Physics 111 -- Mechanics

- Lecturer: Tom Humanic

- Contact info:
  Office: Physics Research Building, Rm. 2144
  Email: humanic@mps.ohio-state.edu
  Phone: 614 247 8950

- Office hours:
  Tuesday 4:30 pm

My lecture slides may be found on my website at
http://www.physics.ohio-state.edu/~humanic/

Course Overview -- Mechanics

Kinematics -- velocity and acceleration, free-falling bodies, projectile motion….

Dynamics -- **Newton's laws of motion** -- forces (gravitational, friction, tension……), motion of objects due to forces……

Work and energy -- potential and kinetic energy, conservation of energy, power……

Impulse and momentum -- conservation of momentum, collisions, center-of-mass of an object, ……

Rotational kinematics and dynamics -- angular velocity and acceleration, torque, angular momentum…..

Chapter 1

Introduction and Mathematical Concepts

1.2 Units

Physics experiments involve the measurement of a variety of quantities.

These measurements should be accurate and reproducible.

The first step in ensuring accuracy and reproducibility is defining the units in which the measurements are made.

SI units

meter (m): unit of length

kilogram (kg): unit of mass

second (s): unit of time

1.2 Units

Table 1.1 Units of Measurement

	System		
	SI	CGS	BE
Length	Meter (m)	Centimeter (cm)	Foot (ft)
Mass	Kilogram (kg)	Gram (g)	Slug (sl)
Time	Second (s)	Second (s)	Second (s)

1.2 Units

The units for length, mass, and time (as well as a few others), are regarded as *base* SI units.

These units are used in combination to define additional units for other important physical quantities such as force and energy.

THE CONVERSION OF UNITS

1 ft = 0.3048 m

1 mi = 1.609 km

1 hp = 746 W

1 liter = 10^{-3} m^3

Example 1 The World's Highest Waterfall

The highest waterfall in the world is Angel Falls in Venezuela, with a total drop of 979.0 m. Express this drop in feet.

Since 3.281 feet = 1 meter, it follows that

(3.281 feet)/(1 meter) = 1

$$\text{Length} = (979.0 \text{ meters})\left(\frac{3.281 \text{ feet}}{1 \text{ meter}}\right) = 3212 \text{ feet}$$

1.3 The Role of Units in Problem Solving

Table 1.2 Standard Prefixes Used to Denote Multiples of Ten

Prefix	Symbol	Factor[a]
tera	T	10^{12}
giga[b]	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deka	da	10^{1}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

[a]Appendix A contains a discussion of powers of ten and scientific notation.
[b]Pronounced jig′a.

Reasoning Strategy: Converting Between Units

1. In all calculations, write down the units explicitly.

2. Treat all units as algebraic quantities. When identical units are divided, they are eliminated algebraically.

3. Use the conversion factors located on the page facing the inside cover. Be guided by the fact that multiplying or dividing an equation by a factor of 1 does not alter the equation.

1.3 The Role of Units in Problem Solving

Example 2 **Interstate Speed Limit**

Express the speed limit of 65 miles/hour in terms of meters/second.

Use 5280 feet = 1 mile and 3600 seconds = 1 hour and
3.281 feet = 1 meter.

$$\text{Speed} = \left(65\,\frac{\text{miles}}{\text{hour}}\right)(1)(1) = \left(65\,\frac{\text{miles}}{\text{hour}}\right)\left(\frac{5280\text{ feet}}{\text{mile}}\right)\left(\frac{1\text{ hour}}{3600\text{ s}}\right) = 95\,\frac{\text{feet}}{\text{second}}$$

$$\text{Speed} = \left(95\,\frac{\text{feet}}{\text{second}}\right)(1) = \left(95\,\frac{\text{feet}}{\text{second}}\right)\left(\frac{1\text{ meter}}{3.281\text{ feet}}\right) = 29\,\frac{\text{meters}}{\text{second}}$$

1.3 *The Role of Units in Problem Solving*

DIMENSIONAL ANALYSIS

[L] = length   [M] = mass   [T] = time

Is the following equation dimensionally correct?

$$x = \tfrac{1}{2} v t^2$$

$$[L] = \left[\frac{L}{T}\right][T]^2 = [L][T]$$

1.3 The Role of Units in Problem Solving

Is the following equation dimensionally correct?

$$x = vt$$

$$[\mathrm{L}] = \left[\frac{\mathrm{L}}{\mathrm{T}}\right][\mathrm{T}] = [\mathrm{L}]$$

1.5 Scalars and Vectors

A *scalar* quantity is one that can be described by a single number:

temperature, speed, mass

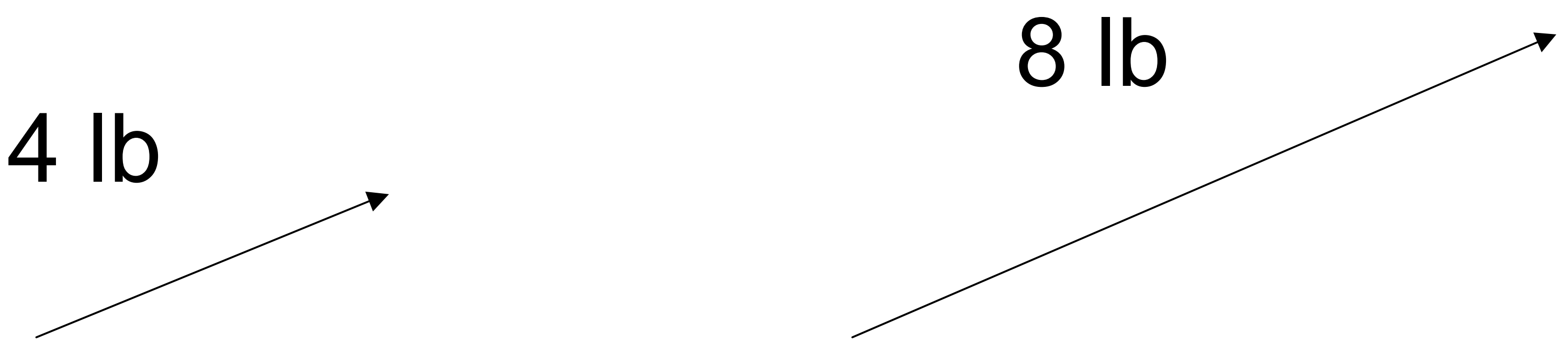
A *vector* quantity deals inherently with both magnitude and direction:

velocity, force, displacement

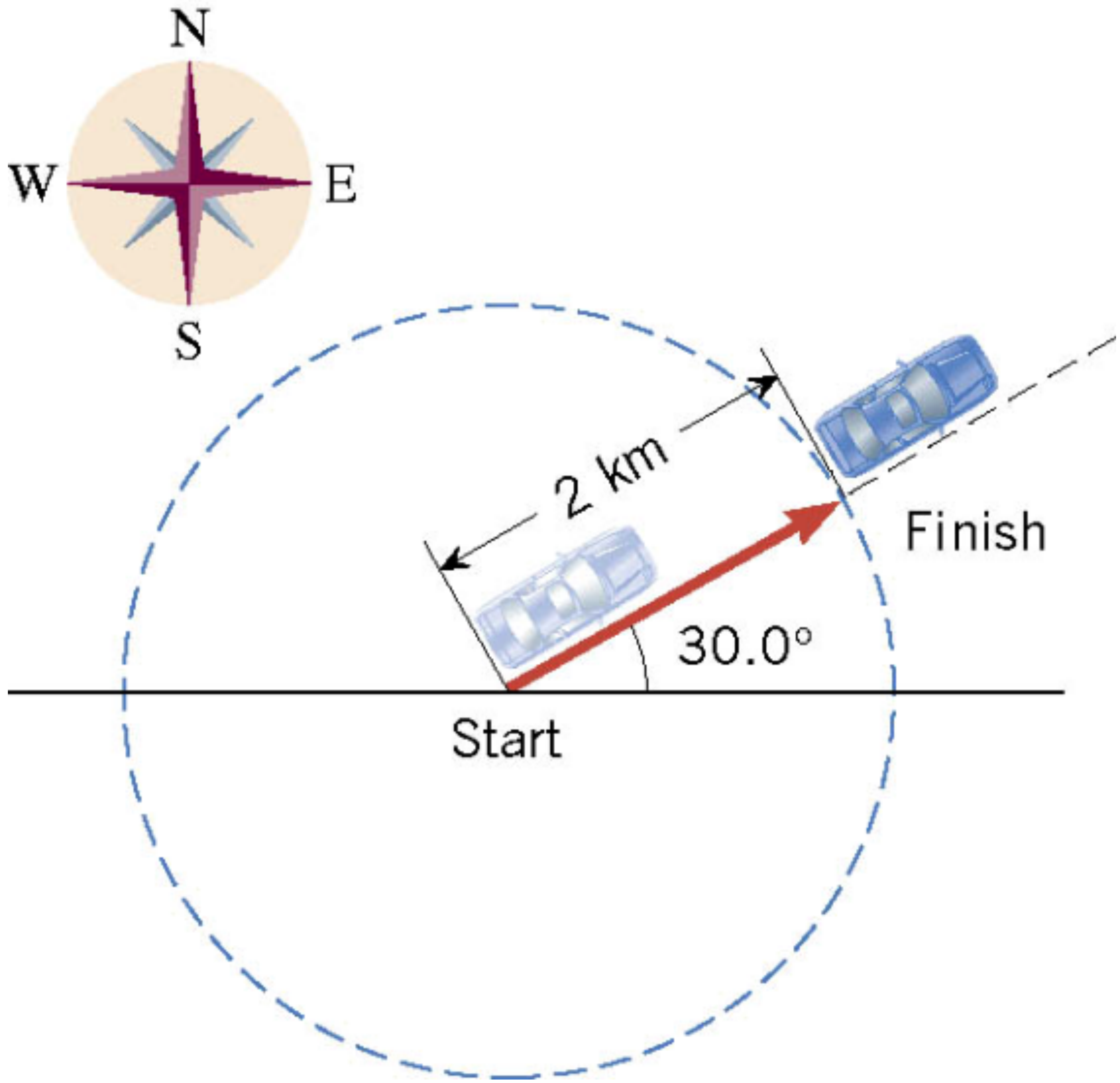
1.5 Scalars and Vectors

Arrows are used to represent vectors. The direction of the arrow gives the direction of the vector.

By convention, the length of a vector arrow is proportional to the magnitude of the vector.



1.5 Scalars and Vectors



Chapter 2

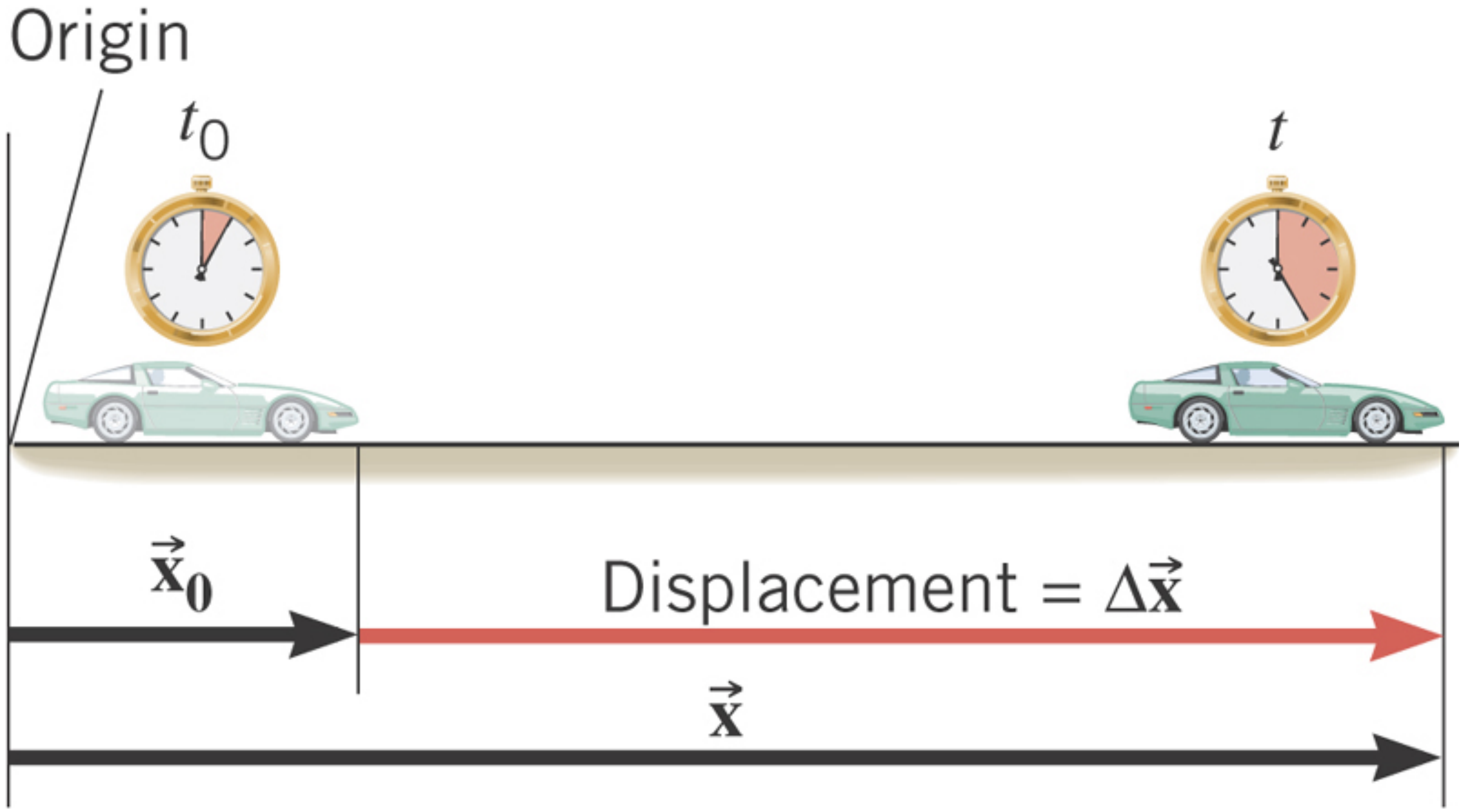
Kinematics in One Dimension

Kinematics deals with the concepts that are needed to describe motion.

Dynamics deals with the effect that forces have on motion.

Together, kinematics and dynamics form the branch of physics known as ***Mechanics.***

2.1 *Displacement*



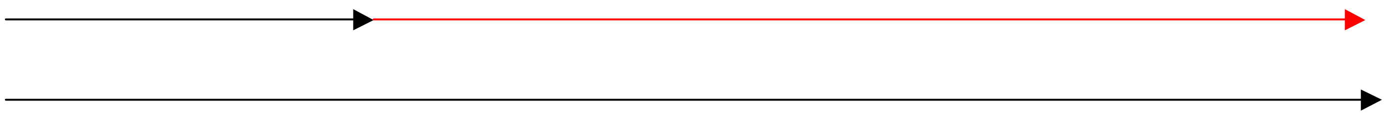
$\vec{\mathbf{x}}_o$ = initial position

$\vec{\mathbf{x}}$ = final position

$$\Delta\vec{\mathbf{x}} = \vec{\mathbf{x}} - \vec{\mathbf{x}}_o = \text{displacement}$$

2.1 Displacement

$$\vec{\mathbf{x}}_o = 2.0\,\text{m} \qquad \Delta\vec{\mathbf{x}} = 5.0\,\text{m}$$

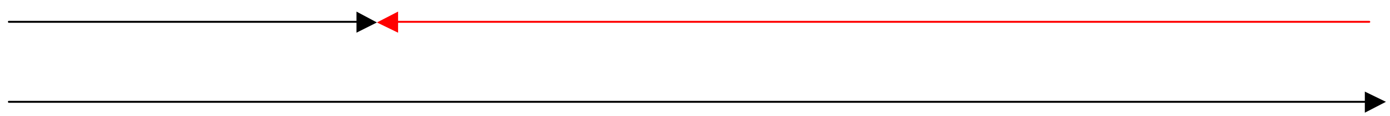


$$\vec{\mathbf{x}} = 7.0\,\text{m}$$

$$\Delta\vec{\mathbf{x}} = \vec{\mathbf{x}} - \vec{\mathbf{x}}_o = 7.0\,\text{m} - 2.0\,\text{m} = 5.0\,\text{m}$$

2.1 Displacement

$$\vec{\mathbf{x}} = 2.0\,\mathrm{m} \qquad \Delta\vec{\mathbf{x}} = -5.0\,\mathrm{m}$$

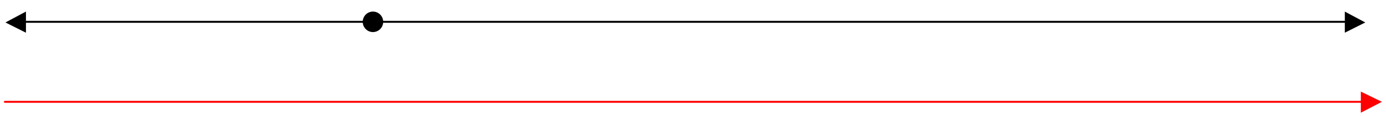


$$\vec{\mathbf{x}}_o = 7.0\,\mathrm{m}$$

$$\Delta\vec{\mathbf{x}} = \vec{\mathbf{x}} - \vec{\mathbf{x}}_o = 2.0\,\mathrm{m} - 7.0\,\mathrm{m} = -5.0\,\mathrm{m}$$

2.1 *Displacement*

$\vec{\mathbf{x}}_o = -2.0\ \text{m}$ $\qquad\qquad\qquad$ $\vec{\mathbf{x}} = 5.0\ \text{m}$



$\Delta\vec{\mathbf{x}} = 7.0\ \text{m}$

$$\Delta\vec{\mathbf{x}} = \vec{\mathbf{x}} - \vec{\mathbf{x}}_o = 5.0\ \text{m} - \left(-2.0\right)\text{m} = 7.0\ \text{m}$$

2.2 Speed and Velocity

Average speed is the distance traveled divided by the time required to cover the distance.

$$\text{Average speed} = \frac{\text{Distance}}{\text{Elapsed time}}$$

SI units for speed: meters per second (m/s)

Example 1 Distance Run by a Jogger

How far does a jogger run in 1.5 hours (5400 s) if his average speed is 2.22 m/s?

$$\text{Average speed} = \frac{\text{Distance}}{\text{Elapsed time}}$$

$$\text{Distance} = (\text{Average speed})(\text{Elapsed time})$$

$$= (2.22\ \text{m/s})(5400\ \text{s}) = 12000\ \text{m}$$

2.2 *Speed and Velocity*

Average velocity is the displacement divided by the elapsed time.

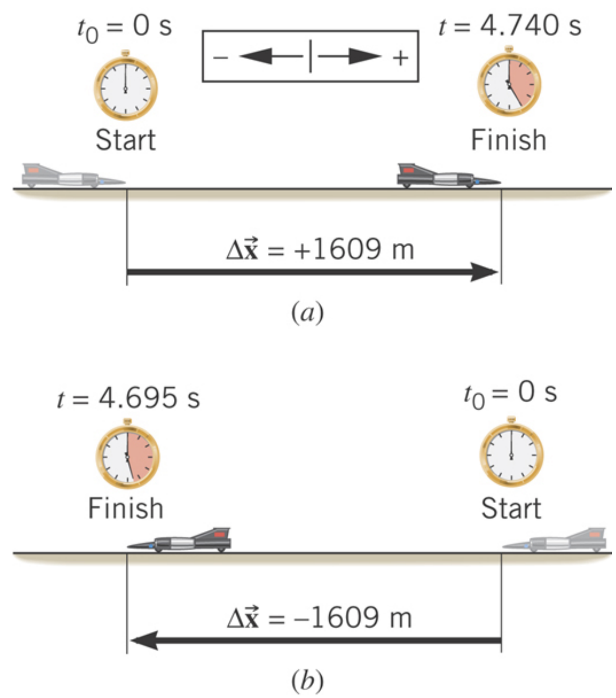
$$\text{Average velocity} = \frac{\text{Displacement}}{\text{Elapsed time}}$$

$$\overline{\vec{\mathbf{v}}} = \frac{\vec{\mathbf{x}} - \vec{\mathbf{x}}_o}{t - t_o} = \frac{\Delta\vec{\mathbf{x}}}{\Delta t}$$

2.2 Speed and Velocity

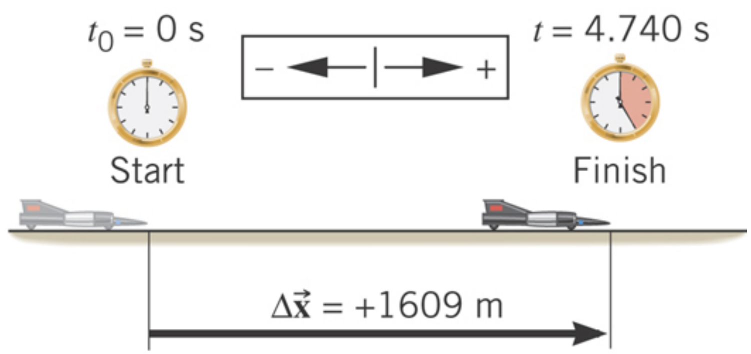
Example 2 The World's Fastest Jet-Engine Car

Andy Green in the car *ThrustSSC* set a world record of 341.1 m/s in 1997. To establish such a record, the driver makes two runs through the course, one in each direction, to nullify wind effects. From the data, determine the average velocity for each run.



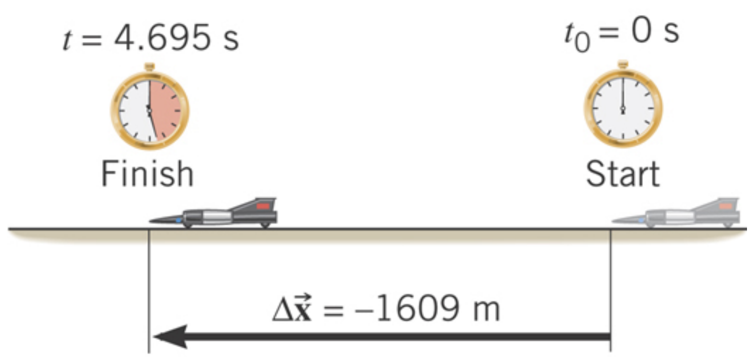
2.2 Speed and Velocity

$$\bar{\vec{\mathbf{v}}} = \frac{\Delta\vec{\mathbf{x}}}{\Delta t} = \frac{+1609\ \text{m}}{4.740\ \text{s}} = +339.5\ \text{m/s}$$



(a)

$$\bar{\vec{\mathbf{v}}} = \frac{\Delta\vec{\mathbf{x}}}{\Delta t} = \frac{-1609\ \text{m}}{4.695\ \text{s}} = -342.7\ \text{m/s}$$



(b)

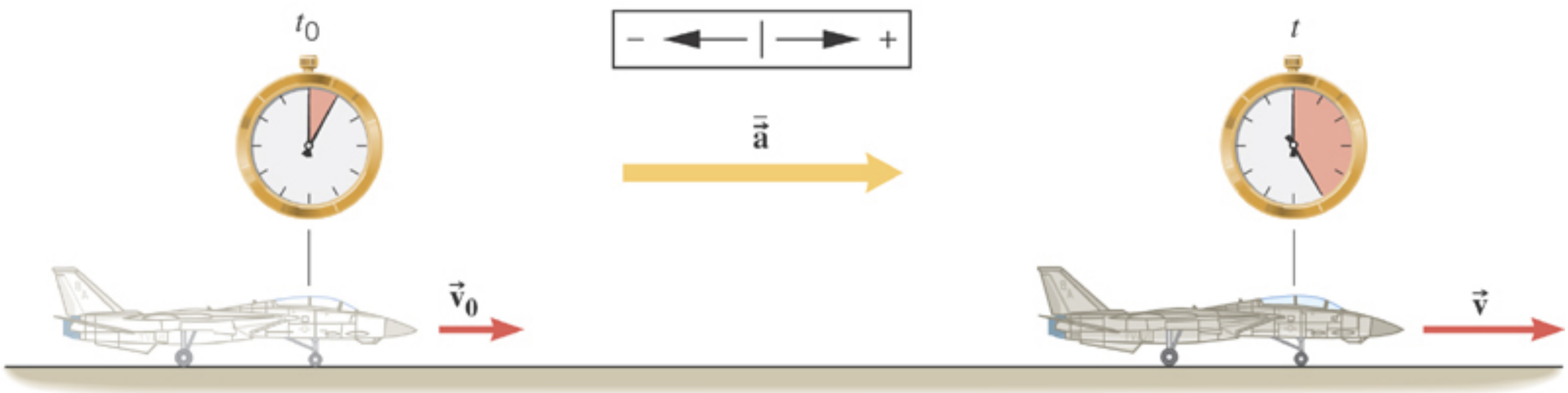
2.2 *Speed and Velocity*

The ***instantaneous velocity*** indicates how fast the car moves and the direction of motion at each instant of time.

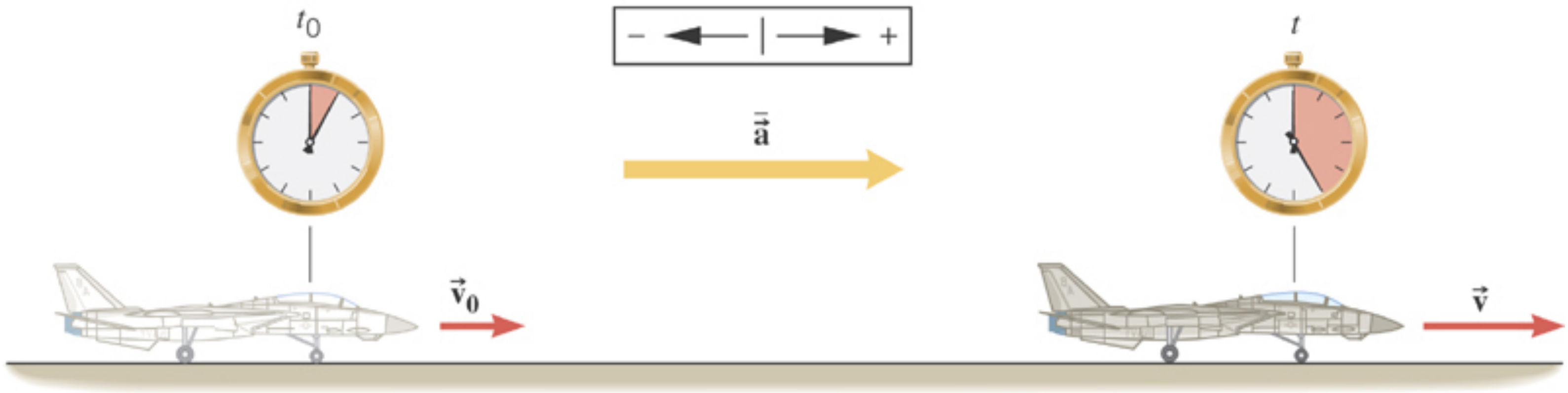
$$\vec{\mathbf{v}} = \lim_{\Delta t \to 0} \frac{\Delta \vec{\mathbf{x}}}{\Delta t}$$

2.3 Acceleration

The notion of *acceleration* emerges when a change in velocity is combined with the time during which the change occurs.



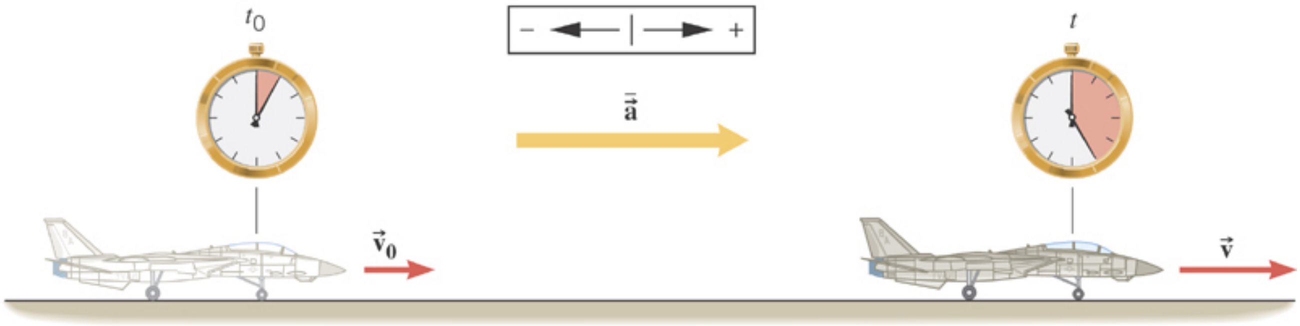
2.3 Acceleration



DEFINITION OF AVERAGE ACCELERATION

$$\overline{\vec{\mathbf{a}}} = \frac{\vec{\mathbf{v}} - \vec{\mathbf{v}}_o}{t - t_o} = \frac{\Delta\vec{\mathbf{v}}}{\Delta t}$$

2.3 Acceleration



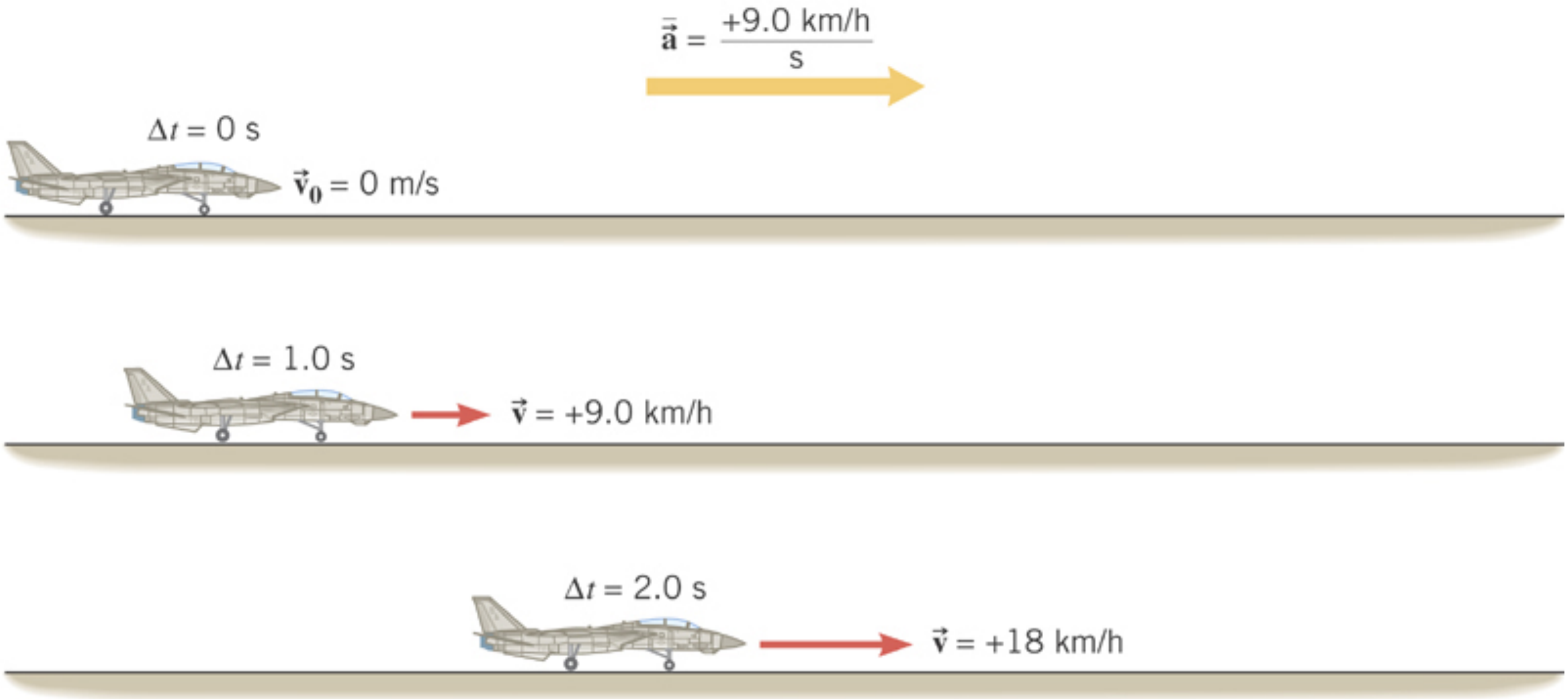
Example 3 Acceleration and Increasing Velocity

Determine the average acceleration of the plane.

$\vec{\mathbf{v}}_o = 0\,\mathrm{m/s}$ $\quad \vec{\mathbf{v}} = 260\,\mathrm{km/h}$ $\quad t_o = 0\,\mathrm{s}$ $\quad t = 29\,\mathrm{s}$

$$\bar{\vec{\mathbf{a}}} = \frac{\vec{\mathbf{v}} - \vec{\mathbf{v}}_o}{t - t_o} = \frac{260\,\mathrm{km/h} - 0\,\mathrm{km/h}}{29\,\mathrm{s} - 0\,\mathrm{s}} = +9.0\frac{\mathrm{km/h}}{\mathrm{s}}$$

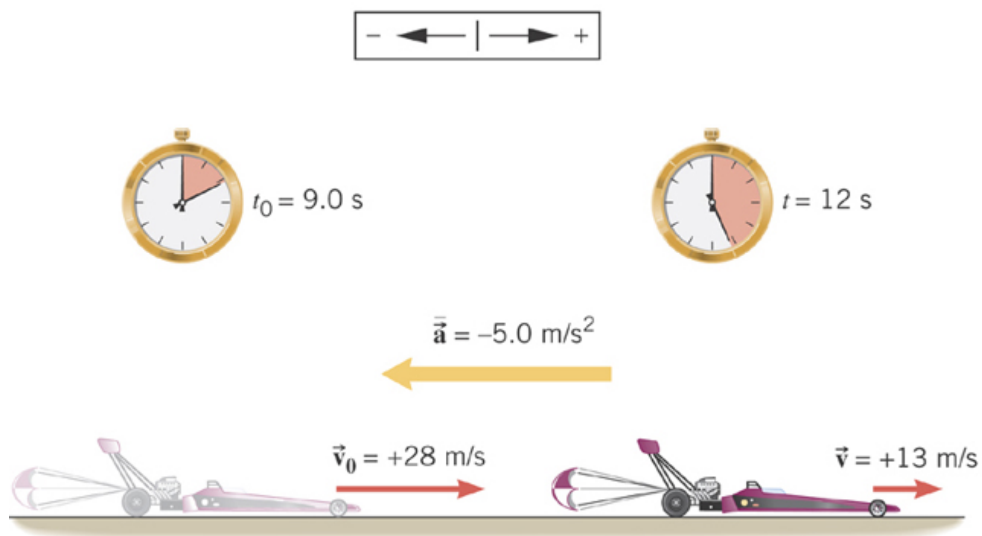
2.3 Acceleration



2.3 Acceleration

Example 3 Acceleration and Decreasing Velocity

$$\bar{\vec{\mathbf{a}}} = \frac{\vec{\mathbf{v}} - \vec{\mathbf{v}}_o}{t - t_o} = \frac{13\,\mathrm{m/s} - 28\,\mathrm{m/s}}{12\,\mathrm{s} - 9\,\mathrm{s}} = -5.0\,\mathrm{m/s^2}$$



(b)

2.3 Acceleration