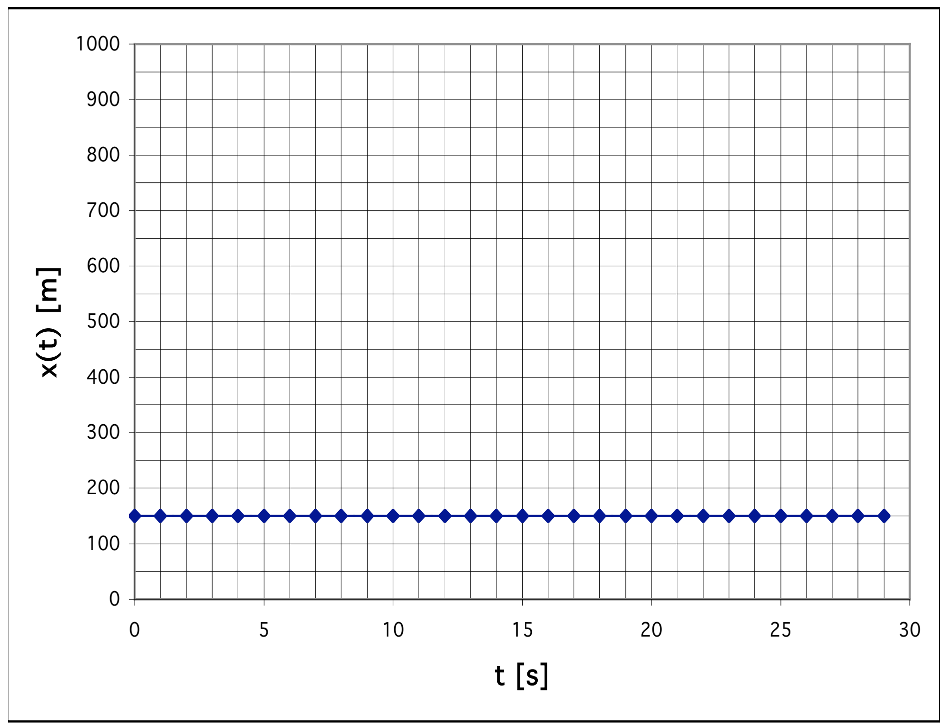


New way to formulate Newton’s First Law:

The acceleration of an object on which the net force is zero will be zero relative to an inertial reference frame.

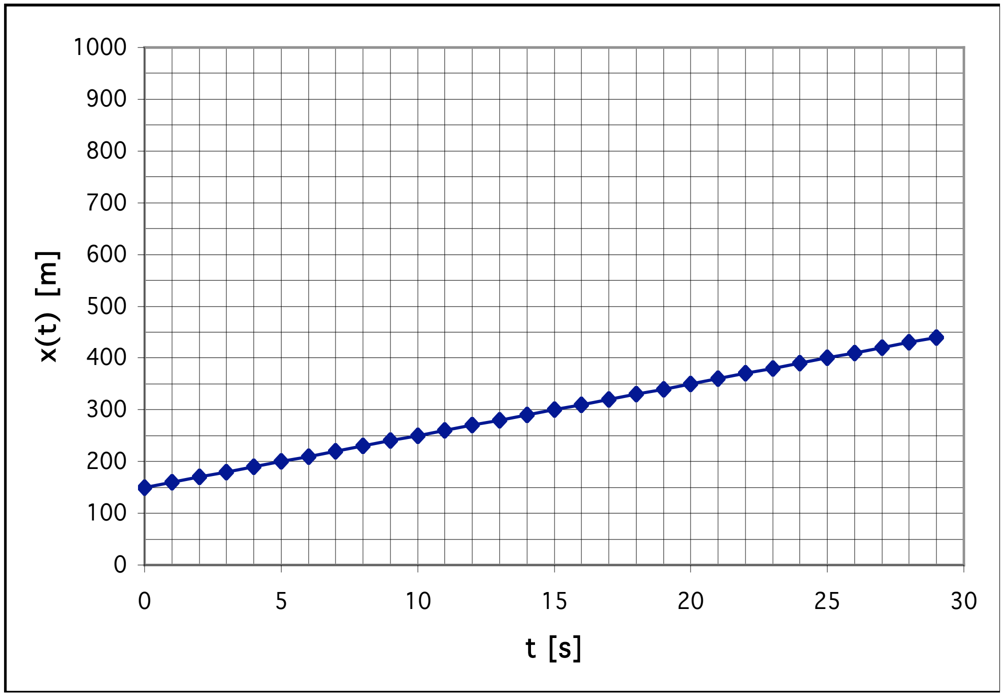
Motion (?) with constant x

- $x(t) = x_0$ (constant) at all times t
- Object is at rest - $v(t) = v_{av} = v_0 = 0$
- Typical graph $x(t)$:



Motion with constant Velocity

- $v(t) = v_{av} = v_0 = \text{const.}$
  $v_0 = (x(t) - x_0)/(t - 0)$
- $x(t) = x_0 + v_0\, t$
- Typical graph $x(t)$:



Motion with constant Acceleration

- $a(t) = a_{av} = a_0 = \text{const.}$
  $a_{av} = (v(t) - v_0)/(t - 0)$
- $v(t) = v_0 + a_0 t$
- Average velocity during the time interval $t = 0 \ldots t$ is given by
  $v_{av}(0 \ldots t) = 1/2\ [v_0 + v(t_1)]$
  $= 1/2\ [v_0 + v_0 + a_0 t] = v_0 + {}^1/_2\, a_0 t$

Constant Acceleration Cont'd

- Plugging it into expression for position:
  $v_0 + {}^1/_2\, a_0\, t = v_{av} = (x(t) - x_0)/(t - 0)$
  $\Rightarrow x(t) = x_0 + v_0\, t + {}^1/_2\, a_0\, t^2$
- Typical graph $x\,(t\,)$: