UNIT 1. Introduction & Kinematics

Instructor: Dr. Lech Jedral

Grade 11 Physics
Olympiads School

Course Overview

- Sixteen 2.5-hour classes, 40 hours total
- Have pens/pencils and your calculator handy to follow in-class examples
- Using cellphones is NOT allowed
- Homework are assigned at the start of every unit; Monday's hwk is due Thursday and Thursday's hwk is due next Monday.
- There will be a midterm and final take–home test

Course Overview

- **Introduction & 1D Kinematics**
- Motion in a Plane (two-dimensional kinematics)

- Newton's Laws

- Work and mechanical energy
- Heat and energy transformation

- Energy transfer through vibrations and waves
- Wave model of sound

- Electricity and magnetism

What is Physics

- **Physics** (from the Greek, *φύσις* (*phúsis*), "nature" and *φυσικῆ* (*phusiké*), "knowledge of my room") is the science concerned with the discovery and understanding of the fundamental laws of the Universe which govern matter, energy, space, and time.

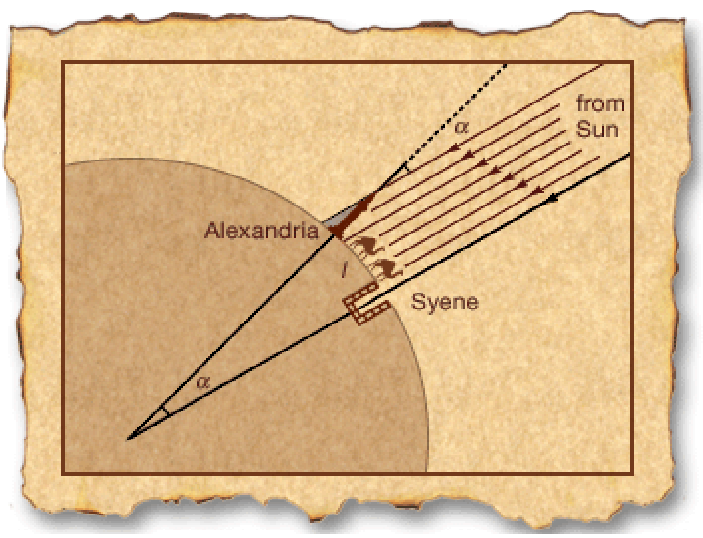
Nowadays Physics

- **Still using Newtonian Physics** – Evryday’s Life

- **Quantum Physics** – Atomic clocks, electronics, computers
- **Theory of Relativity** – Global Positioning System, Black Holes, Gravitational Waves
- **Particle Physics** – LHC, Higg’s Bozon, Standart Model, The String Theory, Early Universe
- **Astrophysics** – Dark Matter, Dark Energy, The future of the Universe, Other universes

From the Past:

Radius of Earth -Measured by Eratosthenes, ~ 2000 years ago



There are things that we must learn *before* we learn any physics.

- **Math**
- **Metrology**

Significant Figures

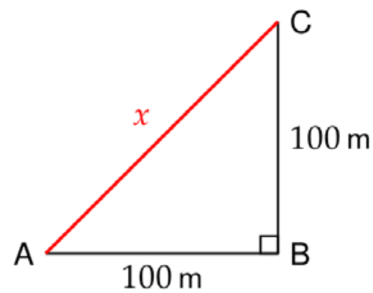
- Physics uses math and experiments, quantities are the result of *measurements*
- Measurements have a finite accuracy, therefore 100.0 m and 100.000 m are different. HOW?
  - We can *count* exactly, but we can not *measure* exactly
  - Let's try !

Dealing with Quantities

In the diagram, A is 100.0 m from B, and B is 100.0 m from C. What is the distance between A and B?

- In your math class, you are *required* to give the exact answer 100√2 m
- In physics, AB and BC are quantities with limited accuracy

In this example, *x*=141.4 m is the best answer



Significant Figures (Digits)

- The more "digits" your measurement has, the more significant figures
- For example:
  - **62.4 cm** - 3 significant digits
  - **0.0310** - 3 significant digits
  - **1.0000** - 5 significant digits
  - **10001** - 5 significant digits
  - **1.23000 x 10^4** - 6 significant digits (Sci. Notation)
  - The last digit is only *estimated*

Significant Figures

Multiplication and Division: The number of significant figures in the answer equals to the number with the fewest significant figures. e.g.:

$$6.4 \times 3.217 = 20.5888 \rightarrow 20$$

Addition and Subtraction: The number of decimal places in the answer equals to the number with the fewest decimal places. e.g.:

$$6.4 + 3.217 = 9.617 \rightarrow 9.6$$

The numbers in red have some uncertainty

Rounding

Most problems in high-school physics have 2 or 3 significant figures

To round to *n* significant figures, check the $(n+1)^{th}$ digit.

- If it is 1 to 4: round **down**
- 5 followed by non-zero or 6 to 9: round **up**
- 5 followed by zero, then check n^{th} digit:
  - if that number is odd, round **up**
  - if that number is even, round **down**

Measurement	Round to
1.2346	1.23
1.3478	1.35
2.4450	2.44
2.5752	2.58

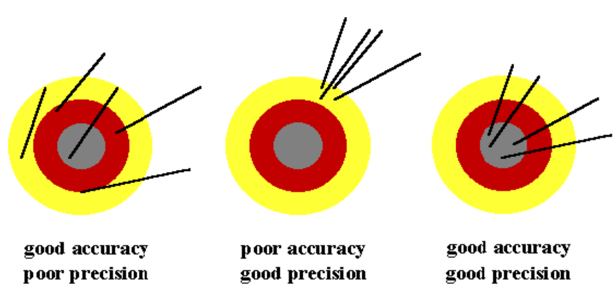
Significant Figures

When doing a homework/research/engineering/design problem:

- Keep at least one more decimal place than needed in intermediate steps (better yet, save *all* decimal places during intermediate steps)
- Round to the appropriate number of sig. figs. **only in the last step**

Accuracy and Precision -The Target Analogy

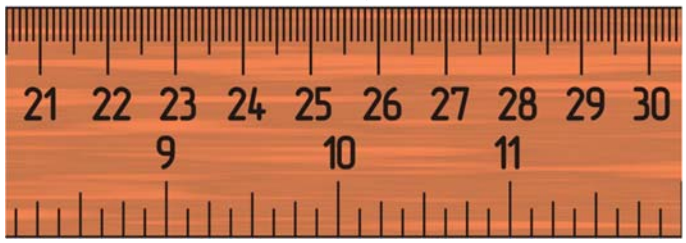
-



Accuracy vs. Precision

They're not the same thing!

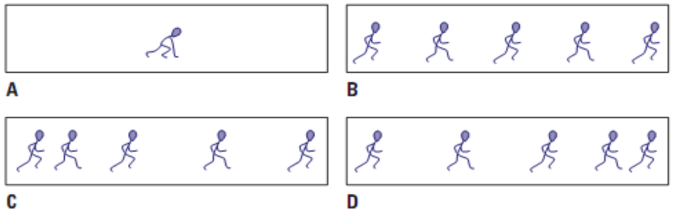
- Accuracy: The closeness of a MEASURED value to a TRUE value
- Precision: The closeness of two or more measurements to each other. Usually is determined by a number of digits the measurement can be represented.
- An electronic scale can show your weight with a precision of 6 significant figures, but if it's not calibrated correctly, is not accurate!

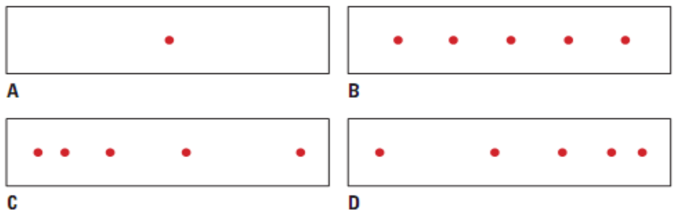


Kinematics

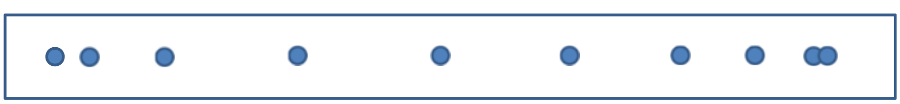
Analysis of Motion

The four different picture shows four different kinds of motion:





Describe this event



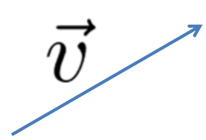
Concepts of Motion

- The concepts in this unit:
  - **Position,Displacement** and **Distance**
  - **Velocity** and **Speed**
  - **Acceleration**

- Displacement, velocity and acceleration are **vectors** quantities
- Distance and speed are **scalar** quantities
- Vectors have a **magnitude** and a **direction**

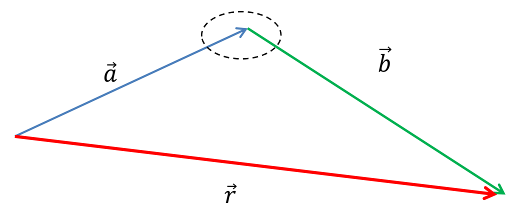
Vectors

- In describing motion, direction matters
  - If I am 15 km from Olympiads School, where am I?
- Vector has two parts: a magnitude and direction
- For vector quantities, we write the symbol with an arrow on top:
- Vector is represented by an arrow:



Adding two vectors graphically

- Tip – to – Toe Method



$\vec{a}+\vec{b} = \vec{r}$ (resultant vector)

Vectors in One Dimension

- Define a positive direction, e.g.
  - If [North] is positive, then [South] is negative
  - If [up] is positive, then [down] is negative
  - If [left] is positive, then [right] is negative
  - If [forward] is positive, then [backwards] is negative
- When solvinging a problem, be sure to indicate which way is positive!
- After that, use (+) and (-) signs to describe the direction. e.g.

+28 m/s

describes the *velocity* of an object. The plus sign is its direction, and 28 m/s is the magnitude

Vectors in Two Dimensions

Vectors of any dimensions can be written as a magnitude and a direction in brackets, i.e.:

magnitude [direction]

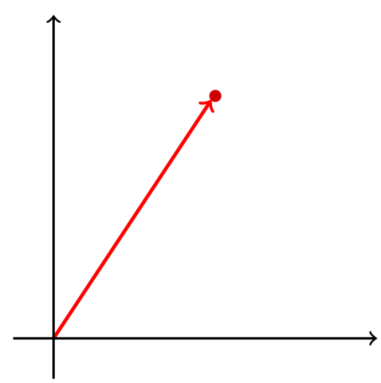
For example, these are displacement vectors:

6.04m [down]

15km [N 56.4° E]

Position

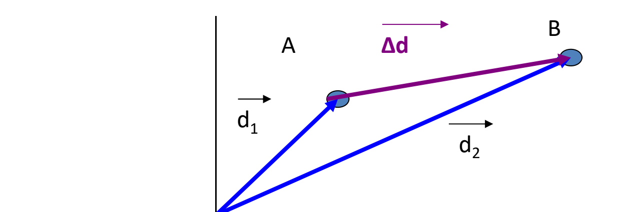
- Location of any object in a coordinate system
- A vector relative to a fixed reference point
  - The "origin" of the coordinate system
  - Always pick a reference point that makes calculations easier
- Besides the reference point, we will also need the axes



Our World is Changing!

- Future = Present + Change
- Final = Initial + Change
- Change = Final - Initial
- What happens, when the position is changing?

DISPLACEMENT



Object moved from A to B

$\vec{d}_1$ - initial position

$\vec{d}_2$ - final position

$$\vec{d}_1 + \vec{\Delta d} = \vec{d}_2$$

Displacement, $\vec{\Delta d}$, is the change in position of an object

$$\vec{\Delta d} = \vec{d}_2 - \vec{d}_1 \qquad \textit{(final – initial)}$$

Displacement: Change in Position

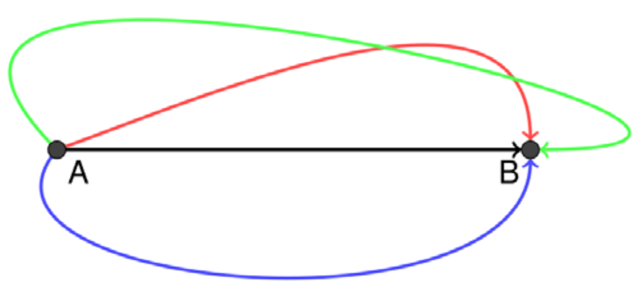
$$\Delta\vec{d} = \vec{d}_2 - \vec{d}_1$$

Quantity	Symbol	SI unit
displacement	$\Delta\vec{d}$	m (metre)
final position	$\vec{d}_2$	m (metre)
initial position	$\vec{d}_1$	m (metre)

- If an object returns to the initial position, then the total displacement is 0

Displacement vs. Distance

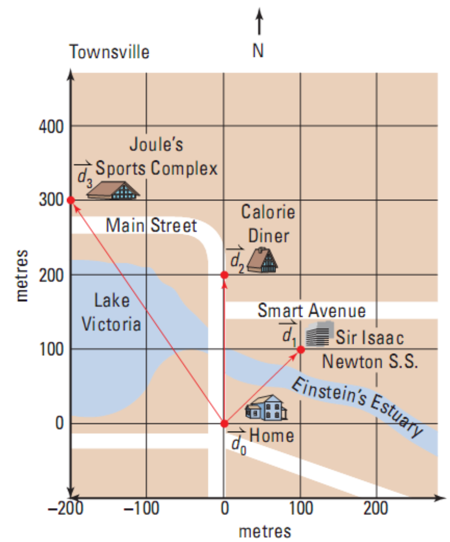
- Distance (*d*) is a **scalar** (no direction), but displacement is a **vector**
- Distance is the length of the path between two points
- Distance depends on how an object travels from one point to another The green, red, blue and black lines all go from A to B, but their distances are different

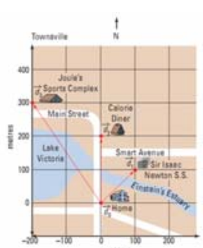


Sample Problem #1

Determine the three displacements between Freda’s home and the other three buildings:

- Home to school
- Home to diner
- Home to sports complex





Solution

$1.\ \Delta\vec{d} = \sqrt{100^2 + 100^2}\ m\ [N45^0E]$

$2.\ \Delta\vec{d} = 200\ m\ [N]$

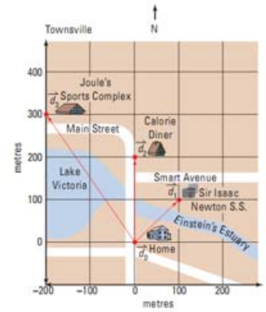
$3.\ \Delta d = \sqrt{300^2 + 200^2}\ \ m$ = 361 m

$\theta = \tan^{-1}(\frac{200}{300})$ = 34^0

$\Delta\vec{d} = 200\ m\ [N34^0$E]

Sample Problem 1a

What is the total distance and displacement if Freda goes to school, dinner, then sports complex everyday?



- Total Daily Distance?

Δd = 100 m + 100 m+ 100 m +100 m + 100m + 200 m + 200 m + 300 m = 1200 m

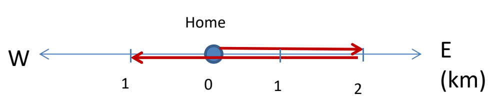
- Daily Displacement?

$\Delta\vec{d} = 0, \qquad if\ Freda\ returns\ home$

Sample Problem #2

Dawn starts from her home, and bikes 2.0 km east, then 3.0 km west.

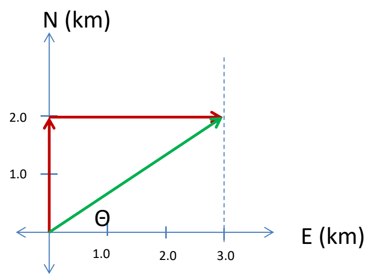
1. Draw a vector diagram and find her final position



$$\Delta\vec{d} = 1\ km\ [W]$$

Sample Problem #3

Dawn starts from home again, but this time she goes 2.0 km north and then 3.0 km east. Draw a vector diagram, and find her final position.



$\vec{d} = \sqrt{3.0^2 + 2.0^2}\ km$ = 3.6 km

$\theta = \tan^{-1}(\frac{2.0}{3.0})$ = 34^0

$\Delta\vec{d} = 3.6\ km\ [E34^0$N] from home

Velocity

Velocity is the **rate of change of position** (how quickly position changes with time). Velocity is also a vector:

$$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t} \quad \text{or} \quad \vec{v}_{ave} = \frac{\vec{d}_2 - \vec{d}_1}{t_2 - t_1}$$

Quantity	**Symbol**	**SI unit**
average velocity	$\vec{v}_{ave}$	$\frac{m}{s}$ (metres per second)
displacement	$\Delta\vec{d}$	m (metres)
time interval	Δt	s (seconds)

Sample Problems

 # 4: Does the **speedometer** of a car provide speed or velocity?

 # 5: A student runs around a 400 m oval track in 80 s. Would the average velocity and average speed be the same? Explain.

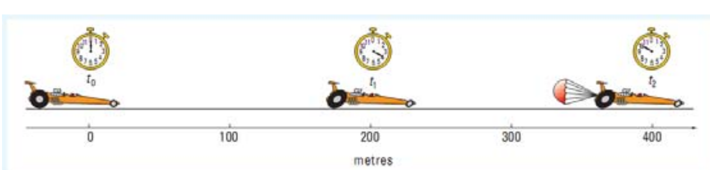
Sample Problem #6

Example 6: A dragster in a race is timed at the 200.0 m and 400.0 m points. The time are shown on the stopwatches in the diagram. Calculate the average velocity for

1. the first 200.0 m $\quad v_{av} = \frac{\Delta \vec{d}}{\Delta t} = \frac{(200.0\ m - 0\ m)\ [fwd]}{20.0s - 0.0\ s} = 10.0\ \mathrm{m/s}\ [\mathrm{fwd}]$

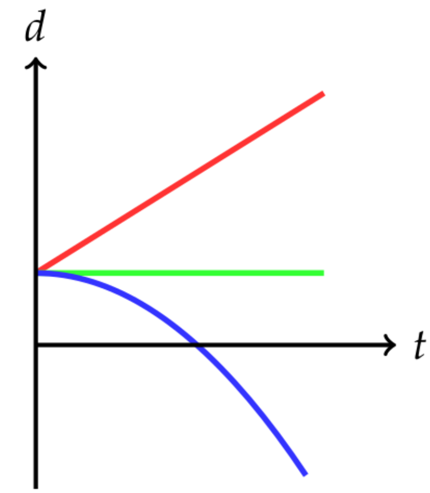
2. the second 200.0 m $\quad v_{av} = \frac{\Delta \vec{d}}{\Delta t} = \frac{(400.0\ m - 200.0\ m)\ [fwd]}{50.0\ s - 30.0\ s} = 6.67\ \mathrm{m/s}$ [fwd]

3. the entire race $\quad v_{av} = \frac{\Delta \vec{d}}{\Delta t} = \frac{(400.0\ m - 00.0\ m)\ [fwd]}{50.0\ s - 0.0\ s} = 8.00\ \mathrm{m/s}$ [fwd]



Motion Graphs

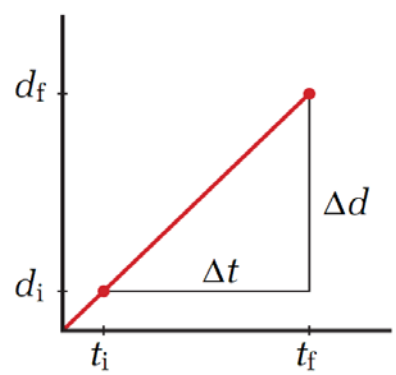
- For one-dimensional motion, we can plot the change in an object's position against time.
- *x*-axis is time *t*, while
- the *y*-axis plots the position *d*
- If the slope is positive, velocity is positive
- If the slope is negative, velocity is negative
- If the slope is zero, the object is not moving



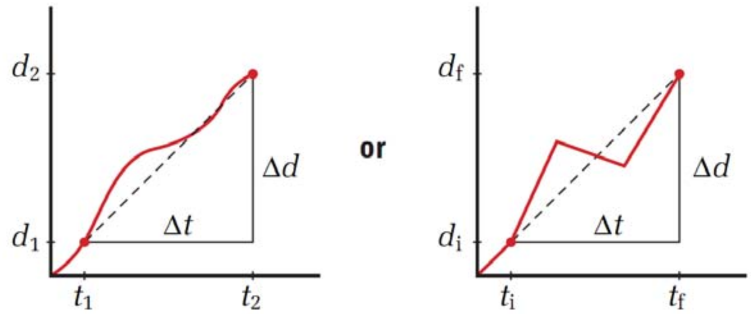
Constant Velocity

- Velocity is not changing over time
- Neither the magnitude nor direction changes
- The plot of the position–time graph is a straight line
- The slope of this straight line is the averge velocity

Position-Time Graph



Average Velocity

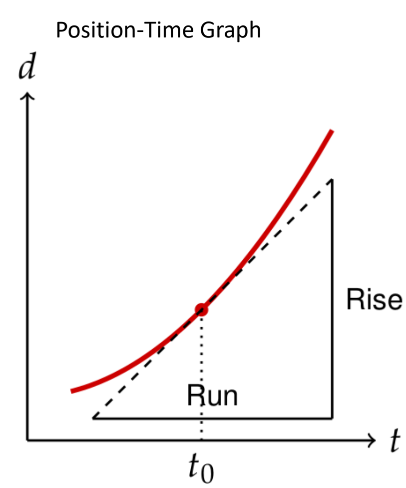


- Both graphs show the same average velocity, but they look very different
- Average velocity is the **slope of the secant** of the position-time graph

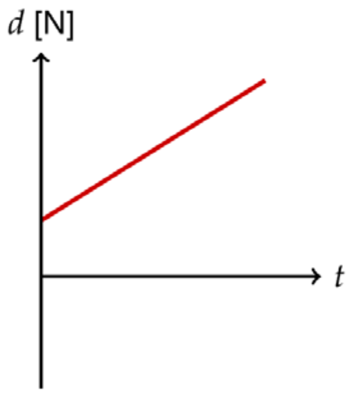
Instantaneous Velocity

The instantaneous velocity of an object, at a specific point in time, is the **slope of the tangent** to the curve of the position-time graph of the object's motion at that specific time.

Let's say I want to find the instantaneous velocity at t_0:



Be Careful!



Look carefully at what this graph is plotting, especially what the axes labels are.

- The object is moving towards **north** with a constant velocity.
- The object is ***<u>not</u>*** moving in the north-east direction.

Acceleration

Acceleration is the **rate of change of velocity** (how quickly velocity changes with time). It is also a vector

- Change in velocity can be a change in magnitude and/or direction
- Unlike displacement vs. distance, and velocity vs. speed, there is no scalar “equivalent” for acceleration

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$$

Quantity	Symbol	SI unit
acceleration	$\vec{a}$	$\frac{\text{m}}{\text{s}^2}$ (metres per second squared)
change in velocity	$\Delta \vec{v}$	$\frac{\text{m}}{\text{s}}$ (metres per second)
time interval	Δt	s (seconds)

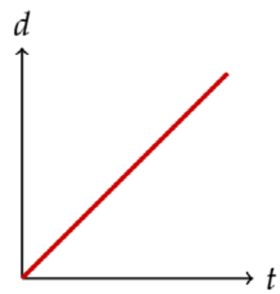
Unit Analysis

$$\frac{\frac{\text{metres}}{\text{second}}}{\text{second}} = \frac{\frac{\text{m}}{\text{s}}}{\text{s}} = \frac{\text{m}}{\text{s}^2}$$

Motion Graphs: Position-Time

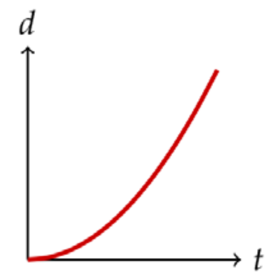
Constant Velocity (uniform motion)

- No acceleration
- Graph is a straight line



Constant Acceleration

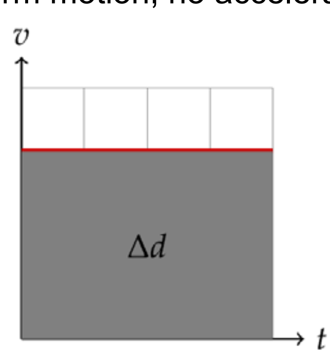
- Graph is a parabola



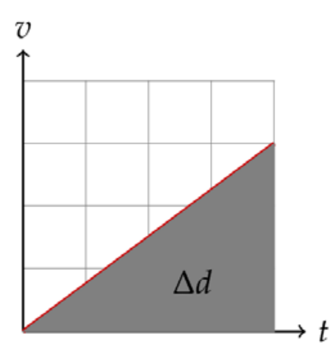
Motion Graphs: Velocity-Time

We can find the displacement by looking at the **velocity vs. tim**e graph.

Constant Velocity
(uniform motion, no acceleration)



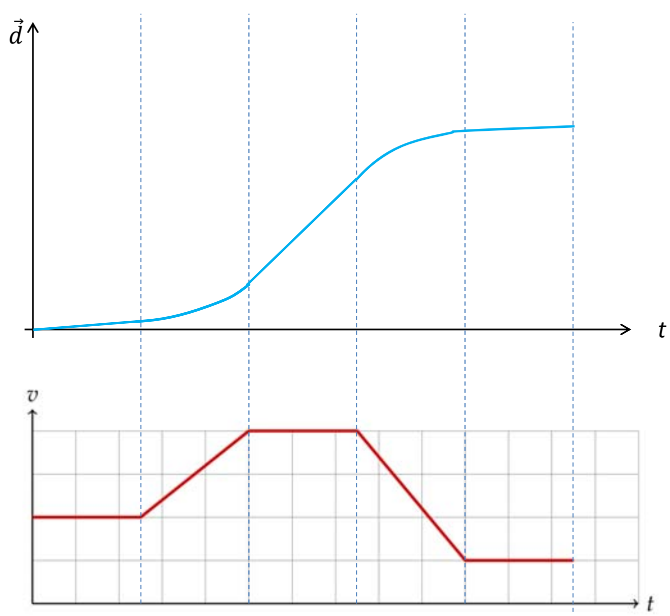
Constant Acceleration



Sample Problem #11

Change the following graph to a **position-time** graph. Assume the displacement starts at zero.

Solution

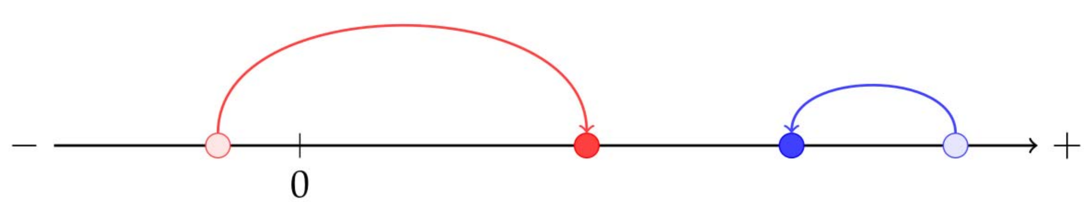


Summary: Position

- For motion in one dimension:
  - (+) Position: on the positive side of the reference point
  - (-) Position: on the negative side of the reference point
- It doesn't matter which way the object is moving, only where it is at that moment

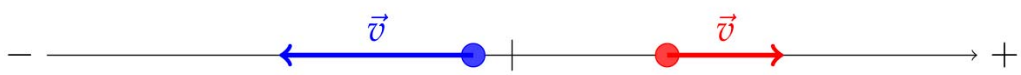
Summary: Displacement & Average Velocity

- It doesn't matter where the object is relative to the reference point, only how it has moved
  - (+) Displacement: motion in the positive direction
  - (-) Displacement: motion in the negative direction
- Average velocity is in the same direction as displacement



Summary: Instantaneous Velocity

- It doesn't matter where the object is, only where it is going at that instant of time
  - (+) velocity: moving in the positive direction
  - (-) velocity: moving in the negative direction



Summary: Acceleration

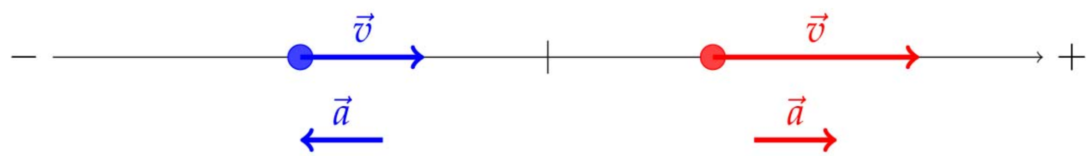
Acceleration is a bit tricky; we have to know the velocity vector as well.

- If acceleration and velocity has the same sign, the object is speeding up (speed increasing)
- If the signs are opposite, then the object is slowing down

Summary: Acceleration

When velocity is positive:

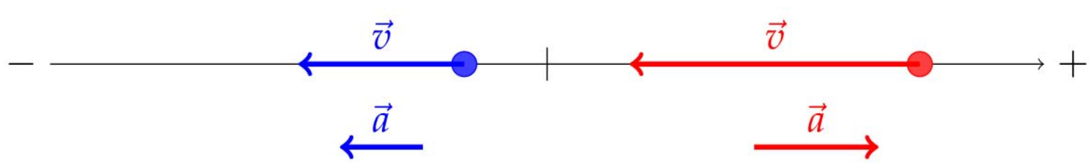
- (+) velocity & (+) acceleration: moving in the positive direction and speeding up
- (+) velocity & (-) acceleration: moving in the positive direction, but slowing down



Summary: Acceleration

When velocity is negative

- (-) velocity & (+) acceleration: moving in the negative direction & slowing down
- (-) velocity & (-) acceleration: moving in the negative direction, and speeding up



1D Kinematic Equations

- For motion that has a constant acceleration, there is a set of equations that relate displacement, velocity and acceleration
- These are called the “kinematics equations”
  - aka: The Big Five Equations

1D Kinematic Equations (“Big Five”)

- Five quantities of interest:

  Δd, v_1, v_2, a and Δt

  Each equation has 4 of the 5
- Which equation you use depends on what information you are given
- Vector notation (arrow on top) not necessary in 1D; use + and - to indicate direction
- If acceleration is not constant, then we must use calculus instead (not part of Grade 11 Physics)

$$\Delta d = v_1 \Delta t + \frac{1}{2} a \Delta t^2$$

$$\Delta d = v_2 \Delta t - \frac{1}{2} a \Delta t^2$$

$$\Delta d = \frac{v_1 + v_2}{2} \Delta t$$

$$v_2 = v_1 + a \Delta t$$

$$v_2^2 = v_1^2 + 2a \Delta d$$

Solving Kimematic Problems

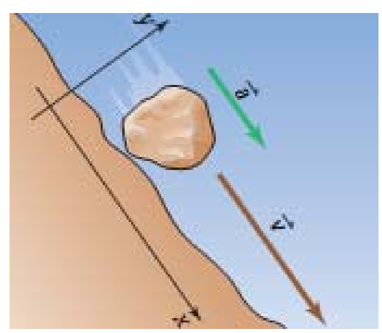
One object: the problem provides 3 of the 5 variables, and you are asked to find a 4th one.

- Define the positive direction
- Apply the correct kinematic equation and solve the problem!

Two objects: Time interval Δt, and displacement Δd of the two objects are related. Identify these relation first!

Sample Problem #12

A slight earth tremor causes a large boulder to break free and start rolling down the mountainside with a constant acceleration of 5.2 m/s^2. What was the boulder's velocity after 8.5 s?



Let [downhill] be positive (see the diagram)

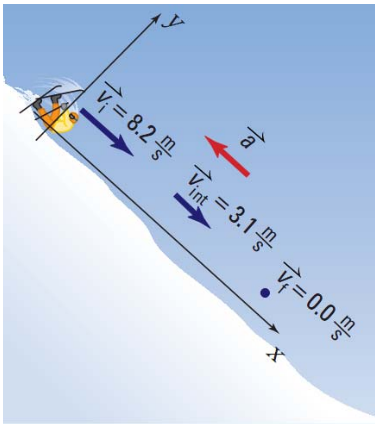
$\vec{v}_1 = 0$
$\vec{a} = +5.2\frac{m}{s^2}$
$\Delta t = 8.5\ s$
$\vec{v}_2 = ?$

$\vec{v}_2 = \vec{v}_1 + \vec{a} * \Delta t$ = 0 + 5.2$\frac{m}{s^2}$$(8.5\ s)$ = 44 m/s

$\vec{v}_2 = 44$ m/s [downhill]

Sample Problem #13

A skier is going 8.2 m/s when she falls and starts sliding down the ski run. After 3.0 s, her velocity is 3.1 m/s. How long after she fell did she finally come to a stop? (Assume constant acceleration.)



Let [downhill] be positive (see the diagram)

$\vec{v}_i = 8.2\ m/s$

$\vec{v}_{int} = 3.1\ \frac{m}{s}$

$\Delta t = 3.0\ s$

$\vec{v}_f = 0$

$\Delta t_f = ?$

$\vec{a} = \frac{\vec{v}_{int} - \vec{v}_i}{\Delta t} = \frac{3.1\,\frac{m}{s} - 8.2\,\frac{m}{s}}{3.0\ s} = -1.7\ m/s^2$

$\vec{v}_f = \vec{v}_i + \vec{a} \times \Delta t_f$

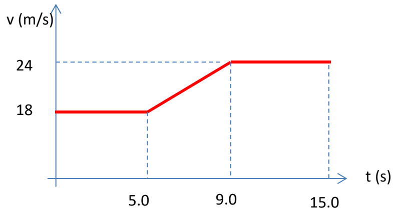
$0 = 8.2\ m/s + (-1.7\ m/s^2)\ \Delta t_f$

$\Delta t_f = 4.8\ s$

Sample Problem #14

A car travels east along a straight road at a constant velocity of 18 m/s. After 5.0 s, it accelerates uniformly for a 4.0 s When it reaches a velocity of 24 m/s, the car proceeds with uniform motion for 6.0 s. Determine the car's total displacement during the trip.

Let [forward] be positive



$\vec{v}_1 = +18\ m/s$

$\vec{v}_2 = +24\ m/s$

$\Delta t_1 = 5.0\ s$

$\Delta t_2 = 4.0\ s$

$\Delta t_3 = 6.0\ s$

$\Delta\vec{d}_1 = \vec{v}_1 \Delta t_1 = (18\ m/s)((5.0\ s) = 90\ m$

$\Delta\vec{d}_2 = \frac{\vec{v}_1 + \vec{v}_2}{2}\Delta t_2 = \frac{18\frac{m}{s} + 24\ m/s}{2}(4.0\ s) = 84\ m$

$\Delta\vec{d}_3 = \vec{v}_3 \Delta t_3 = (24\ m/s)(6.0\ s) = 144\ m$

$\Delta\vec{d} = \Delta\vec{d}_1 + \Delta\vec{d}_2 + \Delta\vec{d}_3 = 318\ m$

$\Delta\vec{d} = 320\ m\ [forward]$

Sample Problem #15

A truck is travelling at a constant velocity of 22 m/s [North]. The driver sees a traffic light turn from red to green soon enough, so he does not have to alter his speed. Meanwhile, a woman in a sports car stopped at the red light. At the moment the light turns green and the truck passes her, she begins to accelerate at 4.8 m/s^2.

1. How long did it take for the sports car to catch up with the truck?
2. How far have both vehicles travelled when the sports car catches up with the truck?

Solution

Let [North] be positive, t - truck, c - car

$\vec{v}_{1t} = +22\ m/s$
$\vec{v}_{1c} = 0$

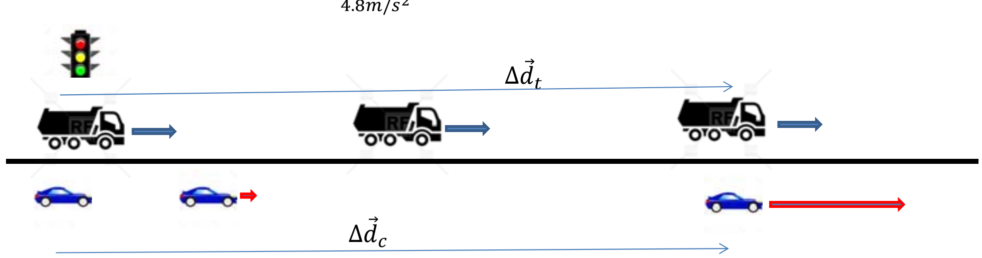
$\vec{a}_c$= 4.8 m/s^2

$\Delta\vec{d}_t = \Delta\vec{d}_c$
$\Delta\vec{d}_t = \vec{v}_{1t}\Delta t$ and $\Delta\vec{d}_c = \vec{v}_{1c}\Delta t + \frac{1}{2}\vec{a}_c\Delta t^2$
$\vec{v}_{1t}\Delta t = \frac{1}{2}\vec{a}_c\Delta t^2$
$\vec{v}_{1t} = \frac{1}{2}\vec{a}_c\Delta t$

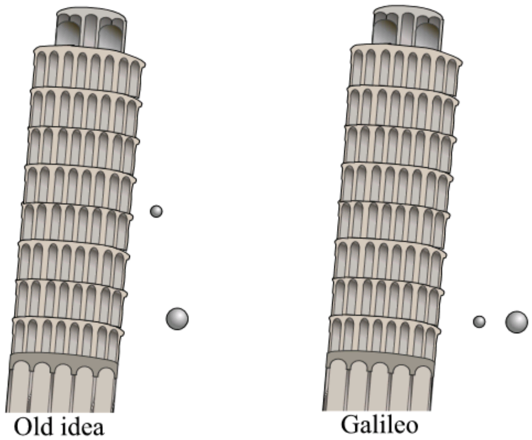
$\Delta t = \frac{2(22\frac{m}{s})}{4.8 m/s^2}$ = 9.2 s

$\Delta\vec{d}_t = \Delta\vec{d}_c$ = (22 m/s)(9.2 s)
= 202 m

$\Delta\vec{d}_t$ = 2.0 x 10^2 m [N] from the intersection



Acceleration Due to Gravity



- Before Galileo people thought that heavier objects fall faster than lighter objects
- Galileo dropped two cannonballs with different masses at the same time; they hit the ground at the same time.

Acceleration Due to Gravity

$$\boxed{\vec{g} = 9.81\,\mathrm{m/s^2}\ [\mathrm{down}]}$$

- Due to the gravitational attraction between the object and the Earth (More on that in Unit 3)
- Always points *down*
- Constant regardless of whether an object is being dropped, or being thrown upwards, downwards or sideways
- Constant regardless of the mass of the object
- The value varies slightly at different parts of Earth

Free Fall

A free-falling object is one that is falling under the influence of gravity alone

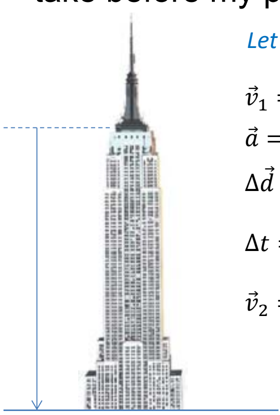
- Acted on only by the force of gravity
- In Grade 11 Physics, we will mostly ignore air resistance

Examples:

- A baseball after it is thrown
- A skydiver just after jumping out of an airplane
- A bullet fired from a gun
- The International Space Station (yes!)

Sample Problem #16

I am standing on observation deck on the 86th floor of the Empire State Building in New York City, which is about 320 m above ground. I accidentally drop my phone onto Fifth Avenue below. Ignoring air resistance, how long does take before my phone hit the pavement below? At what velocity?



Let [down] be positive

$\vec{v}_1 = 0$

$\vec{a} = \vec{g} = 9.81 \frac{m}{s^2} [down]$

$\Delta\vec{d} = +320\ m$

$\Delta t = ?$

$\vec{v}_2 = ?$

$\Delta\vec{d} = \vec{v}_1 \Delta t + \frac{1}{2}\vec{g}\Delta t^2$

$\Delta\vec{d} = \frac{1}{2}\vec{g}\Delta t^2$

$\Delta t = \sqrt{\frac{2\Delta d}{g}}$

$\Delta t = \sqrt{\frac{2(320m)}{9.81\ m/s^2}}$

$\Delta t = 8.1\ s$

$\vec{v}_2 = \vec{v}_1 + \vec{g} * \Delta t$

$= 0 + 9.81 \frac{m}{s^2}(8.1\ s)$

$= 79.2$ m/s

$\vec{v}_2 = 79$ m/s [down]

Unit 1 Homework - Answers

3. a) 50 m; (b) 50 m [down]
4. 7.5 m/s; 0
5. a) 45 m/s; b) 9.81m/s2 [down]
6. 2.5 m/s2 [uphill]
7. a) 6.20 m/s2; b) 4.48 s; c) 454 m
8. 13 m/s
9. 4.3 m
10. 98.2 m; 8.1 s
11. 34 s
12. c
13. a
14. b
15. b
16. e
17. d
18. e
19. c
21. e) 132 m [E]