Biophysics

1. semester 2024/25

associate professor Jure Pražnikar
email: jure.praznikar@upr.si

1

Motion in one dimension: displacement, speed, velocity, acceleration

2

Kinematics: describes the motion

Kinematics describes *quantitatively* how a body moves through space.

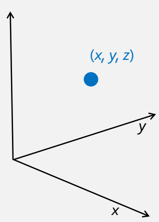
We'll begin by treating the body as rigid and non-rotating, so we can fully describe the motion by following its center.

Dynamics accounts for the observed motion in terms of forces, etc. We'll get to that later.

3

Measurement motion:

The starting point:



To measure **motion**, we must first measure **position**.

We measure position relative to some fixed-point O, called the origin.

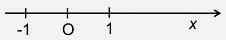
We give the ball's location as (x, y, z): we reach it from O by moving x meters along the x-axis, followed by y parallel to the y-axis and finally z parallel to the z-axis.

4

One-Dimensional Motion: Distance Traveled and Displacement

The **frame of reference** in one dimension is just a **line**!

Think of a straight road.



This time we've made explicit that the *x*-axis also extends in the *negative* direction, so we can label all possible positions.

Driving a car, the **distance** traveled is what the odometer reads.

The **displacement** is the difference $x_2 - x_1$ from where you started (x_1) to where you finished (x_2).

Distance and displacement are only the same *if you only go in one direction*!

5

Distance and Displacement

- Take highway as straight line
- Drive to Ljubljana: distance = 120 km, displacement = 120 km.
- Drive to Ljubljana and halfway back:
- Distance = 180 km, displacement = 60 km.
- Drive to Portorož. (opposite direction)
- Distance = 15 km, displacement = -15 km.

6

Average Speed and Average Velocity

Average speed = distance car driven/time taken

Average velocity = **displacement**/time taken,
so **average velocity is a vector**! It can be **negative**.

$$v = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x}{\Delta t}$$

Example: <u>round</u> trip to Ljubljana.

Average speed = 120 km/h ≈ 33 m/sec.

Average *velocity* = zero! >> displacement is zero!!

7

Average Trip Speed

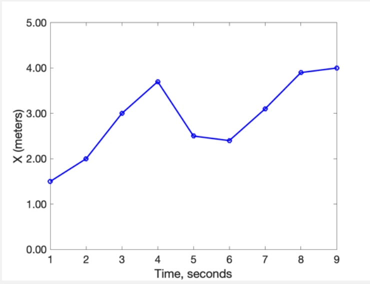
You drive 60 kilometers at 60 km/h, then 60 kilometers at 30 km/h. What was your average speed?

A. 40 km/h
B. 45 km/h
C. 47.5 km/h

8

How would you calculate instantaneous velocity when t=5.00s?

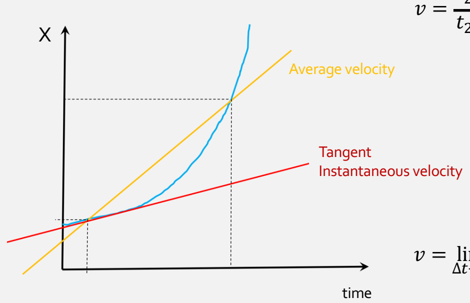
Time (s)	1	2	3	4	5	6	7	8	9
X (m)	1.5	2	3	3.7	2.5	2.4	3.1	3.9	4



9

Instantaneous Velocity

$$v = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x}{\Delta t}$$



$$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

10

Instantaneous Velocity

That's the velocity at **one moment of time**: car speedometer gives instantaneous speed.

To find this, we need to find car's displacement in a very short time interval (to minimize speed variation).

Mathematically, we write:

$$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

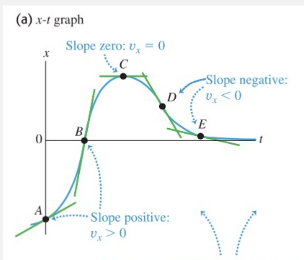
This "lim" just means taking a succession of shorter and shorter time intervals at the moment in time (infinity small dt).

The instantaneous velocity is the limit of the velocity function when Δt approaches zero, that is to say, the ***derivative of space relative to time****.*

11

Instantaneous Velocity

Differentiation: tangent to curve at some point



University Physics with Modern Physics [13th Edition] - Young & Freedman

12

Acceleration

Average acceleration = velocity change/time taken

$$a = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}$$

Notice that acceleration relates to change in velocity exactly as velocity relates to change in displacement.

Velocity is a vector, so **acceleration is a vector**.

Taking **displacement towards Ljubljana as positive**:
Slowing down while driving *to Ljubljana*: **negative acceleration**.
Speeding up driving *to Portorož*: ***also,* negative acceleration**!

13

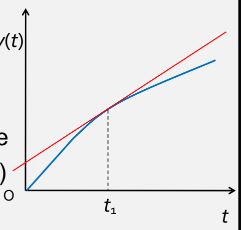
Instantaneous Acceleration

This is just like the definition of instantaneous velocity:

The instantaneous acceleration

$$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt}$$

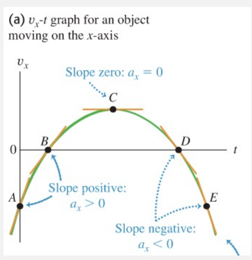
The acceleration at time t_1 is the slope of the velocity graph $v(t)$ at that time.



14

Instantaneous Acceleration

Differentiation: tangent to curve at some point



University Physics with Modern Physics [13th Edition] - Young & Freedman

15

Units - motion

Displacement: meters (can be positive or negative)

Velocity = rate of change of displacement, units:
Meters per second, written m/s.

Acceleration = rate of change of velocity, units:
Meters per second per second, written m/s^2.

16

Constant Acceleration

Constant acceleration means the rate of change of velocity is constant.

$$\frac{dv}{dt} = a = const.$$

The solution to this equation is $v = v_0 + at$

17

Distance and Constant Acceleration

At constant acceleration,

$$\frac{dx}{dt} = v(t) = v_0 + at$$

The solution of this equation is $x(t) = x_0 + v_0 t + \frac{1}{2}at^2$

18

Constant Acceleration Formulas

$$v = v_0 + at$$

$$x(t) = x_0 + v_0 t + \frac{1}{2}at^2$$

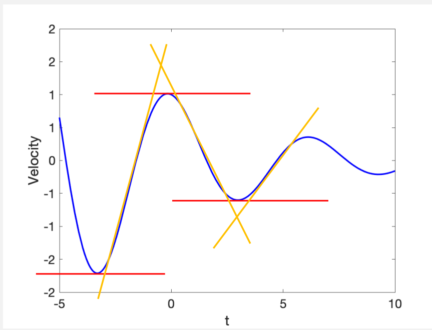
$$v^2 = v_0^2 + 2a(x - x_0)$$

the last one is simply derived by eliminating *t* between the first two

19

Example

At what time acceleration is largest (lowest)?

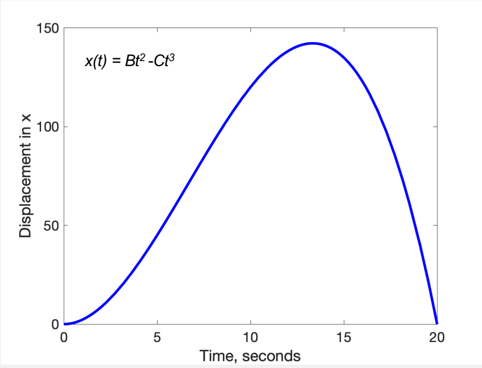


20

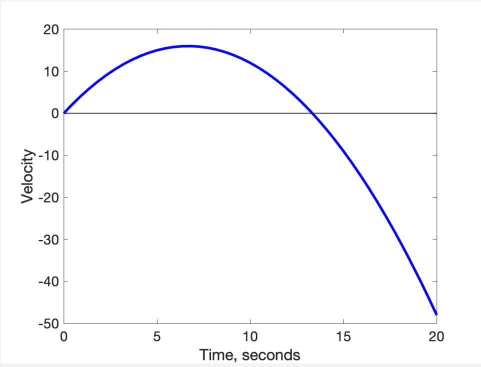
Exercises

Motion of a particle is described with function: $x(t) = Bt^2 - Ct^3$, ($B = 2.4\ ms^{-2}$, $C = 0.12\ ms^{-3}$). What it is average acceleration and average speed after 10 seconds? Calculate instant velocity in time t = 0s, 5s, 10s. At what time particle stops?

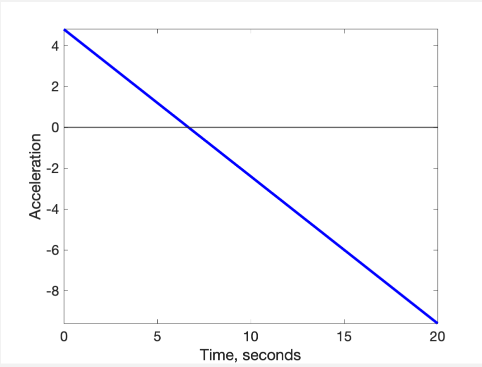
21



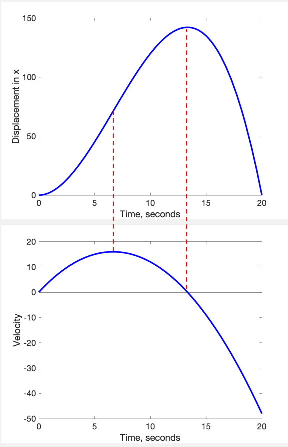
22



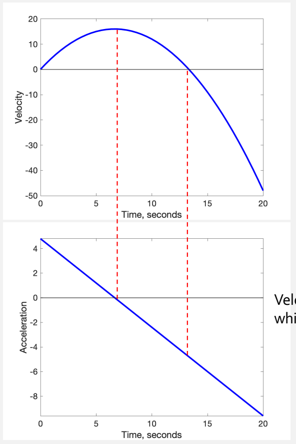
23



24



25



Velocity is max,
while acceleration is zero.

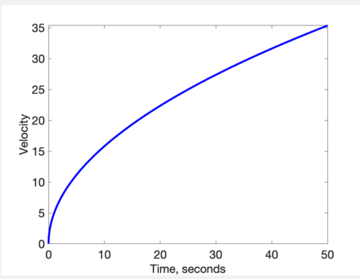
Velocity is zero,
while acceleration is negative.

26

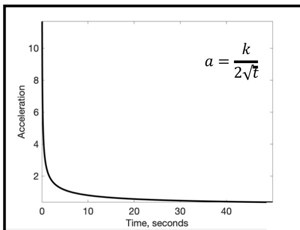
Exercises

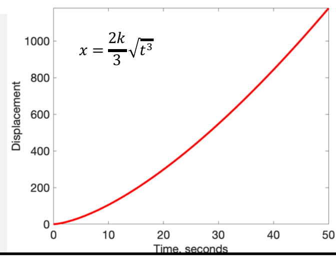
Train moves with velocity $v = k\sqrt{t}$. $k = 5\, m\, s^{-\frac{3}{2}}$

Find displacement and acceleration.

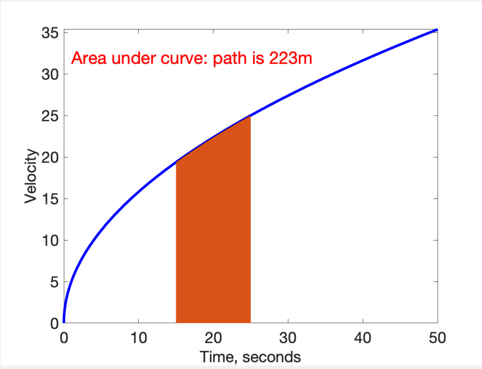


27





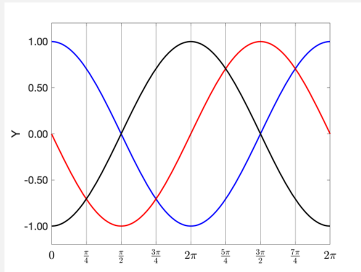
28



29

Exercises

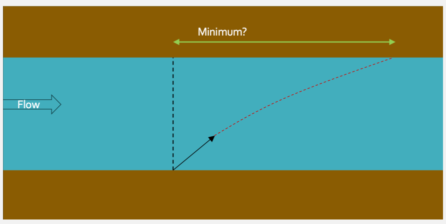
Movement of an object is described with the next function: *x =Acos(ωt)*. Write function for speed v(t) and acceleration a(t), assume that A and *ω are* constants. Draw graphs *x(t), v(t), a(t)*.



30

Exercise

We want to cross the river, and our boat is going twice as slow as the river's current. In which direction (angle!) do we have to steer the boat so that the distance to the starting point is the shortest?



31