## LINEAR KINEMATICS

Kinematics is a part of mechanics.
Kinematics: description of movements, without getting into what causes those movements

translation: the object maintains the same orientation.
rectilinear translation: all points of the object move in straight lines. curvilinear translation: all points of the object follow curved paths. rotation: the object changes orientation. general motion: the combination of a translation with a rotation.

Linear kinematics studies translation, ignoring its causes.

Angular kinematics studies rotation, ignoring its causes.

We will deal first with linear kinematics.

## Position

Position (also called "displacement"): an object's location at any particular time.

A 100-meter swimming race in a 50 -meter pool:


## Velocity

Velocity: the rate at which location changes with time
velocity $=\frac{\Delta \text { location }}{\Delta \text { time }}=\frac{\Delta \mathrm{S}}{\Delta \mathrm{t}}=\frac{\text { final location }- \text { initial location }}{\text { final time }- \text { initial time }}$
where $\Delta$ means "change in"

For the first length:
$\mathrm{v}_{1 \mathrm{st}}=\frac{50 \mathrm{~m}-0 \mathrm{~m}}{29 \mathrm{~s}-0 \mathrm{~s}}=\frac{50 \mathrm{~m}}{29 \mathrm{~s}}=1.72 \mathrm{~m} / \mathrm{s}$
(Notice the units for velocity: meters per second.)

For the second length:
$\mathrm{v}_{2 \mathrm{nd}}=\frac{0 \mathrm{~m}-50 \mathrm{~m}}{60 \mathrm{~s}-29 \mathrm{~s}}=\frac{-50 \mathrm{~m}}{31 \mathrm{~s}}=-1.61 \mathrm{~m} / \mathrm{s}$
(Negative sign means swimmer is moving in the negative direction: toward the left.)

Average velocity values for 10 -meter sections of the race:

| $\mathrm{t}(\mathrm{s})$ | $\mathrm{S}(\mathrm{m})$ | $\mathrm{v}_{\mathrm{avg}}(\mathrm{m} / \mathrm{s})$ |
| :--- | :---: | :---: |
| 0.0 | 0 |  |
| 4.7 | 10 | $(10-0) /(4.7-0)=2.13$ |
| 10.3 | 20 | $(20-10) /(10.3-4.7)=1.79$ |
| 16.2 | 30 | $(30-20) /(16.2 / 10.3)=1.69$ |
| 21.6 | 40 | $(40-30) /(21.6-16.2)=1.85$ |
| 29.0 | 50 | $(50-40) /(29.0-21.6)=1.35$ |
|  |  |  |

Velocity versus time plot:


Using shorter and shorter distances (or times) the "steps" in the graph become smaller and smaller. The graph looks something like this:


Instantaneous velocity: average velocity between a given instant and another instant that is infinitely close to it

If we had used very detailed (and real!) data, the graph for the full race would actually look like this:


Later we will see why.

Notice that:
Velocity: positive during first length; negative during second length.
Velocity at $\mathrm{t}=0 \mathrm{~s}$ : zero.
Velocity at $\mathrm{t}=29 \mathrm{~s}$ : zero.
Velocity at $\mathrm{t}=60 \mathrm{~s}, 61 \mathrm{~s}, 62 \mathrm{~s}, 63 \mathrm{~s}$, etc.: zero.

## Acceleration

Acceleration is to velocity what velocity is to position.

Acceleration: the rate at which velocity changes with time
acceleration $=\frac{\Delta \text { velocity }}{\Delta \text { time }}=\frac{\Delta \mathrm{v}}{\Delta \mathrm{t}}=\frac{\text { final velocity }- \text { initial velocity }}{\text { final time }- \text { initial time }}$

Example:

$$
\mathrm{v}=4 \mathrm{~m} / \mathrm{s} \xrightarrow[\Delta \mathrm{t}=2 \mathrm{~s}]{ } \mathrm{v}=9 \mathrm{~m} / \mathrm{s}
$$

It took you 2 seconds to change velocity from $4 \mathrm{~m} / \mathrm{s}$ to $9 \mathrm{~m} / \mathrm{s}$ (a velocity change of $5 \mathrm{~m} / \mathrm{s}$ ).
In each of those 2 seconds, velocity changed by an average amount of $(5 / 2=) 2.5 \mathrm{~m} / \mathrm{s}$.
So acceleration $=2.5$ meters per second per second, or $2.5 \mathrm{~m} / \mathrm{s} / \mathrm{s}$, or $2.5 \mathrm{~m} / \mathrm{s}^{2}$.

Positive and negative accelerations

small $\oplus$ velocity $\underset{\text { (this is a speeding up) }}{ }$ large $\oplus$ velocity | $\Theta$ velocity $\longrightarrow \oplus$ velocity |  |
| :---: | :---: |
| large $\Theta$ velocity |  |
| (but this is a slowing down!) |  |

| large $\oplus$ velocity $\qquad$ (this is a slowing down) small $\oplus$ velocity |  |
| :---: | :---: |
| $\oplus$ velocity $\longrightarrow \Theta$ velocity | $\bigcirc$ acceleration |
| small $\Theta$ velocity $\qquad$ large $\Theta$ velocity (but this is a speeding up!) |  |



Accelerations during the swimming race, and relationships with force made on swimmer


Note: When velocity is zero, acceleration is not necessarily zero. In the example, acceleration was not zero at $\mathrm{t}=29 \mathrm{~s}$.

Units:

- linear displacement (or position):

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meters (m)
meters/second (m/s)
meters/second/second (m/s/s)
or
meters /second squared (m/s 2}
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Types of translations:

- uniform motion:
- uniformly accelerated motion: acceleration is constant
- variably accelerated motion: acceleration is not constant

