Study of Motion

Fundamental Physical Quantities

- What is Motion?
- How do we quantize it?

  - Space
  - Time
  - Matter

- All physical quantities involve measurement of Space, Time, Matter

Space

- For all practical purposes **Distance** is the space between two points in 1 dimension
- Eventually it will be more complex in 3D.
- Common Terms Length, Width, Height, Diameter… (ft, in, mi, m, micron etc…)

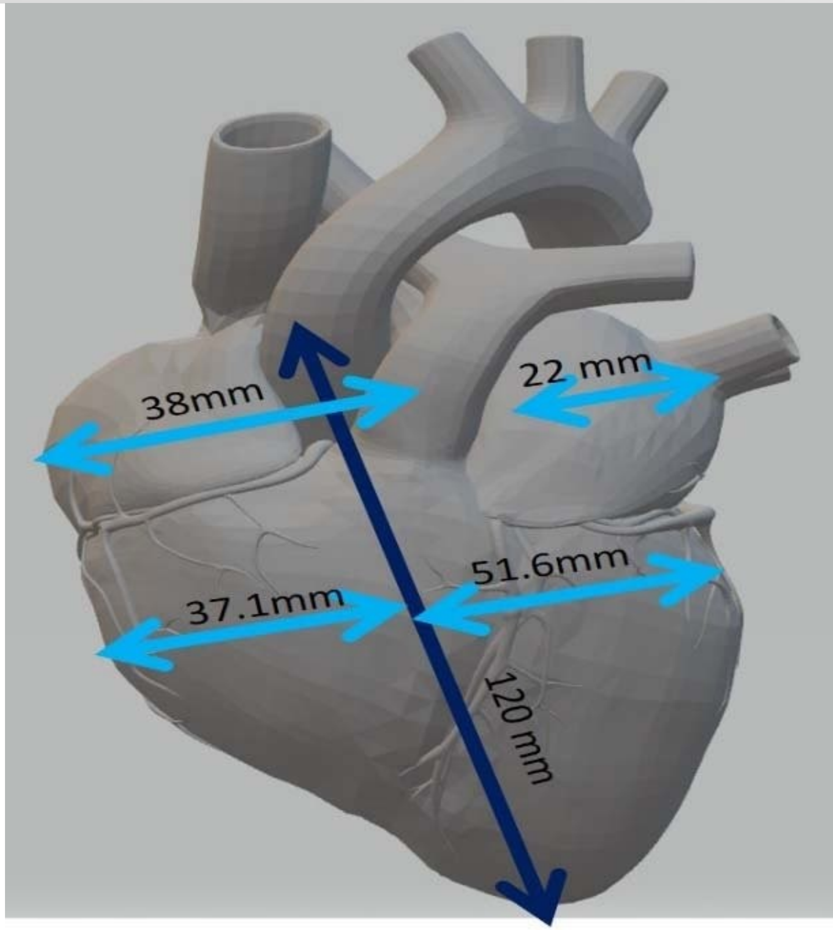
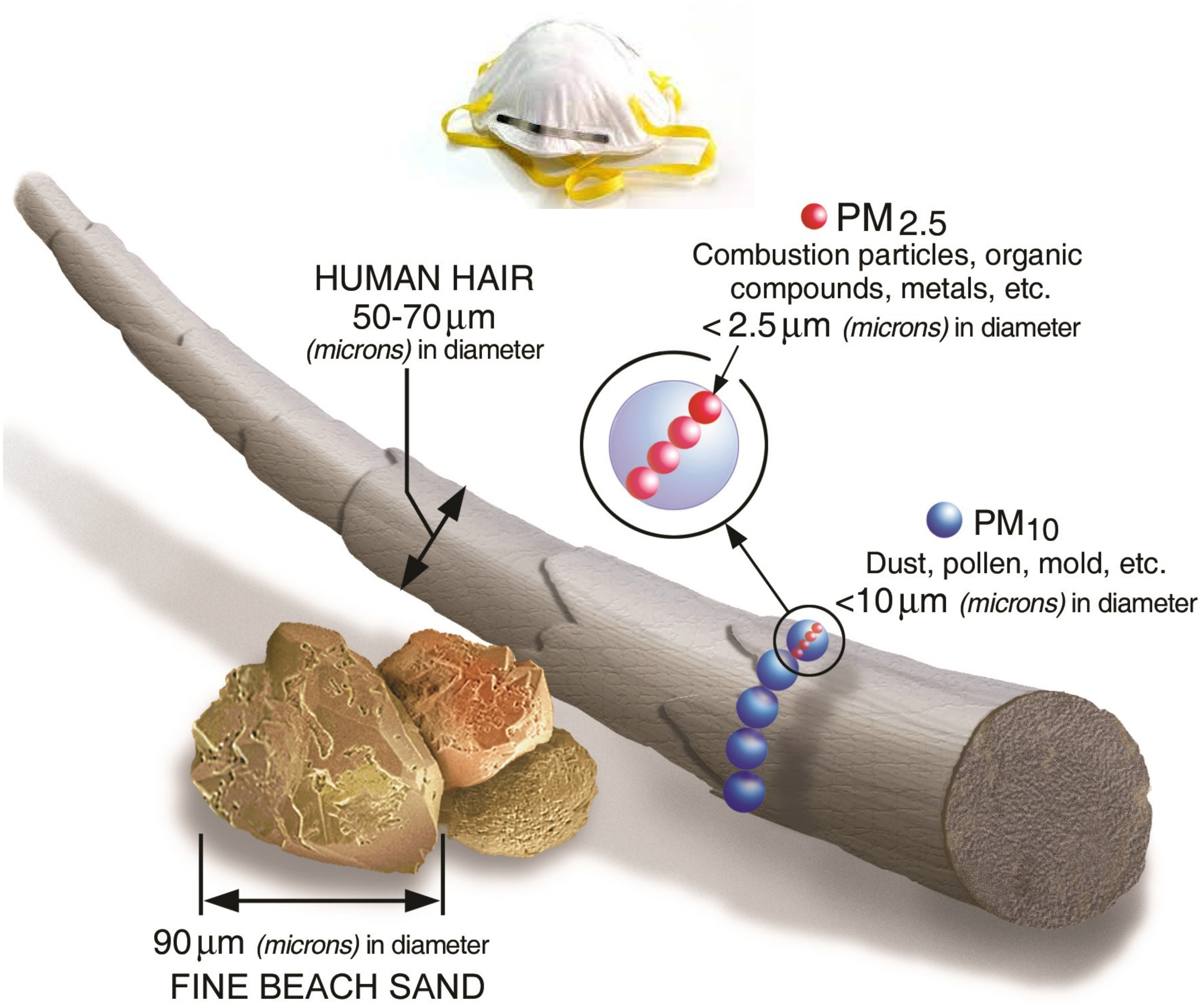


Table 1.1 Some Representative Sizes and Distances

Size/Distance	Metric	English
Size of a nucleus	1×10^{-14} m	4×10^{-15} in.
Size of an atom	1×10^{-10} m	4×10^{-9} in.
Size of a red blood cell	8×10^{-6} m	3×10^{-4} in.
Typical height of a person	1.75 m	5.75 ft
Tallest building	830 m	2,722 ft
Diameter of Earth	1.27×10^{7} m	7,920 miles
Earth–Sun distance	1.5×10^{11} m	9.3×10^{7} miles
Size of our galaxy	9×10^{20} m	6×10^{17} miles

Units: Meters (m), foot (ft), Inches (in)

Space


HUMAN HAIR
50-70 µm
(microns) in diameter
PM2.5
Combustion particles, organic compounds, metals, etc.
< 2.5 µm (microns) in diameter
PM10
Dust, pollen, mold, etc.
<10 µm (microns) in diameter
90 µm (microns) in diameter
FINE BEACH SAND

Space – Quantization 1D, 2D & 3D

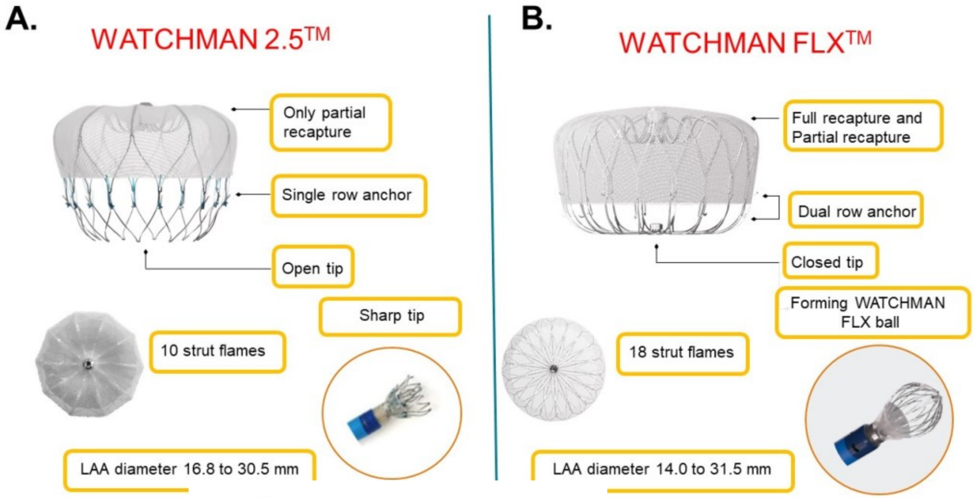
Quantizing thing we need in real life

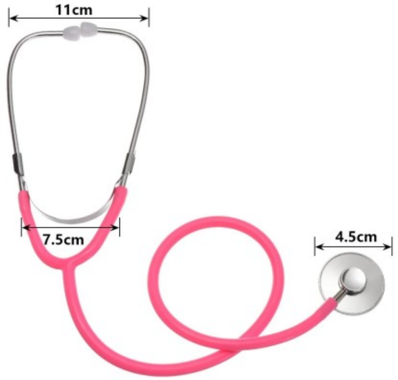
1D = Length / 2D = Surface Area / 3D = Volume

Must know the difference between surface and volume. And how to calculate the surface and volume of common objects.

Common Volumes:

- Box = L x W x H
- Cylinder = $\pi R^2 \times H$
- Sphere = $4/3 \pi R^3$





What is the surface are of Stethoscope to be effective?

See and practice with cheat-sheet for more information

		SI	IP
1D	Length	m (meter)	ft (foot)
2D	Area	m^2 (square meter)	ft^2 (square ft)
3D	Volume	m^3 (cubic meter)	ft^3 (cubic ft)

Time - Quantization

What is Time? How do we quantize time?

Time is based on the measure of periodic processes that repeat over and over and over… kind of Tick Tock, Tick Tock

Year (S)	31556926 Seconds
Day (S)	24 Hours
Hour (S)	60 Minutes
Minute (S)	60 Seconds
Second (S)	0.000277778 Hr
Femto-seconds	one-quadrillionth of a second or 10^{-15} of a second or 1⁄1 000 000 000 000 000 of a second

Units: Seconds (s), Mins (min), Hours (Hr)

Time

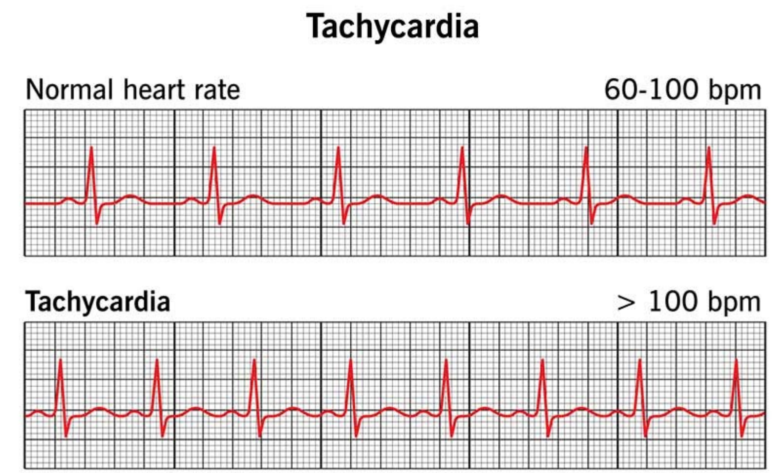
… kind of Tick Tock, Tick Tock

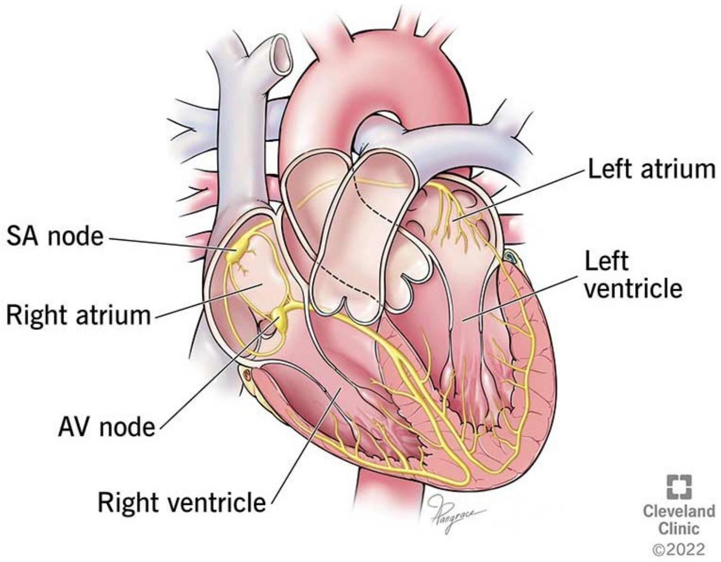
Period: The time for one complete cycle of a process that repeats T (s)

$$T = \frac{1}{f}$$

Frequency: The number of cycles of periodic process that occur per unit of time f (1/s) or (s^{-1}) or hertz (Hz)

$$f = \frac{1}{T}$$





Units: Period (s), frequency (Hz)

Time

A mechanical time stop watch use a balance wheel that rotates back and forth 10 times in 2 seconds.

What is the frequency of the balance wheel?

Mass - Quantization

- Is Mass = Weight? **NO**

Mass is a measure of how much matter an object contains.

Given a patient of certain mass

- One nurse could push or pull a gurney with a patient (inertia)
- One nurse cannot lift a gurney with a patient (the concept of weight froce and gravity)

Inertia implies the concept of how difficult to speed up or slow down an object more in Chapter 2

Weight force is a physical quantity related to mass, but it certainly is NOT mass they are different

Units: Mass (kg), grams (g)

Speed

Speed is a key concept to quantize motion. It is the **ratio** of distance over time.

Speed: Rate of movement. Time rate of change of distance from a reference point. The distance traveled by the time elapsed.

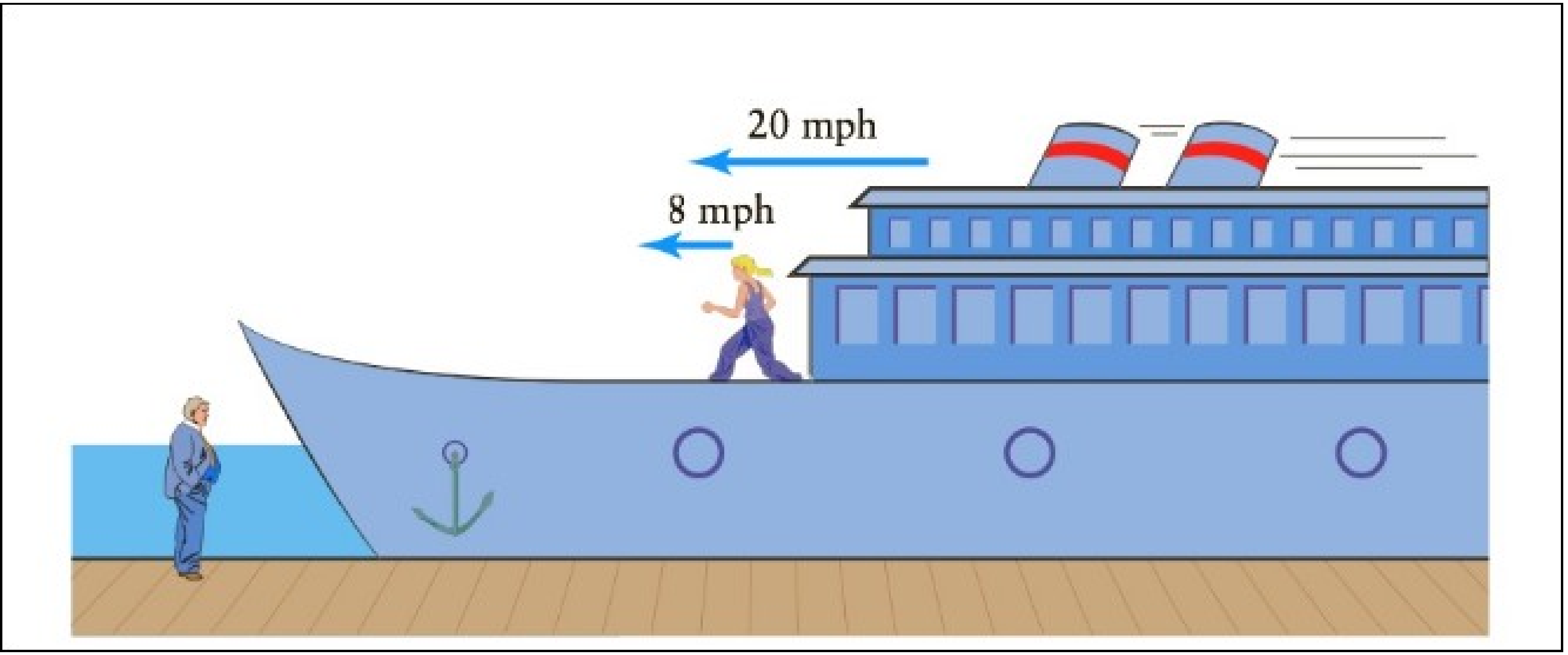
$$v = s = \frac{d}{t} = \frac{\Delta d}{\Delta t} = \frac{distance}{\text{elaped}\ time} = \frac{meter}{second} = \frac{miles}{hours}$$

- Speed is a relative concept (need a reference frame).
- Speed and velocity are used interchangeably but mean different things
  - Velocity is a vector (Magnitude & Direction) where the magnitude is a scaler called Speed
- Average Speed is total distance divided by the total time
- Instantaneous Speed is the distance divided by very small time
- When an object is moving at constant speed, then
  - the average speed = instantaneous speed
  - It is safe to estimate the distance using $d = v * t$

Units: (m/s), (mph), (km/hr)

Speed Relativity

What is the speed of the woman?



Speed

What is the distance traveled by a hiker after 3hrs and 25mins knowing that his average speed is 2.7 mph

Average Speed vs Instantaneous Speed vs Constant Speed

Using the data find the

1. Average Speed?
2. Instantaneous Speed for the following segments
    a) 0-10
    b) 20-30
    c) 50-60
    d) 60-70
    e) 70-80

What can you say about the speed of the segments a), b), c), d), e)?

Segment (meters)	Time (seconds)
0–10	1.85
10–20	1.02
20–30	0.91
30–40	0.87
40–50	0.85
50–60	0.82
60–70	0.82
70–80	0.82
80–90	0.83
90–100	0.90
Total Distance: 100 m	Total Time: 9.69 s

Velocity

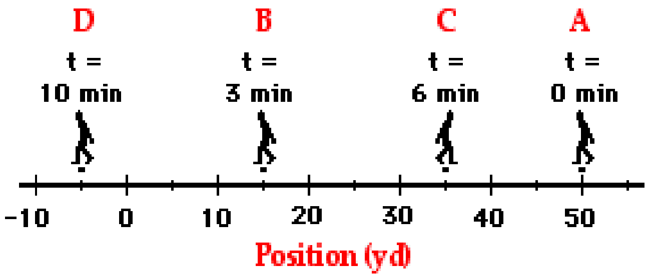
Velocity: Speed in a **particular direction** (same unit as speed) directed motion.

A critical concept in motion is direction.

Changing the direction of moving object will have an impact on its velocity. To reach a certain destination we need both speed and direction. Maintaining constant speed while changing direction might lead to the wrong destination. Velocity is good application of a **Vector** (defined by **both** a scalar and direction)

Speed is the scalar component of Velocity

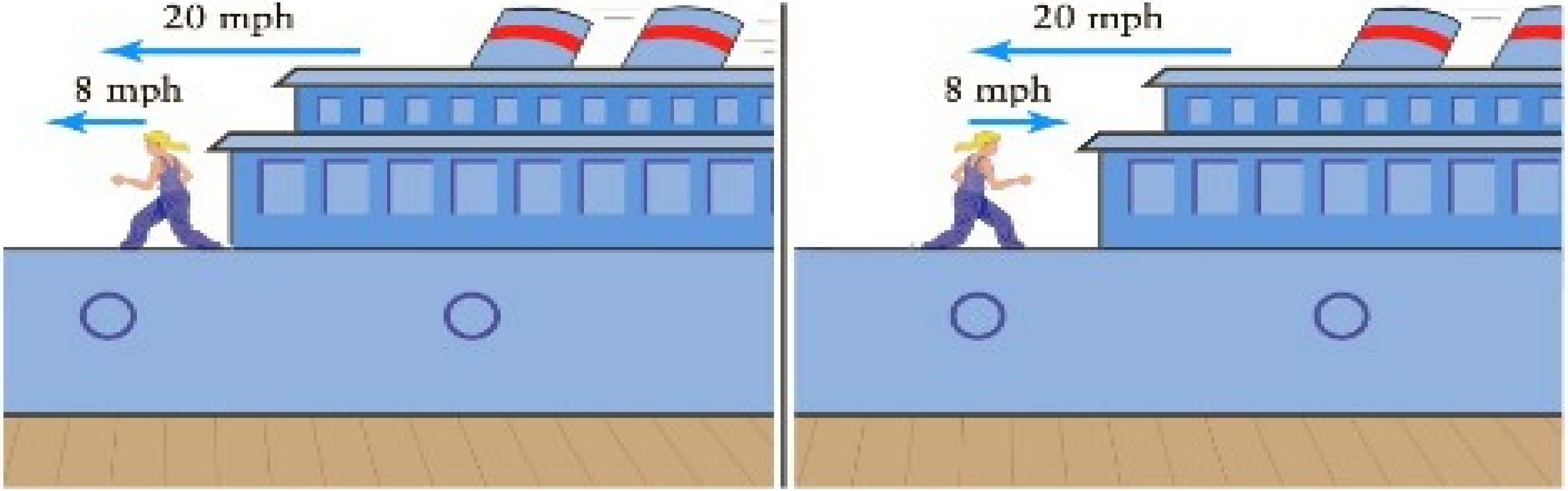
Speed does not become negative when the velocity is negative. A negative velocity means the direction is opposite to a reference point



Units: Speed (m/s), (mph), (km/hr)

Speed vs Velocity

What is the speed of the woman?



Velocity – Vector Manipulation

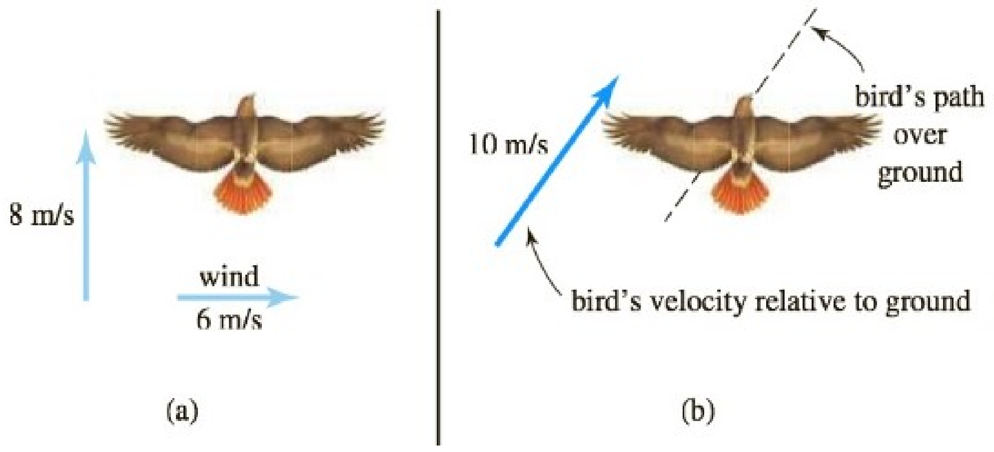
2 Methods for vector manipulation

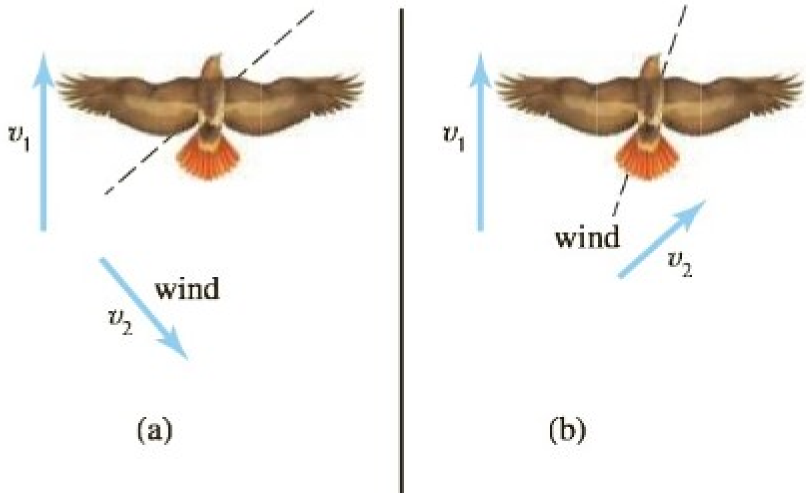
Method 1 Graphical Tail to Head:

- Good for simple problems

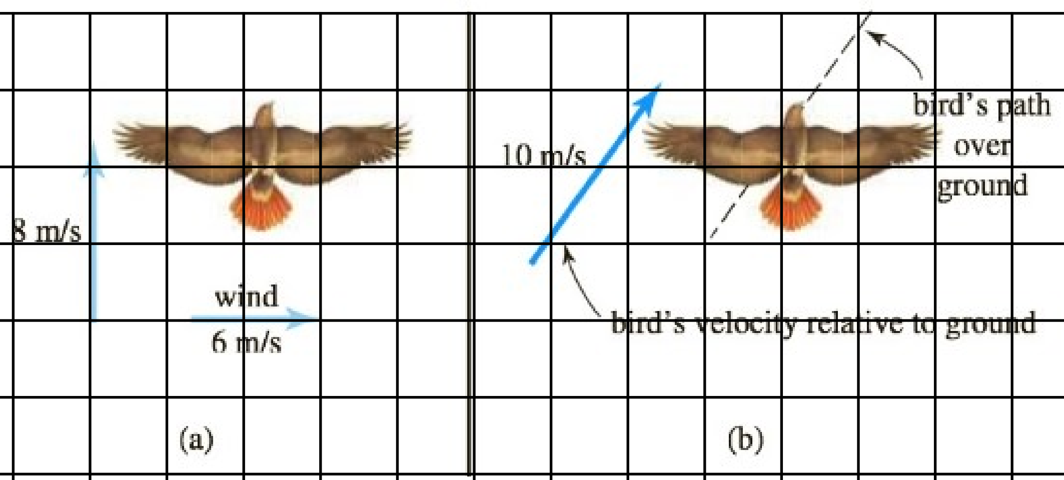
Method 2 Vector decomposition:

- Break all vectors into X and Y
- Sum all X and Sum all Y
- Use Pythagoras for resultant magnitude
- Use Trigonometry

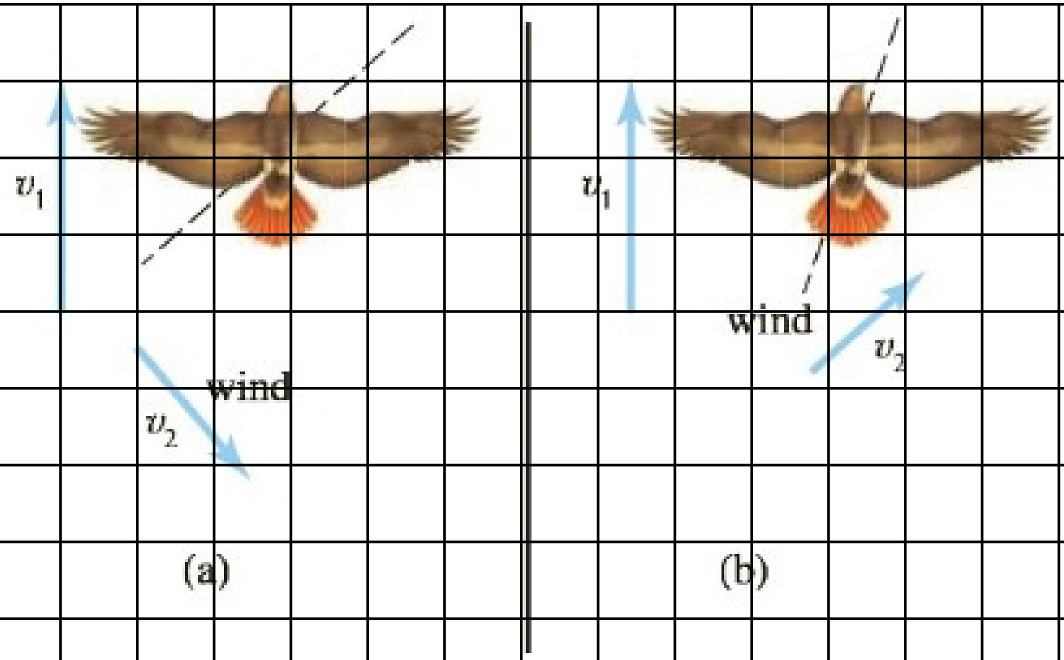




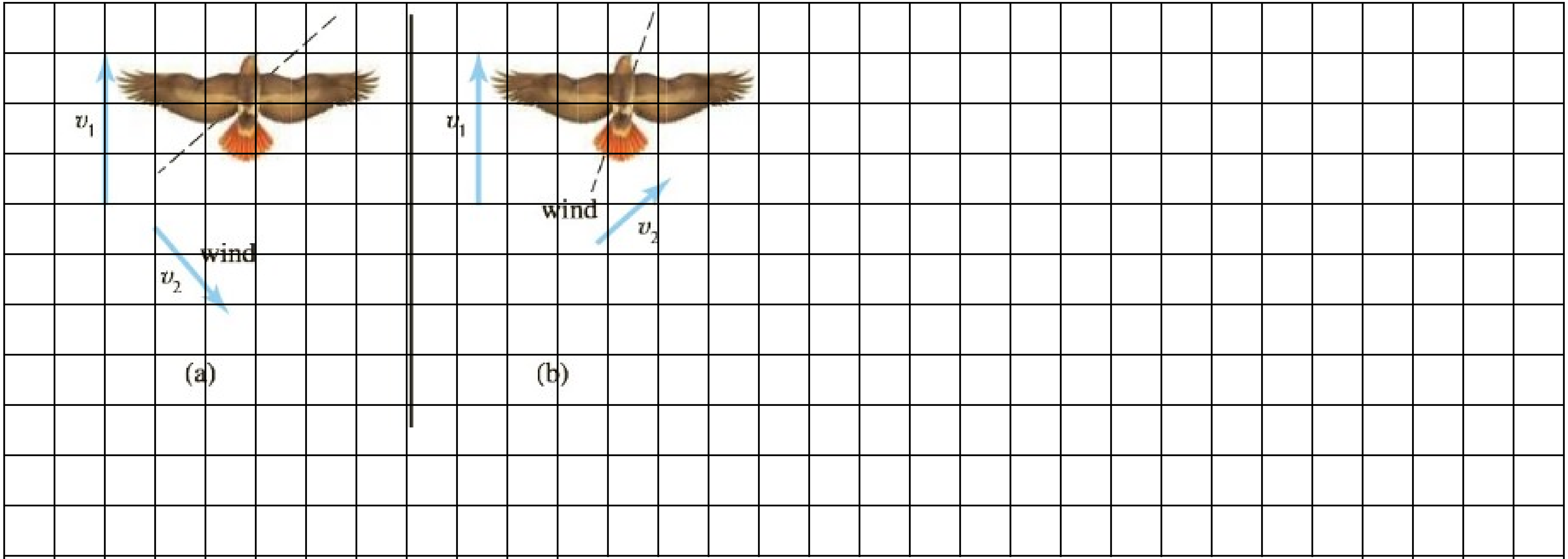
Velocity – Vector Manipulation



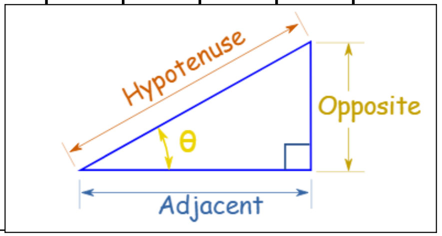
Velocity – Vector Manipulation



Velocity – Vector Addition – X-Y Decomposition



- Pythagoras $c^2 = a^2 + b^2$
- tan (θ) = Opposite / Adjacent

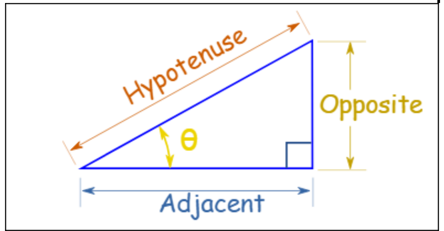


Practice – Vector Manipulation

A crate is pushed on with a force of 10N, at angle of 45 degree below horizontal.

What are the components of the force?

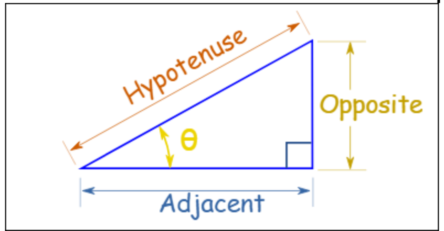
- Pythagoras $c^2 = a^2 + b^2$
- tan (θ) = Opposite / Adjacent



Practice – Vector Manipulation

What would be the NET force at an object knowing that the horizontal force is 4 N and Vertical force is 3 N?

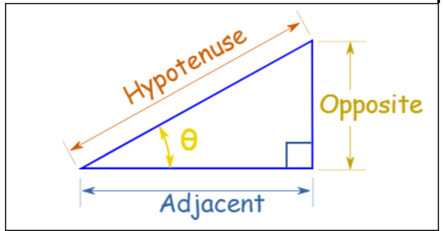
- Pythagoras $c^2 = a^2 + b^2$
- tan (θ) = Opposite / Adjacent



Practice – Vector Manipulation

What would be the NET force at an object knowing that the horizontal force is 4 N and vertical force is 3 N and a force of 10 N at an angle 45 degree below horizontal?

- Pythagoras $c^2 = a^2 + b^2$
- tan (θ) = Opposite / Adjacent



Acceleration

It is the **Rate of Change of Velocity** over **Time:**

Note the following terms are similar and used frequently in physis as well as in daily life from cardio vascular, to electronics, to music: Rate, Ratio, per, division

Acceleration: Rate of change of velocity. The change in velocity divided by the time elapsed.

$$a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i} = \frac{m}{s^2}$$

	m/s^2	g
Freely falling body on Earth	9.8	1
Free falling body on the Moon	1.6	0.16
Space Shuttle	29	3
Highest Survived by Human	245	46
Spin washing Machine	400	41
Bullet from a rifle	2,000,000	200,000

Units: acceleration (m/s^2)

Acceleration

- Remember Acceleration is:

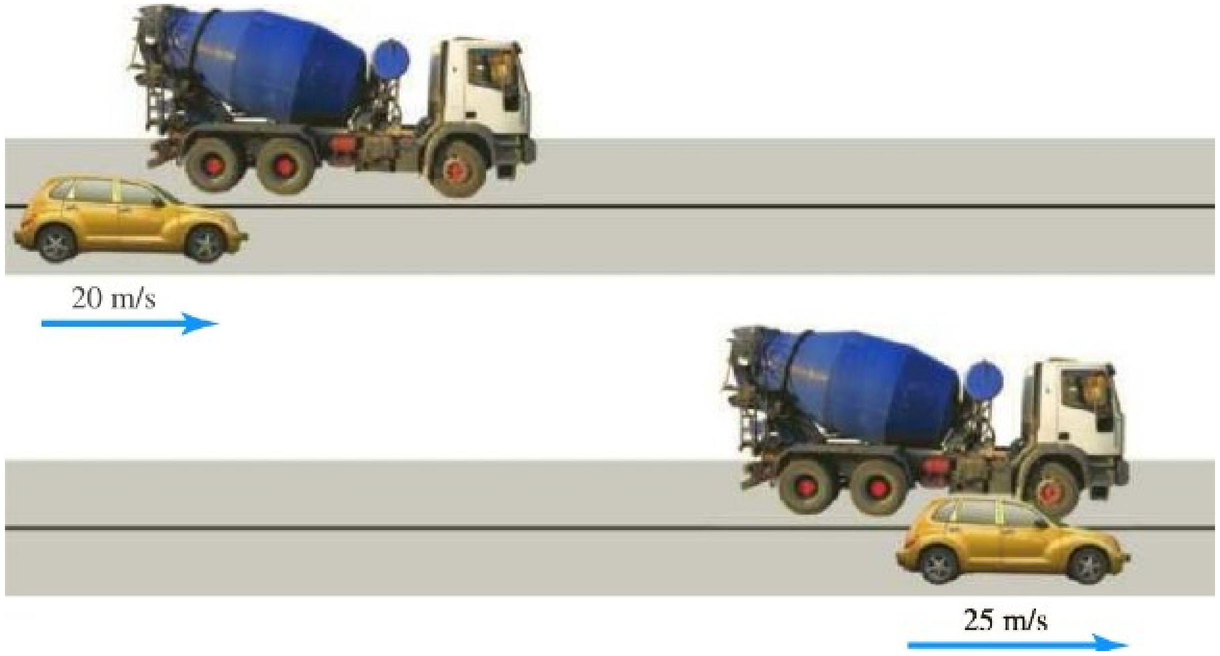
the change of velocity over time.

$$a = \frac{\Delta v}{\Delta t}\left(\frac{m}{s^2}\right)$$

- Objects in motion can change their speed or direction – Acceleration
- Acceleration is a VECTOR (noted with an arrow) which means it has a magnitude (scalar) and direction.

Acceleration

A car accelerates from 20 to 25 m/s in 4 seconds as it passes a truck. What is its acceleration?



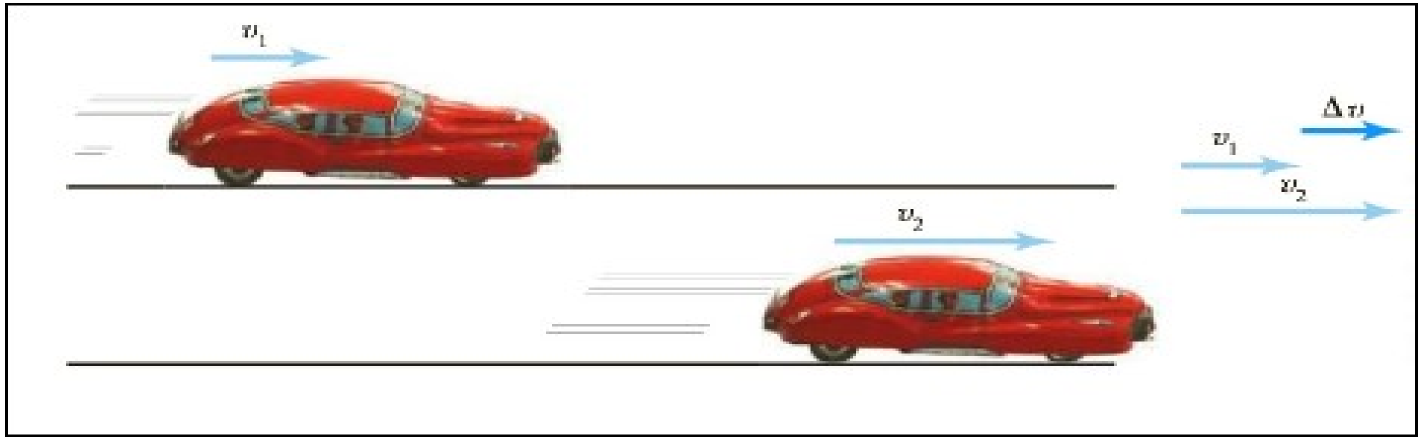
Acceleration

A biker traveling south takes 12 seconds to comes down to a stop from a speed of 20mph.

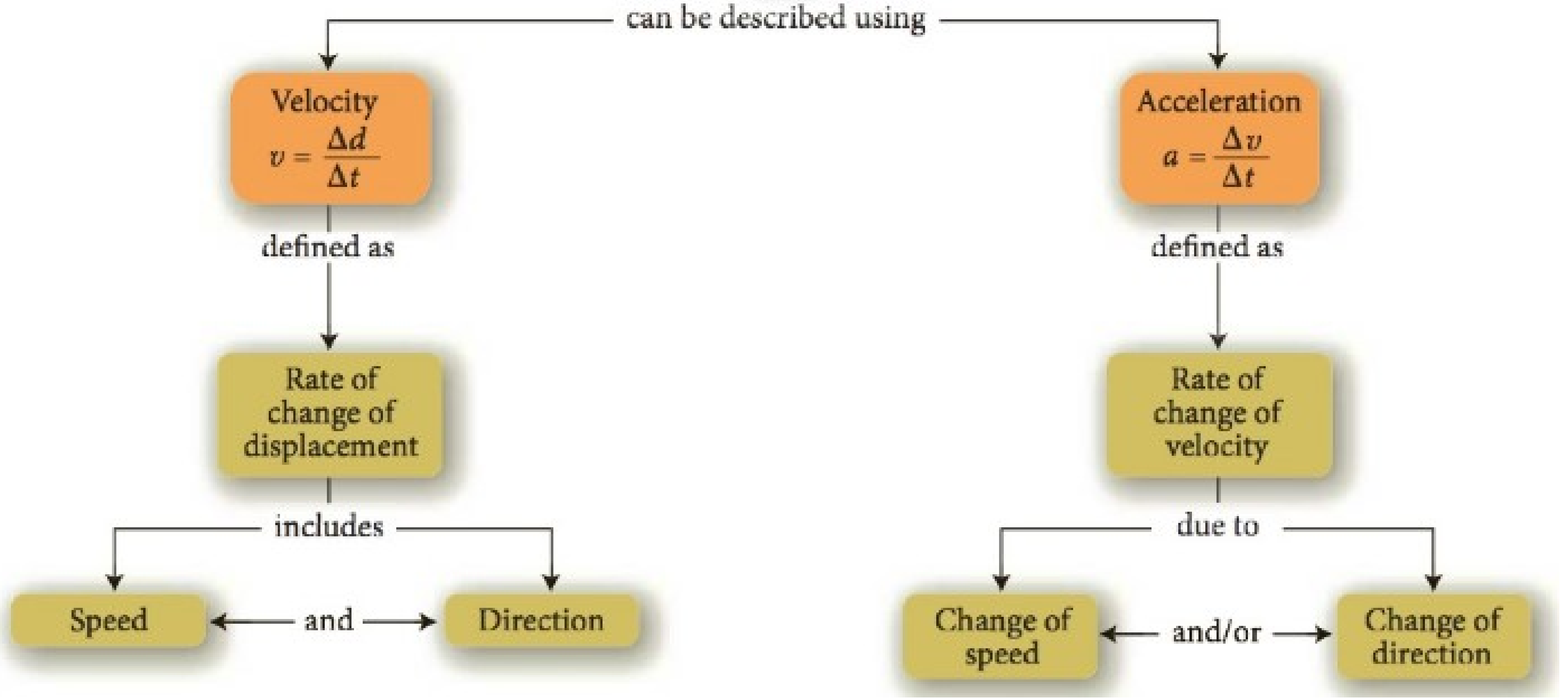
What is the biker's acceleration in m/s^2?

Acceleration

- Free falling objects are very popular examples, these object fall with constant acceleration.
- The g force specifies the force exerted on falling object usually a multiple of g (9.8 m/s^2) 3g, 4g. These quantities are not to be mixed with cell phone generations (3G, 4G, 5G)
- Acceleration is a vector, see resulting vector which represents the rate of change of velocity over time



Motion – Velocity - Acceleration



Acceleration - Centripetal

We do it every day!

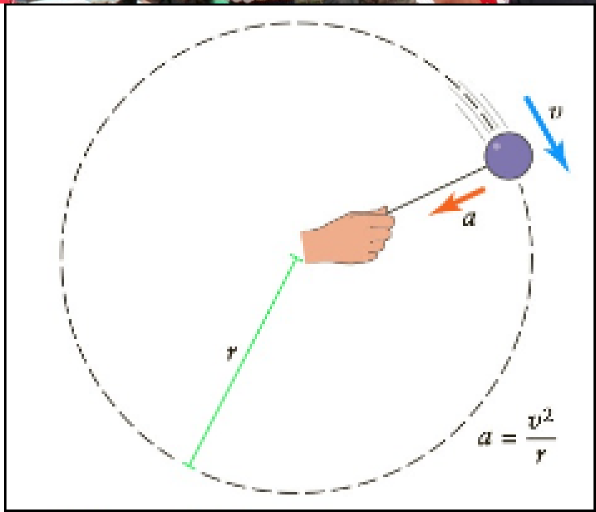
- Salad Spinner
- Washing Machine
- Amusement Park Spins Ride

Lets check the units

$$a = \frac{v^2}{r}\left(\frac{m}{s^2}\right)$$

Lets check the proportionalities

- A higher velocity → Higher acceleration
- A higher radius → Lower acceleration



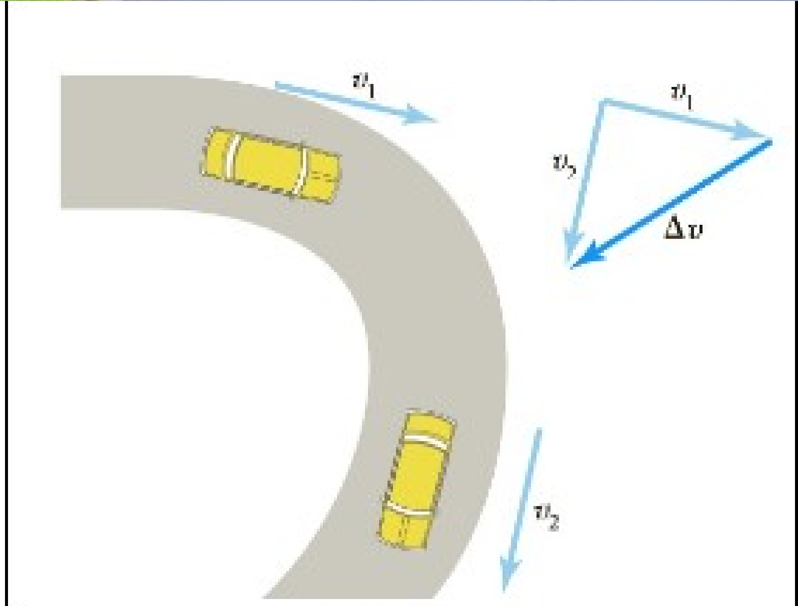
Acceleration - Centripetal

So why do we need to slow down on a curve?

Image 2 is an excellent example of vector addition, the change in direction of the vector velocity caused a change in acceleration.

Lets calculate the Centripetal Acceleration if $V1$ = 45mph, and $V2$ = 20mph assuming that the approximate radius of the curve is 65ft 6in

$$a = \frac{v^2}{r}\left(\frac{m}{s^2}\right)$$



How about we plot a vs V on a graph.
Increment V by 2 ie. (0, 10, 20, 40, 80)

Practice – Centripetal Acceleration

Lets calculate the Centripetal Acceleration when V1 = 45mph, then V2 = 20mph knowing radius of the curve 65ft 6in.

Motion Type 1 – Constant Velocity

Object at rest (object with zero speed) – the most common type of constant speed but it is special case.

Uniform Motion 3 condition: object moves with a

1. non-zero speed $v \neq 0$
2. constant speed $\frac{\Delta v}{\Delta t} = 0$
3. fixed direction

When the speed is constant the graph of motion is straight line (y= ax+b), where d is the y, the slope a is represented by v, x is represented by t, and b = 0

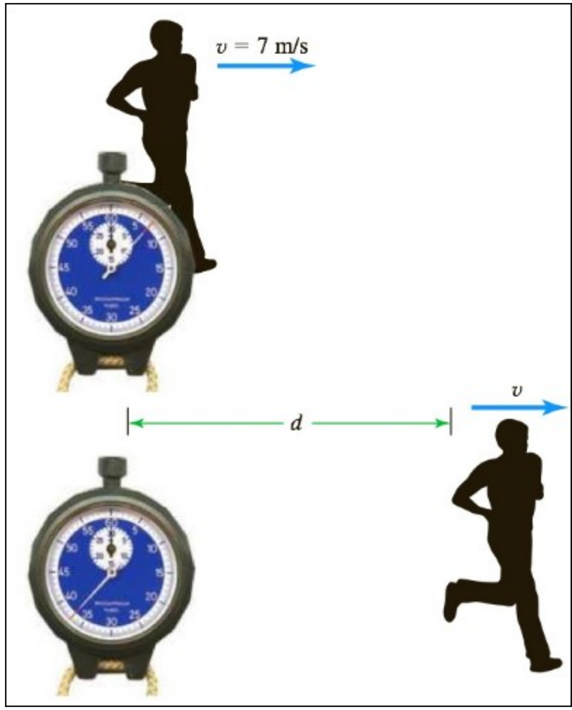
$$d = v * t$$

So what happens when velocity changes? All hell breaks lose! Acceleration

Practice – Uniform Motion Constant Velocity

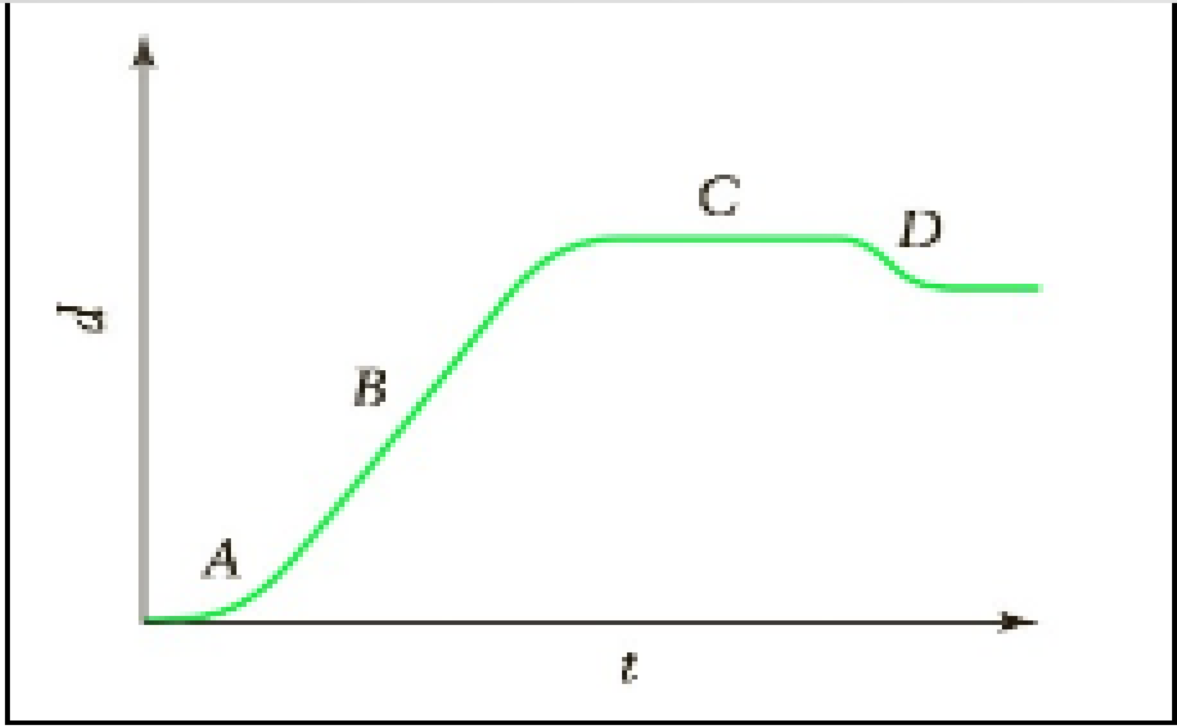
A runner is running at a Steady Pace of 7m/s.

How does the distance of the runner changes with respect to person sitting on a bench?



Motion Type Explanation

- Lets Examine the graph of distance vs time
  - At point A car start to speed
  - At point B the car velocity is constant
  - At point C the car stopped
  - At point D the car is making reverse

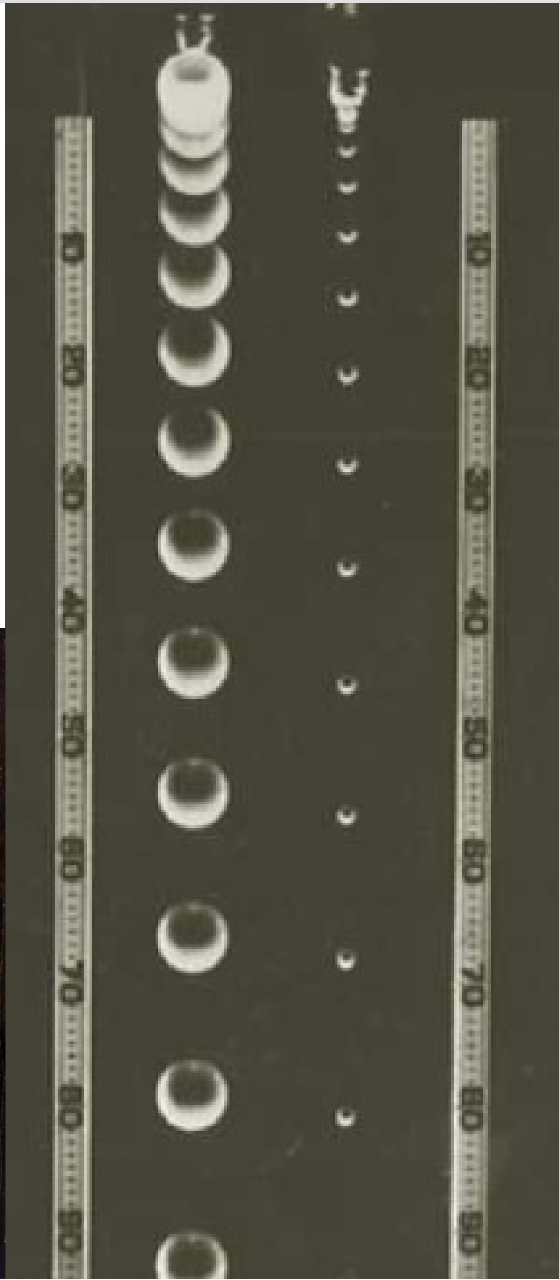


Point	Rest v=0?	$\frac{\Delta v}{\Delta t} = 0?$	Direction?	Straight Line?	Slope
A	No	No	+ (RTL)	No	Yes
B	No	Yes	+ (RTL)	Yes	Yes
C	Yes	Yes	N/A	Yes	0
D	No	NO	- (LTR)	No	Yes

Acceleration

Strobe photograph of two free falling object. Even though one is much heavier than the other, they have same constant acceleration.

Galileo Pisa Tower Experiment.



Motion Type 2 – Constant Acceleration

What is the velocity of an object with Constant Acceleration

The simplest examples is an object in free fall $a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$

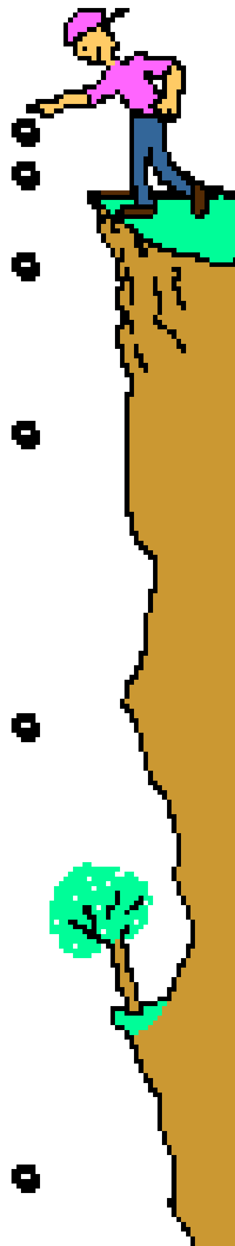
We are starting from **rest** then $t_i = 0$ & $v_i = 0$, $a = \frac{\Delta v}{\Delta t} = \frac{v_f - 0}{t_f - 0} = \frac{v_f}{t_f}$

Rearranging $v_f = a * t_f$

We claim for an object with a constant acceleration, & starting from rest th general formula is: $v = a * t$

The gravitational acceleration on earth $a = g = 9.8\left(\frac{m}{s^2}\right)$ then

We can claim for an object in free fall with a constant acceleration, & starting from rest the formula is: $v = 9.8\left(\frac{m}{s^2}\right) * t$



Practice – Free Falling Object starting from Rest

Using the equation of the last slide, let's make a table, then plot.

How to find the distance traveled by a free falling object after a certain time?

Practice – Free Falling Object starting from Rest

The masses of an earring and neckless are 5 grams and 200 grams, respectively. Both fell at the same from the balcony of 12 story apartment.

After 7 seconds, what is their respective speed?

How to find the distance traveled by a free falling object after a certain time?

Motion Type 2 – Constant Acceleration

We showed that for constant velocity: $d = v * t \; (eq1)$

For a constant velocity again, the average velocity equals the average of the instantons velocities: $\bar{v} = \frac{v_t + v_0}{2}$ *(eq2)*

We showed that a free fall object experiences constant acceleration and thus $v = a * t \; (eq3)$

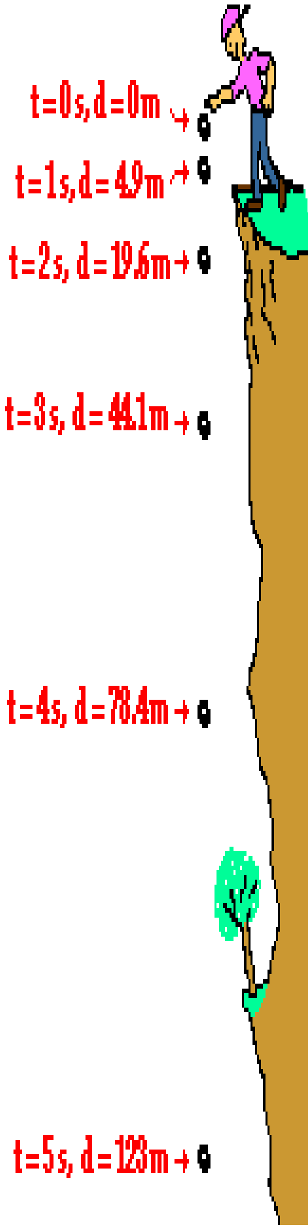
Plug eq3 into equ2 $\bar{v} = \frac{a * t + v_0}{2} \; (eq4)$ plug eq1 into eq4 $\frac{d}{t} = \frac{a * t + v_0}{2} \; (eq5)$

Rearrange $d = \frac{a * t^2}{2} + \frac{v_0 t}{2} \; (eq6)$

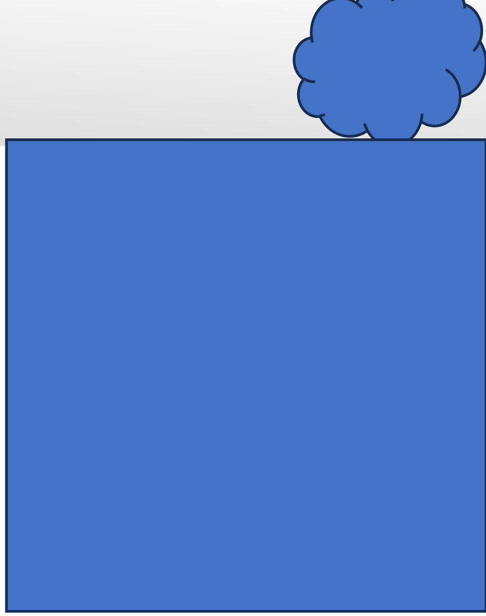
Started from rest, $v_0 = 0$, thus $d = \frac{a * t^2}{2} \; (eq7)$

Rearrange and claim for an object with contestant acceleration and starting from rest the general formula is:

$$d = \frac{a * t^2}{2}$$



Practice – Free Falling Object starting from Rest



Let's make a table and a plot …

for a free falling object i.e. $a=g=9.8m/s^2$

Plot of d (Y) as a function of time (x) would be a straight line, with a slope (rise /run) = $9.8m/s^2$.

Practice – Free Falling Object starting from Rest

The masses of an earring and neckless are 5 grams and 200 grams, respectively. Both fell at the same from the balcony of 12 story apartment.

After 7 seconds, how far did they fall from the top?

Things to remember

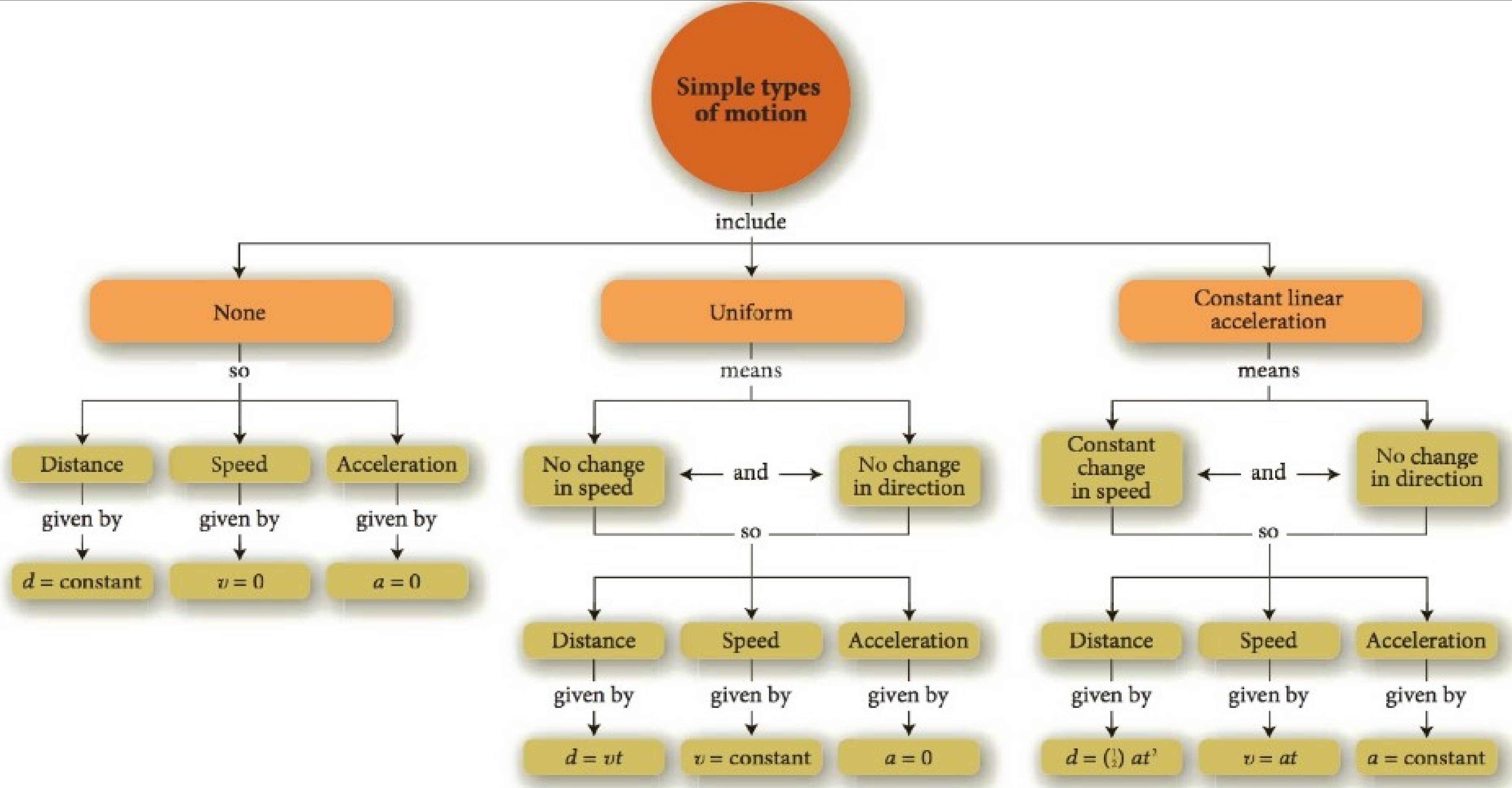
Constant Velocity Uniform Motion

- $d = v * t$
  - Note that the slope is v(m/s)

Constant Acceleration i.e. falling object starting from rest

- $v = a * t$
  - Note the slope is a (m/s2)
- $d = \frac{a * t^2}{2}$
  - Note it is not linear relationship

Things to remember



Helpful Formulas – Easier to understand than to memorize

Motion	Equation	Physical
Object at Rest	$d = constant$	Distance is constant (fixed value)
	$v = 0$	Velocity zero
	$a = 0$	Acceleration zero
Uniform Motion	$d = v\, t$	Distance is proportional to time
	$v = constant$	Velocity is constant (fixed value)
	$a = 0$	Acceleration zero
Uniform Acceleration (from rest)	$d = 0.5\, a\, t^2$	Distance Proportional to time squared
	$v = a\, t$	Velocity Proportional to time
	$a = constant$	Acceleration is constant (fixed value)
Distance is always measure from object initial location.		