

PHY117 HS2026

Find the lecture notes for today here!

<https://www.physik.uzh.ch/de/lehre/PHY117/HS2026.html>

user: physik-phy117, pass: einstein5%

Prof. Ben Kilminster
Prof. Florencia Canelli
Sept. 15th, 2026
Week 1, Lecture 1

Lectures also streamed to 15-G-60
(if you can't get a seat here)

Uhrzeit	Raum
15:00 - 17:00	Y04-G-30 Y15-G-60

Web page : <https://www.physik.uzh.ch/de/lehre/PHY117/HS2026.html>

Lectures and reference materials will be uploaded here

PHY117, Physics for Life Sciences 1

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Schedule

Lecturer :

→ [Prof. Ben Kilminster](#)

Lectures (PHY117.1):

Tuesday 15:00 - 16:45, Y04-G-30 (live broadcast to Y15-G-60)

Wednesday 15:00 - 16:45, Y04-G-30 (live broadcast Y15-G-60)

Webcasts will be available on OLAT. (Unfortunately, the smell of gunpowder is not rendered.)

Lectures with and without notes

Lecture schedule (13 lectures)	Topics	Lecture notes	Additional resources
Week 1 Sept. 15-16, 2026	Intro, units, principles of motion	↓ PHY117_HS2026_Week1_L1.pdf (PDF, 14 MB) ↓ PHY117_HS2026_Week1_L1.prenotes.pdf (PDF, 12 MB)	Physics 1 script: chapters 1-5

Course info sheet (1): (on website)

[PHY117-info-sheet-2026.pdf](#)

PHY 117

HS 2026

Physics II for Biomed (Modern Physics)

Lectures: Tuesdays 13:00-15:00, Wednesdays 13:00-15:00 **Y04-G-30** (overflow: Y15-G-60)

Prof. Ben Kilminster (ben.kilminster@physik.uzh.ch), Prof. Florencia Canelli (florencia.canelli@physik.uzh.ch)

Prof. K's office hours : 36-J-50 Tuesdays 12:00-13:00 (or by appointment – please arrange in the breaks)

Class page: <https://www.physik.uzh.ch/de/lehre/PHY117/HS2026.html> (user: physik-phy117, pass: einstein5%)

Teachers assistants :

Frau Ruth Bründler (ruth.bruendler@physik.uzh.ch) (English/German speaking): In charge of exercises & sessions

Anson Kwok (English/Mandarin/Cantonese speaking): In-class TA

Exercise session groups :

1	Classes	Adrian Omlin
2		Archimedes Wildhaber
3		Bryan Koch
4		Céline Wallart
5		Daniel Scheiner
6		David Annoni
7		Esteban Tapia Perlas
8		Ethan Sebastian
9		Hugo Schreckenberger
10		Julia Schmied
11		Kilian Schönenberger
12		Lukas Blose
13		Marc Urech
14		Maurice Matthäus
15		Ryan Samolis
16		Shaip Gashi

Info sheet (2):

References:

Kilminster's Physics 1 & 2 scripts (available on the course web site)

Introductory university physics text book. We use the following :

Tipler (Very good explanations, main text I follow)

Halliday & Resnick (similar)

Young & Freedman (similar)

(Find one that explains the physics well for you.)

Assessments : **Please register on OLAT:** <https://lms.uzh.ch/> This is how we send you assignments

Please log in to see if you can access the course. If not, check your UZH email is registered properly.

- 1) Weekly OLAT quizzes: These are conceptual questions (true/false). You can complete these on OLAT to test your understanding of the lecture. 17% of the final exam will be in a similar format to these questions.
- 2) Weekly written exercises: 83% of the final exam will be similar to these questions.
 - a. New exercise sheet every week, assigned on Monday. First homework published this week. You will not be graded on these. You should try to **solve the problems on your own** since this develops the neutral circuitry necessary to solve exercises. (To pass final exam!!)
 - b. You will be assigned to one exercise session: Monday 13:00-15:00, 15:00-17:00, Thursday 8:00-10:00, 13:00-15:00, 15:00-17:00; Friday 8:00-10:00, 13:00-15:00.
First exercise sessions: Thu. Sept. 24th, Fri. Sept. 25th, Mon. Sept. 28th
 - c. TAs will show how to solve assigned weekly exercise sheets, answer questions, and go through additional exercises if time. TAs will keep an attendance list. Note: **You should go to the exercise sessions.** This is where you learn how to solve problems. In your exams, you will have to solve very similar problems. One problem will almost be the same. Remember, you need to practice solving exercises yourself. Memorizing solutions will not help – what helps is learning how to solve problems like these.
- 3) **Final exam. (Jan. 20th, 2027).** [UZH exam schedule](#)
 - a. Exam style :
 1. **Similar style to OLAT and written exercises, but different problems.** (Memorizing solutions doesn't help)
 2. Will be in German and English
 3. Expect question from exercise sessions & relating to experiments shown in lecture
 4. Formula sheet will be provided (available online). (No private information allowed.)
 5. We also provide calculators.
- 4) Grade : 100% final exam

Make sure you are registered for OLAT at lms.uzh.ch

Weekly exercises & quizzes here



26HS PHY117.1 Physik f...

- Lecture Recording
- Diverse documents
- Quizzes
- Forum Exercises
- Forum Lecture

26HS PHY117.1 Physik für die Life Sciences

Welcome to Physics for Life Sciences

If you have booked this module, you are registered automatically.

Lectures

Lectures are on **Tuesdays and Wednesdays: 15:00 - 17:00 in Y04-G-30**

Lecture material will be posted on the course web site (link follows)

A podcast for the lecture will be recorded and will be available here in OLAT about 24 hours after the lecture. Please understand that we only have limited influence on the processing time of the videos.

Even though we provide a podcast, we recommend attending the lecture on site as it is basically designed for that.

Discussion about the lecture here.

Discussion about the exercises here.

Today, a survey will become available on OLAT. Please fill this out.

FAQ

Q: When do I get assigned to an exercise session?

A: Registration ends Sept. 18th, assignments will be published by Sep. 21st. First exercise session: Thursday, Sept. 24th.

Q: Can I change my exercise session ?

A: We will only consider requests to switch groups after the registration deadline has passed, and only in cases of scheduling conflicts; with so many students, there's no other way to handle it.

For questions related to the booking of PHY 117 (e.g. late booking), exercise group assignments:

-> Frau Bründler (ruth.bruendler@physik.uzh.ch)

For questions about the content of the exercises:

-> Frau Bründler (ruth.bruendler@physik.uzh.ch)

For questions about how to solve exercises:

-> Contact the TA of your assigned exercise group

For all questions not directly related to the lecture PHY 117 (e.g.

Questions about booking chemistry, mathematics or biology modules):

-> Studienberatung from biologists/biomedical scientists or the relevant subject

For questions about the transfer of credits from previous physics lectures (e.g. PHY 118 or lectures at ETH):

-> Prof. Christof Aegerter (aegerter@physik.uzh.ch)

Reference materials

Ben Kilminster, Introductory Physics 1. [↓ Physics-1-Kilminster-2026.v1 \(PDF, 5 MB\)](#)

Ben Kilminster, Introductory Physics 2. [↓ Physics-2-Kilminster-2026.v1 \(PDF, 4 MB\)](#)

Physics I: Introduction to physics



PHYSIK INSTITUT
UNIVERSITÄT ZÜRICH

PROF. BEN KILMINSTER

INTRODUCTION TO MECHANICS, WAVES, AND FLUID
DYNAMICS

This script is the first part of an undergraduate course in introductory physics. It is typically taught in the first semester, with part 2 often taught in the second semester. The level of material is appropriate for physics majors as well as those in the life sciences. The latter may not be expected to learn the full level of detail included that would be expected of physics majors, but may still benefit from the additional material in order to understand better. It is recommended that students should be already familiar with geometry and also take or have taken a class in mathematics that covers vectors and calculus (derivatives and integrals).

These notes provide a deeper understanding of the material. Some of it is beyond what is taught in lecture and beyond what you need to know.

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Physics II: Introduction to physics



PROF. BEN KILMINSTER

INTRODUCTION TO ELECTRICITY, MAGNETISM, ELECTROMAGNETISM, AND THERMODYNAMICS

This script is the second part of an undergraduate course in introductory physics. It is typically taught in the second semester, with part 1 often taught in the previous semester. The level of material is appropriate for physics majors as well as those in the life sciences. The latter may not be expected to learn the full level of detail that would be expected of physics majors, but may still benefit from the additional material in order to understand some concepts in more depth. It is recommended that students should be already familiar with geometry and also take or have taken a class in mathematics that covers vectors and calculus (derivatives and integrals).

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Reference materials: German-English helper

PHY 117

Physics Terms helper

physical quantity (SI base units in blue) (radiation physics units)	Deutsch	Symbol	SI unit	Simplified Formula to help with units	in other SI units	typical units in radiation physics	conversions
Length	Länge	l	meter = m				
time	Zeit	t	second = s				
velocity	Geschwindigkeit	v	m/s			c=3E8 m/s	
acceleration	Beschleunigung	a	m/s ²				
mass	Masse	m	kilogram = kg			1eV/c ²	1eV/c ² = 1.78E-36 kg
momentum	Impuls	p	kg*m/s	p=mv			
force	Kraft	F	Newton = N	F = ma	1N = kg*m/s ²		
torque	Drehmoment	τ	N*m	$\tau = rF \sin\theta$	kg*m ² /s ²		
energy, work	Energie, Arbeit	E, W	Joule = J	W = Fx	1J = kg*m ² /s ²	1eV	1eV = 1.602E-19J
power	Leistung	P	Watt = W	P = E/t	1W = kg*m ² /s ³		
pressure	Druck	P	Pascal = Pa	P = F/area	1Pa=1N/m ²		
Electrical charge	Elektrische Ladung	q	Coulomb = C			e = electron charge	1e = 1.602E-19C

physical quantity (SI base units in blue) (radiation physics units)	Deutsch	Symbol	SI unit	Simplified Formula to help with units	in other SI units
Electrical current	Stromstärke	I	Ampere = Amp = A	I = q/t	1A=1C/s
Electric potential	Elektrische Spannung	V or ϕ	Volt = V	Power = IV	1V = 1W/A
Electric field	Elektrisches Feld	E	N/C = V/m		
Magnetic field	Magnetische Flussdichte	B	Tesla = T	F=BI l	1T=1N/(A*m)
Resistance	Elektrischer Widerstand	R	Ohms = Ω	V = IR	1 Ω = 1V/A
Capacitance	Elektrische Kapazität	C	Farad = F	C=q/V	1F = 1C/V
Temperature	Temperatur	T	Kelvin = K		
amount of substance	Stoffmenge	N	Mol		
luminous intensity	Lichtstärke	I _v	Candela = cd		
radioactivity	Radioaktivität	A _{Bq}	Becquerel = Bq		1/s
Absorbed dose	Energiedosis	D _T	Gray = Gy		m ² /s ² = J/kg
Equivalent dose	Äquivalentdosis	H _T	Sievert = Sv		m ² /s ² = J/kg

Formula sheet (same as final exam)

PHY117 Formula Sheet

Mechanics

Velocity	$\vec{v} = \frac{d\vec{r}}{dt}$
Speed	$v = \vec{v} $
Acceleration	$\vec{a} = \frac{d\vec{v}}{dt}$
Acceleration components	$a_r = \frac{v^2}{r}$ and $a_T = \frac{d \vec{v} }{dt}$
Position	$x(t) = x_0 + v_0 t + \frac{1}{2} a t^2$
Velocity	$v^2 = v_0^2 + 2a\Delta x$ and $v(t) = v_0 + at$
Newton's second law	$\sum \vec{F} = m\vec{a}$
Newton's third law	$\vec{F}_{12} = -\vec{F}_{21}$
Gravitational force	$\vec{F}_g = m\vec{g}$
Gravitational force law	$\vec{F}_g = \frac{Gm_1m_2}{r^2}$
Newtons second law of rotation	$\sum \tau = I\alpha$
Centripetal force	$F_r = \frac{mv^2}{r} = mr\omega^2$
Centripetal acceleration	$a_r = \frac{v^2}{r} \hat{r} = -r\omega^2 \hat{r}$
Angular position	$\Delta s = r\Delta\theta$ and $\theta(t) = \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2$
Angular velocity	$\omega = \frac{d\theta}{dt} = \frac{v}{r}$ and $\omega = \frac{2\pi}{T}$ and $\omega = \omega_0 + \alpha t$
Angular acceleration	$\alpha = d\omega/dt$
Angular momentum	$\vec{L} = \vec{r} \times \vec{p}$ and $\vec{L} = I\vec{\omega}$
Coordinates center of mass	$r_{cm} = \frac{\sum m_i r_i}{\sum m_i}$
Torque	$\vec{\tau} = \vec{r} \times \vec{F}$ and $\vec{\tau} = \frac{d\vec{L}}{dt}$
Impulse	$\vec{F}\Delta t = \Delta\vec{p} = m\Delta\vec{v}$

Energy and work

Kinetic energy:	$K = \frac{1}{2}mv^2$
Potential energy (gravity)	$U = mgh$
Potential energy (spring)	$U = \frac{1}{2}kx^2$
Work	$W_{1 \rightarrow 2} = \int_1^2 \vec{F} d\vec{r}$ and $W_{1 \rightarrow 2} = \int_1^2 \tau d\theta$
Work-energy theorem	$W_{1 \rightarrow 2} = K_2 - K_1$ and $W = \Delta K = -\Delta U$
Work and potential energy	$\Delta U = -W$
Law of conservation of energy	$K + U = \text{constant}$

Fluids

Hydrostatic

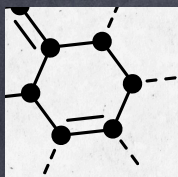
Pressure	$p = \frac{F}{A}$
Compressibility	$B = -\frac{p}{\Delta V/V}$
Pressure distribution in liquids	$p = p_0 + \rho gh$
Capillarity	$\Delta h = \frac{2\gamma \cos \theta_c}{\rho g r}$
Buoyancy	$F_b = \rho_l V_{dis} g$
Bouyancy in centrifuge	$F_b = m_l \omega^2 r$
Centrifugal "force"	$F_c = m_o \omega^2 r$

Hydrodynamics

Flow rate	$I_V = \frac{\Delta V}{\Delta t} = Av$ v : homogeneous velocity
Continuity equation	$I = \text{constant}$ ($v_1 A_1 = v_2 A_2$)

Practice for the exam by using this formula sheet as a starting point for solving weekly exercises

Physics help!


$$E_k = \frac{1}{2}mv^2$$


STUDY CENTER HS26

Tutoring Sessions

Chemistry	Physics
Tuesday 17:15 - 20:00	Wednesday 17:15 - 19:15

📍 Y19-J-94/98

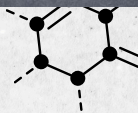
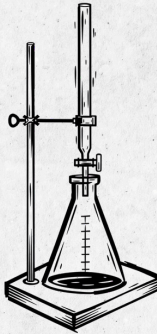
✉ atomoi@chem.uzh.ch



ATOMOI

Qlat for frequently asked chemistry topics and summaries:




$$F = \frac{Gm_1m_2}{r^2}$$


Tools for exercises



phyphox[®]
physical phone experiments

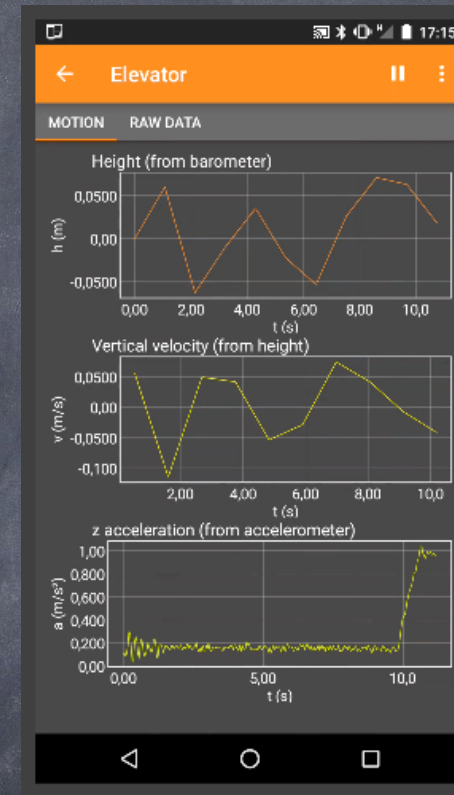
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Contribute

Your smartphone is a mobile lab.

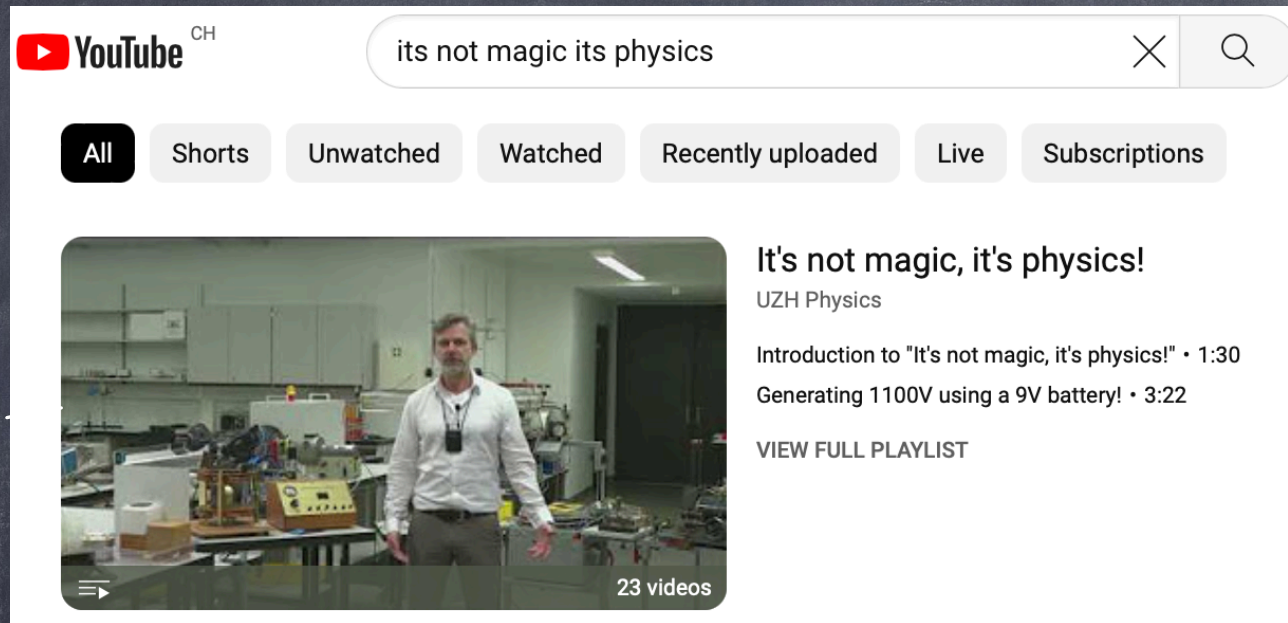
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Google Play  Download on the
App Store



Download for your smartphone:
(If your handy is not so handy, find a partner)

Youtube channel



<https://youtu.be/tR4B0jQ0DPU?feature=shared>

physics:

Deals with matter, energy, + the principles of motion for particles, and waves:

- Interactions of particles

small [molecules, atoms, nuclei, quarks]

large [gases, liquids, solids]

Physics explains chemistry, biology, geology, astronomy,
cosmology, medicine

PHY 117 provides a foundation for PHY 127
(modern physics for biology, biomedicine) that will allow you
to understand measurement tools, like ~~NMR~~
MRI, CT scans, PET scans, x-rays, synchrotrons,
free electron lasers

Some basic units

<u>measurement</u>	<u>symbol</u>	<u>unit</u>
distance	x	meter [m]
time	t	seconds [s]
mass	m	kilograms [kg]

From these units, we derive other units

velocity	$V = \frac{x}{t}$	$\frac{m}{s}$	
acceleration	$a = \frac{V}{t}$	$\frac{m}{s^2}$	
force	$F = ma$	$\frac{kg \cdot m}{s^2}$	$\rightarrow$ Newton [N]
energy	$E = Fx$	$\frac{kg \cdot m \cdot m}{s^2}$	$\rightarrow$ Joule [J]

Dimensional analysis of units as a tool

Is this a valid formula?

$$X = \frac{E}{F} + vt + \frac{a}{V}$$

Do the units work?

$$[m] \stackrel{?}{=} \left[\frac{\frac{kg \cdot m}{s^2}}{\frac{kg \cdot m}{s^2}} \right] + \left[\frac{m}{s} \cdot s \right] + \left[\frac{\frac{m}{s^2}}{\frac{m}{s}} \right]$$

$$[m] \stackrel{?}{=} [m] + [m] + \left[\frac{1}{s} \right] \quad \underline{\text{NO}}$$

How many meters does light travel in one year?

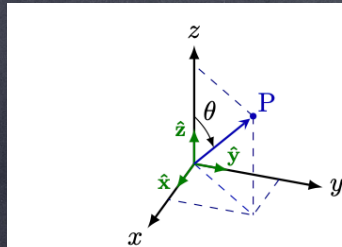
$$c = 3.00 \times 10^8 \frac{m}{s} \quad "E" = 10^{\wedge}$$

$$x = vt = ct = (3.00 \times 10^8 \frac{m}{s}) \cdot (1 \text{ year}) \cdot \left(\frac{365 \text{ days}}{1 \text{ year}} \right) \cdot \left(\frac{24 \text{ hours}}{1 \text{ day}} \right) \cdot \left(\frac{60 \text{ min.}}{1 \text{ hour}} \right) \cdot \left(\frac{60 \text{ s}}{1 \text{ min.}} \right)$$

$$X = 9.46 \times 10^{15} \text{ m} = 9.46 \times 10^{15} \text{ m}$$

3 significant figures

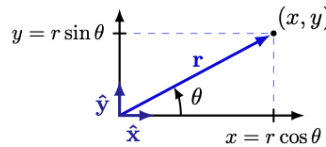
vectors are useful for describing a quantity that has a magnitude and a direction (distance, velocity, acceleration, force, ...)



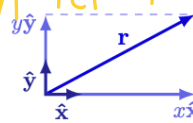
(a) Position vector in a 3D Cartesian coordinate system.

$$\mathbf{r} = x\hat{x} + y\hat{y} + z\hat{z}$$

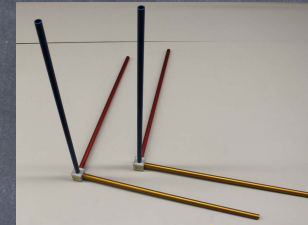
unit vectors point in x, y, z directions
 $|\hat{x}| = |\hat{y}| = |\hat{z}| = 1$



(b) Position vector in a 2D Cartesian coordinate system.



(c) A vector can be broken down into its x and y vector components.



you may have used $\hat{i}, \hat{j}, \hat{k}$ or $\hat{e}_x, \hat{e}_y, \hat{e}_z$

A vector has components that are perpendicular.

we use $\vec{r}$ or $\mathbf{r}$ or $\vec{r}$ as symbols for a vector

The magnitude of a vector in 3-D is:

$$|\vec{r}| = \sqrt{x^2 + y^2 + z^2} = r \quad (\text{scalar})$$

Example: $\vec{a} = 3\hat{x} + 2\hat{y} - 4\hat{z}$ $|\vec{a}| = \sqrt{3^2 + 2^2 + (-4)^2} = \sqrt{29}$

In the script, you find rules for vector operations:

- adding vectors
- dot products of two vectors $\vec{a} \cdot \vec{b}$

also taught in MAT 182

Motion is described by formulas or functions of time;

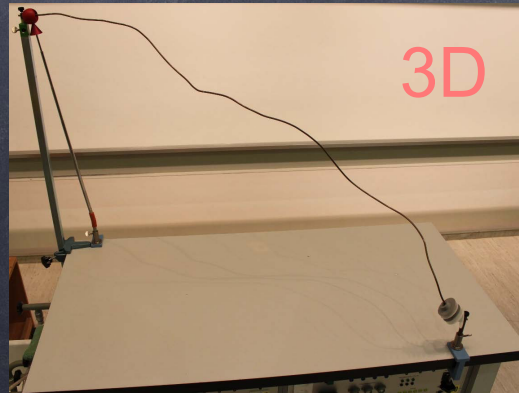
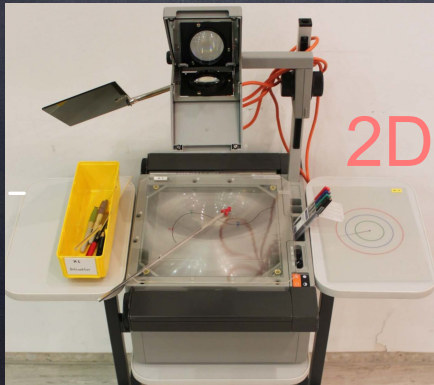
$$\left. \begin{aligned} x &= x(t) \\ y &= y(t) \\ z &= z(t) \end{aligned} \right\}$$

means that the formulas depend on time.

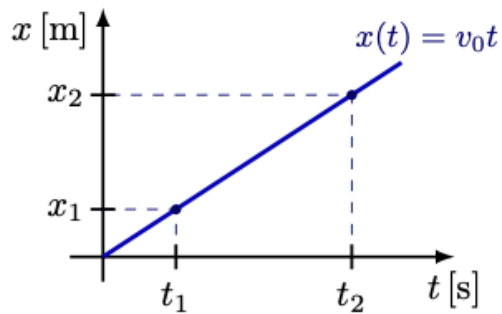
Each component can be treated separately although time is the same in each formula.

The motion of a vector in 3D is described by a vector as a function of time:

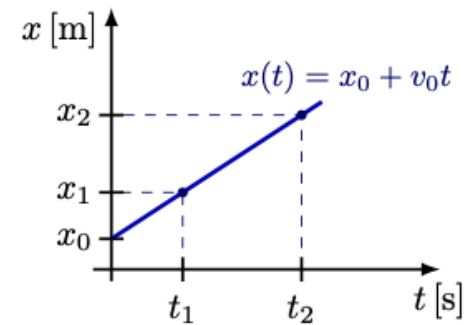
$$\vec{r}(t) = x(t) \hat{x} + y(t) \hat{y} + z(t) \hat{z}$$



Motion in 1-Dimension (1D) : constant velocity



(a) Starting at $x(0) = 0$ at $t = 0$.



(b) Starting at an offset $x(0) = x_0$ at $t = 0$

velocity is the slope of x vs. t

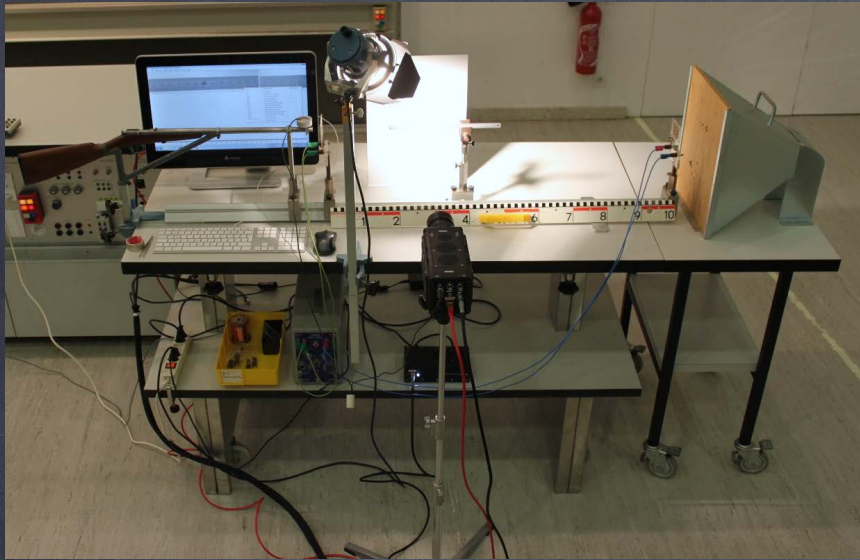
$$v = \frac{x_2 - x_1}{t_2 - t_1}$$

$$x(t) = x_0 + v_0 t$$

$$y = mx + b$$

$\uparrow$ slope $\uparrow$ intercept

Is our bullet faster than the speed of sound?



$$(v = 343 \frac{m}{s})$$

2.5 cm, 3.6 cm, 4.65 cm, 5.7 cm

$$\Delta t = 1.1 \text{ cm} = \Delta t_1$$

$$1.05 \text{ cm} = \Delta t_2$$

$$1.05 \text{ cm} = \Delta t_3$$

$$\Delta t = 4 \times 10^{-5} \text{ s}$$

(25,000 frames/s)

$$\langle \Delta x \rangle = \frac{\sum_{i=1}^N (\Delta x_i)}{N}$$

sample standard deviation = "sigma"

$$\sigma_{\Delta x} = \sqrt{\frac{\sum_{i=1}^N (\langle \Delta x \rangle - \Delta x_i)^2}{N-1}}$$

$$\langle \Delta x \rangle = \frac{(1.1 + 1.05 + 1.05) \text{ cm}}{3} = \frac{3.2 \text{ cm}}{3} = 1.067 \text{ cm}$$

$$\sigma_{\Delta x} = 0.029 \text{ cm}$$

$$\rightarrow \Delta x = 1.067 \pm 0.029 \text{ cm}$$

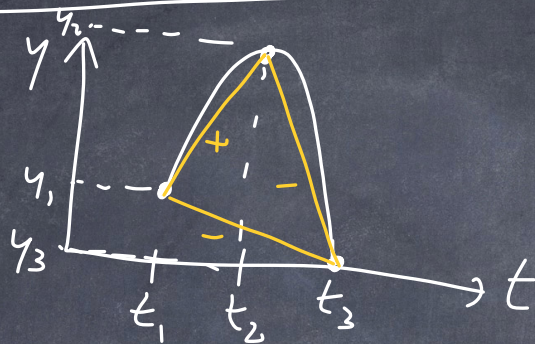
$$v = \frac{\Delta x}{\Delta t}$$

so

$$v = \frac{1.067 \pm 0.029 \text{ cm}}{4.5 \times 10^{-5} \text{ s}} \cdot \frac{1 \text{ m}}{100 \text{ cm}} = 237.1 \pm 6.4 \text{ m/s}$$

Slower!

What if velocity changes?



+y
Ball thrown
vertically up

we can calculate an average velocity between any 2 points:

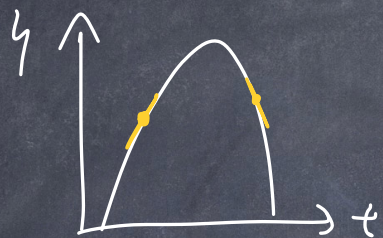
$$t_1 \rightarrow t_2 : V = \frac{y_2 - y_1}{t_2 - t_1} \quad + \text{ slope}$$

$$t_2 \rightarrow t_3 : V = \frac{y_3 - y_2}{t_3 - t_2} \quad - \text{ slope}$$

$$t_1 \rightarrow t_3 : V = \frac{y_3 - y_1}{t_3 - t_1}$$

+ and - indicate
the direction of the
velocity along the y-axis
(since velocity is a vector)

As time Δt gets smaller, we approach the instantaneous velocity at each moment in time.



The tangent to the curve of distance vs. time is the instantaneous velocity.

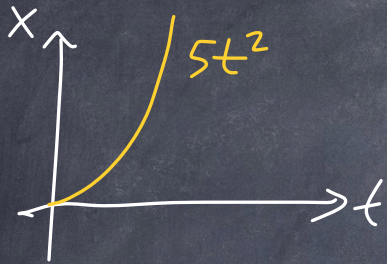
As $\Delta t \rightarrow 0$ (Δt approaches 0)

velocity $V = \lim_{\Delta t \rightarrow 0} \frac{\Delta y}{\Delta t} = \frac{dy}{dt} =$ slope of the line that is tangent to the y vs. t curve.

speed: magnitude of $\frac{dy}{dt}$ is $\left| \frac{dy}{dt} \right|$

speed is not a vector, it is a scalar quantity (always positive)

If $x(t) = 5t^2 \left(\frac{m}{s^2}\right)$, what is $v(t)$?



Let's calculate $v(t)$ from first principles.

$$x(t) = 5t^2$$

At some later time, $t + \Delta t$, the position is $x(t + \Delta t) = 5(t + \Delta t)^2$

The change $\Delta x = x(t + \Delta t) - x(t)$

$$\Delta x = (\cancel{5t^2} + 10t\Delta t + 5(\Delta t)^2) - \cancel{5t^2}$$

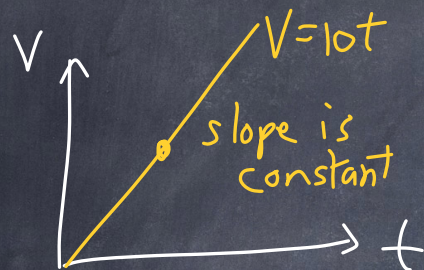
$$\Delta x = 10t\Delta t + 5(\Delta t)^2$$

average velocity: $\frac{\Delta x}{\Delta t} = \frac{10t\cancel{\Delta t} + 5(\Delta t)^2}{\cancel{\Delta t}} = 10t + 5\Delta t$

the instantaneous velocity

$$V = \lim_{\Delta t \rightarrow 0} \frac{\Delta x}{\Delta t} = 10t + 5\cancel{\Delta t}^0 = 10t$$

$$V = 10t$$



what about acceleration?

$$a = \lim_{\Delta t \rightarrow 0} \frac{\Delta V}{\Delta t} = \frac{dV}{dt}$$

a is the
tangent to the
 V vs. t curve

Repeating, we find $\Delta V = V(t + \Delta t) - V(t)$

$$= 10(t + \Delta t) - 10t$$

$$= \cancel{10t} + 10\Delta t - \cancel{10t}$$

$$\Delta V = 10\Delta t$$

$$a = \frac{\Delta V}{\Delta t} = \frac{10\cancel{\Delta t}}{\cancel{\Delta t}} = 10 \frac{m}{s^2} \text{ with units}$$

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

$$v = \frac{dx}{dt}$$

$$a = \frac{d}{dt} \left(\frac{dx}{dt} \right) = \frac{d^2 x}{dt^2}$$

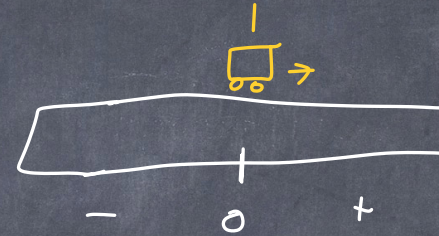
acceleration is the second derivative of the position "with respect to time" (wrt) time

MAT 182 [General rule for derivatives:
If $x = ct^n$

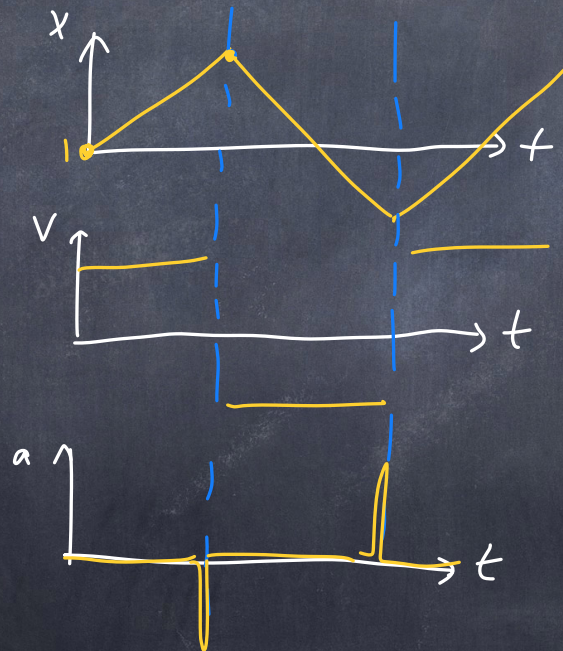
$$\frac{dx}{dt} = cnt^{n-1}$$

$$x = 5t^2$$

$$v = \frac{dx}{dt} = 5 \cdot 2 t^{2-1} = 10t$$



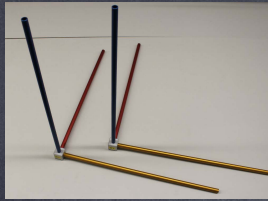
Air car experiment



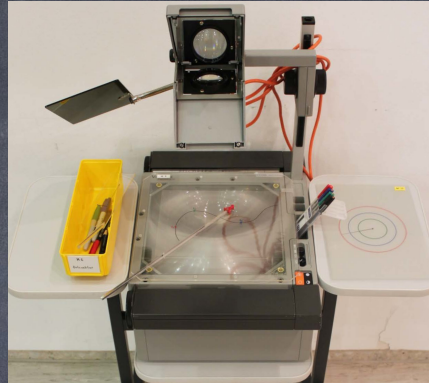
velocity is the
slope of x vs. t

acceleration is the
slope of v vs. t

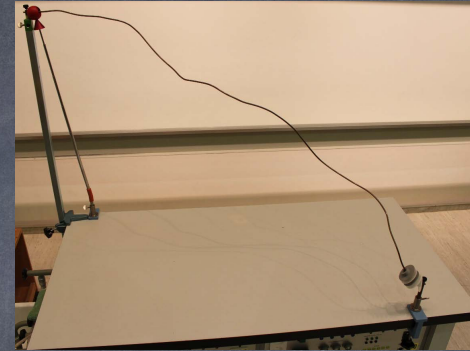
Experiments



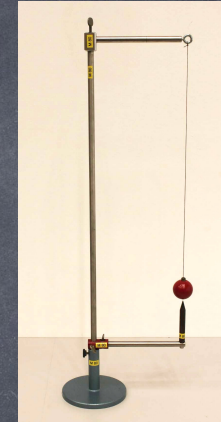
M1



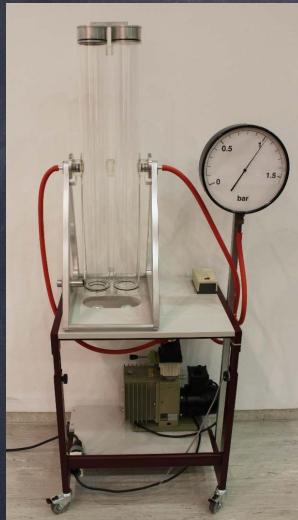
M6



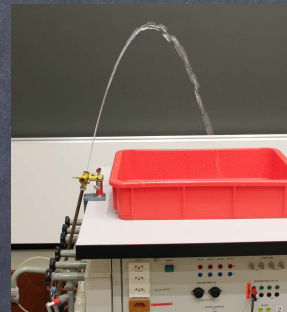
M10



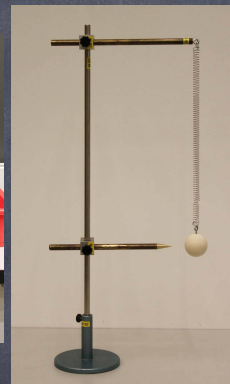
M80



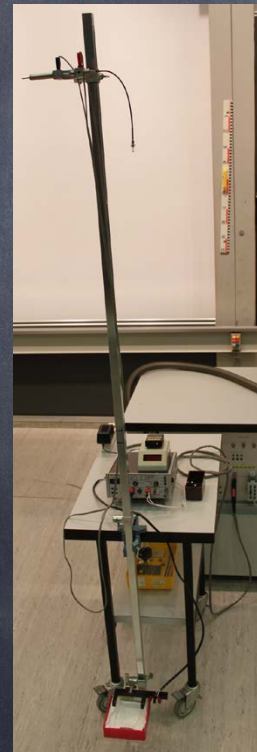
M46



M48



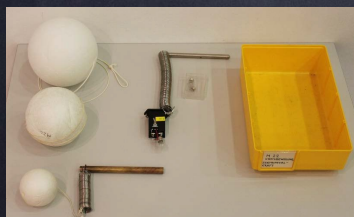
M82



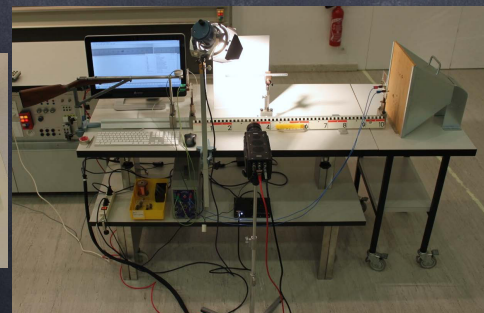
M40



M198



M22



M12



M27