

Physics 1 - Mechanics

Yair Mau

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about

I taught the Physics 1 course in Mechanics at the Faculty of Agriculture, Hebrew University, from 2017 to 2021. Although I don't teach this any longer, I think that the materials I developed for the course might be useful to some. Most of the material found here is in hebrew.

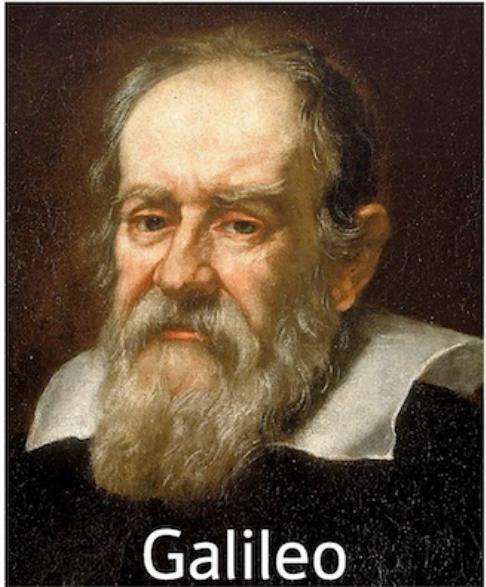
goals

This basic Physics course has three main goals:

- By the end of this course you will be able to look at the world around you and start describing it in a formal (mathematical) language.
- By the end of this course you will be able to read a graph and tell the story behind it, i.e., you will translate a formal (mathematical) language into regular speech any human can understand.
- We will get acquainted with the concept of Energy. This, in my humblest opinion, is one of the most important ideas in Science.

patron saint

Galileo is undoubtedly our hero in this course. Honorable runners-up: Archimedes and Newton.



Galileo

Philosophy [nature] is written in that great book which ever is before our eyes – I mean the universe – but we cannot understand it if we do not first learn the language and grasp the symbols in which it is written. The book is written in mathematical language, and the symbols are triangles, circles and other geometrical figures, without whose help it is impossible to comprehend a single word of it; without which one wanders in vain through a dark labyrinth.

”

Part I

topics

lecture notes

Book: I loosely use Halliday & Resnick's *Principles of Physics* (11th edition).

Software: I use [Stylus Labs Write](#) to write my classnotes, it is available for Windows, Mac, Linux, Android, and iOS.

Hardware: I use both a Wacom Cintiq 16 and an iPad air.

Legend:

lecture notes pdf

lecture notes source (write) svgz

powerpoint

widget in jupyter notebook (might take a while to load...)

other materials

animations and gifs

subject	lectures	other
basic math		
units		
1d kinematics		
vectors		
2d kinematics		
circular motion		
Newton's laws		
work-energy theorem		
potential energy		
potential energy diagrams		
linear momentum		
gravitation		
hydrostatics		
hydrodynamics		

[Click here](#) for details on all lectures of the 2021-22 academic year.

Here are other [very nice videos](#) not directly related to any specific topic.

extra: basic math

I will assume that student in this course have a minimal proficiency in math. Find below some links for basic math that we will need during this course. I will not teach any of these topics, if you feel that you don't fully know this stuff, please go ahead and study these topics asap.

Trigonometry

[Khan Academy](#)
[Michel van Biezen](#)

Pre-algebra

Arithmetic properties; factors and multiples; fractions; decimals; negative numbers and coordinate plane; ratios, rates, proportions; equations, expressions, and inequalities; exponents, radicals, and scientific notation.

[Khan Academy](#)

Algebra

[Michel van Biezen](#)

,

extra: units

basic units and prefixes

Units for three SI base quantities

Quantity	Unit Name	Unit Symbol
Length [L]	meter	m
Time [T]	second	s
Mass [M]	kilogram	kg

Some prefixes for SI Units that you **must** remember!

Factor	Prefix	Symbol
10^9	giga-	G
10^6	mega-	M
10^3	kilo-	k
10^{-2}	centi-	c
10^{-3}	milli-	m
10^{-6}	micro-	μ
10^{-9}	nano-	n

exponent rules

Exponent Rules

Assume that a and b are nonzero real numbers, and m and n are any integers.

1) Zero Property of Exponent

$$b^0 = 1$$

2) Negative Property of Exponent

$$b^{-n} = \frac{1}{b^n} \quad \text{OR} \quad \frac{1}{b^{-n}} = b^n$$

3) Product Property of Exponent

$$(b^m)(b^n) = b^{m+n}$$

4) Quotient Property of Exponent

$$\frac{b^m}{b^n} = b^{m-n}$$

5) Power of a Power Property of Exponent

$$(b^m)^n = b^{mn}$$

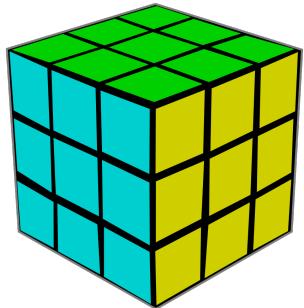
6) Power of a Product Property of Exponent

$$(ab)^m = a^m b^m$$

7) Power of a Quotient Property of Exponent

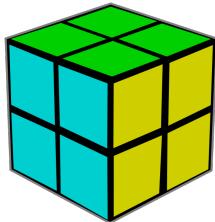
$$\left(\frac{a}{b}\right)^m = \frac{a^m}{b^m}$$

volume and surface area



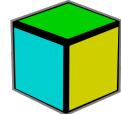
sides = 3
surface = $3^2 \times 6 = 54$
volume = $3^3 = 27$

surface/volume = 2



sides = 2
surface = $2^2 \times 6 = 24$
volume = $2^3 = 8$

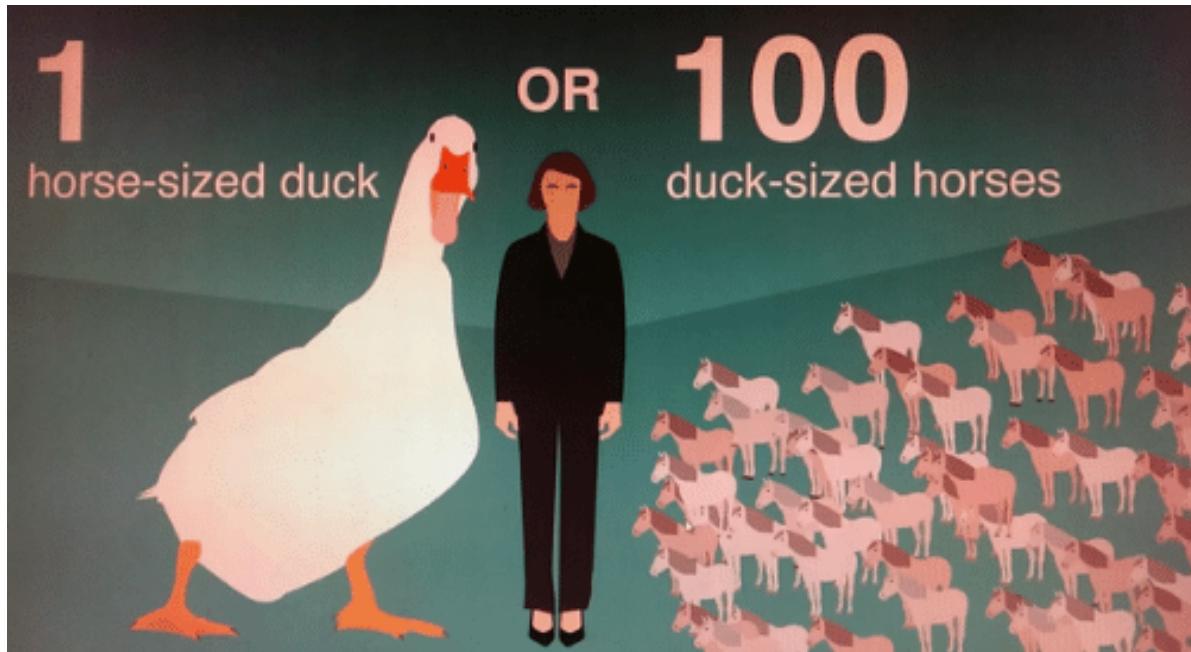
surface/volume = 3



sides = 1
surface = $1^2 \times 6 = 6$
volume = $1^3 = 1$

surface/volume = 6

1 horse-sized duck or 100 duck-sized horses?



Would you rather fight 100
duck-sized horses or one horse-
sized duck ...

extra: 1d kinematics

The Physics Classroom

This is an *excellent* interactive website, with lots of useful exercises:

[Distance vs. Displacement](#), [Acceleration](#), [Name That Motion](#), [Motion Diagrams](#), [Graph That Motion](#), [Match That Graph](#), [Position-Time Graphs - Conceptual Analysis](#), [Position-Time Graphs - Numerical Analysis](#), [Dots and Graphs](#), [Which One Doesn't Belong?](#), [Free Fall](#), [Up and Down](#).

Video Lectures

Khan Academy - One-dimensional motion

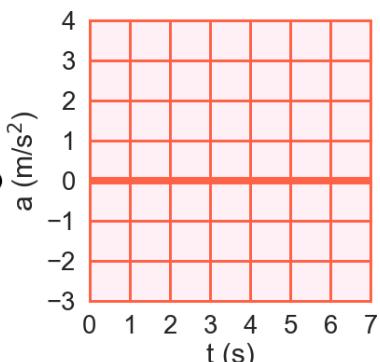
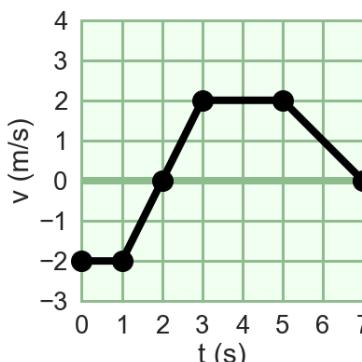
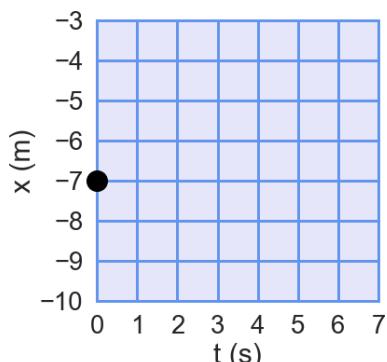
Motion in a Straight Line: Crash Course Physics #1

Michel van Biezen - Lectures in MOTION IN ONE DIMENSION

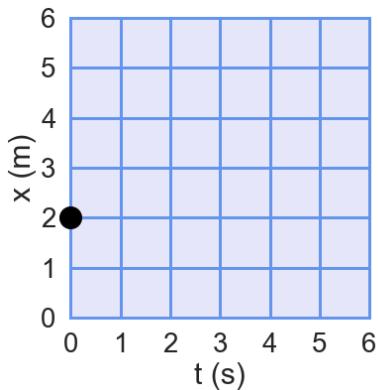
Michel van Biezen - Lectures in Motion in 1 Dimension: GRAPHIC SOLUTIONS

x , v , a graphs

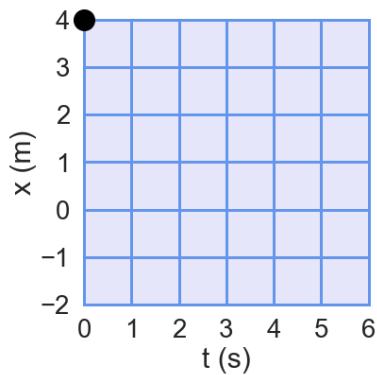
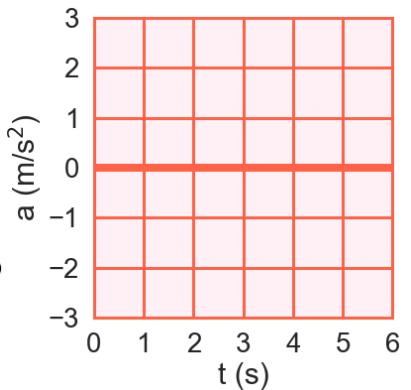
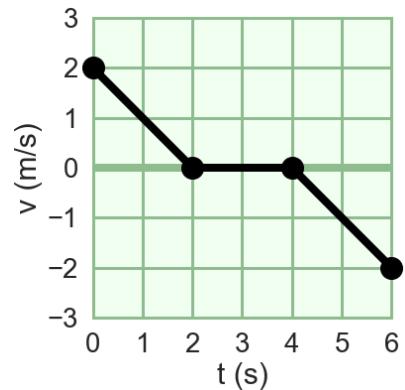
Draw the missing curves, with black dots in the same instants in time as in the given curve.
All curved lines are parabolas.



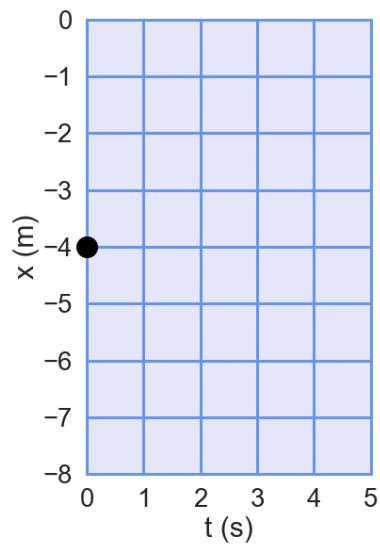
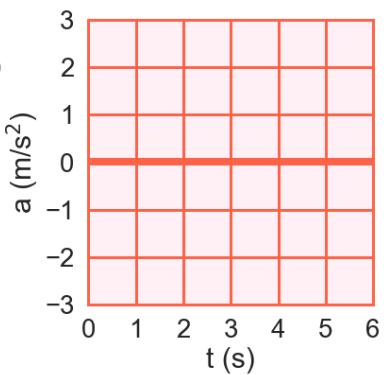
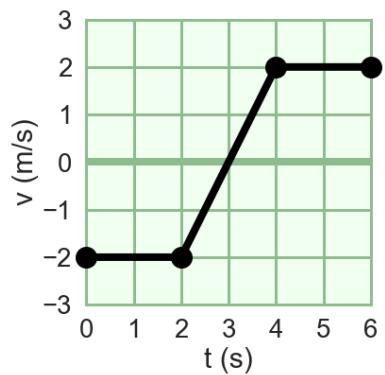
Exercise 1



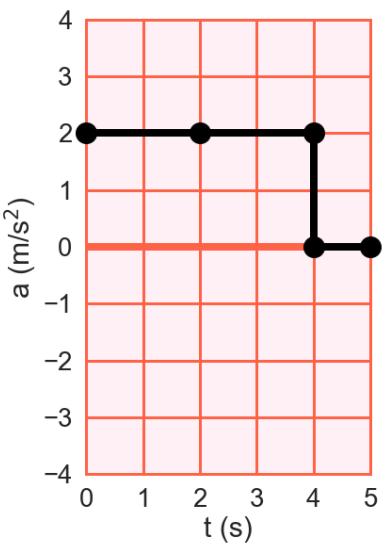
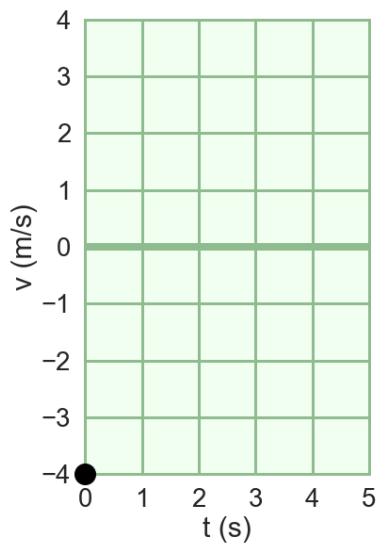
Exercise 2

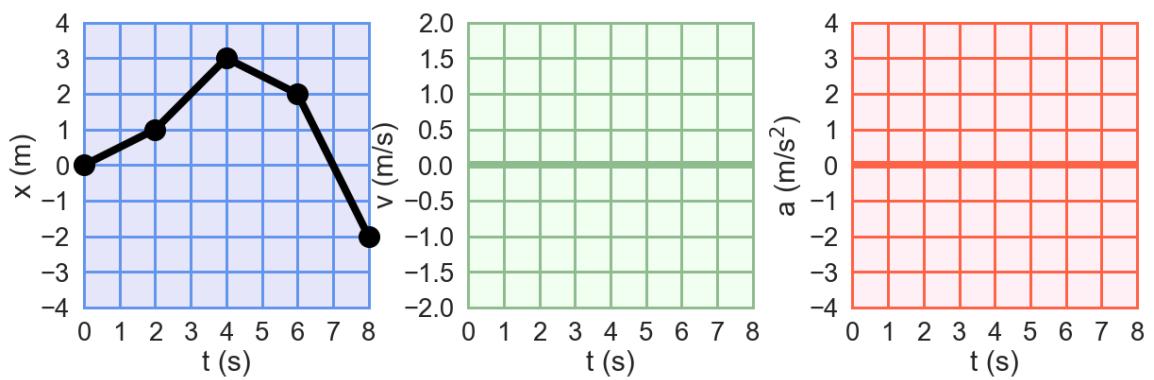


Exercise 3

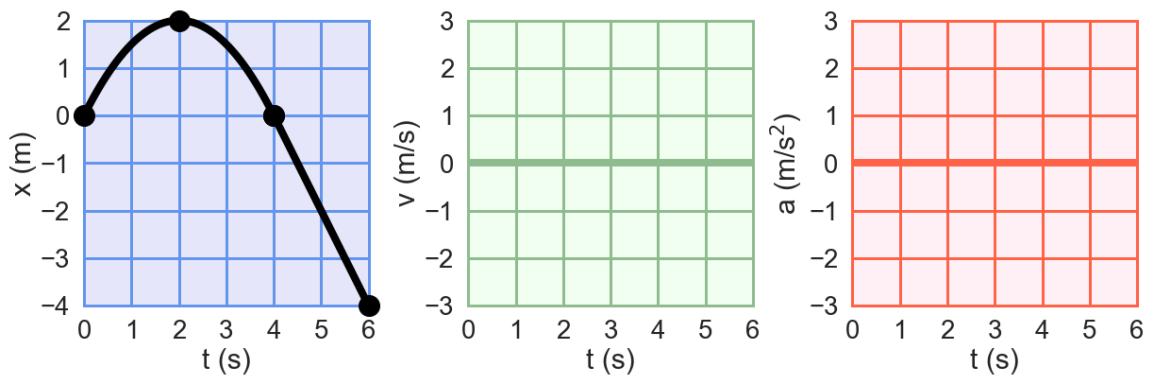


Exercise 4





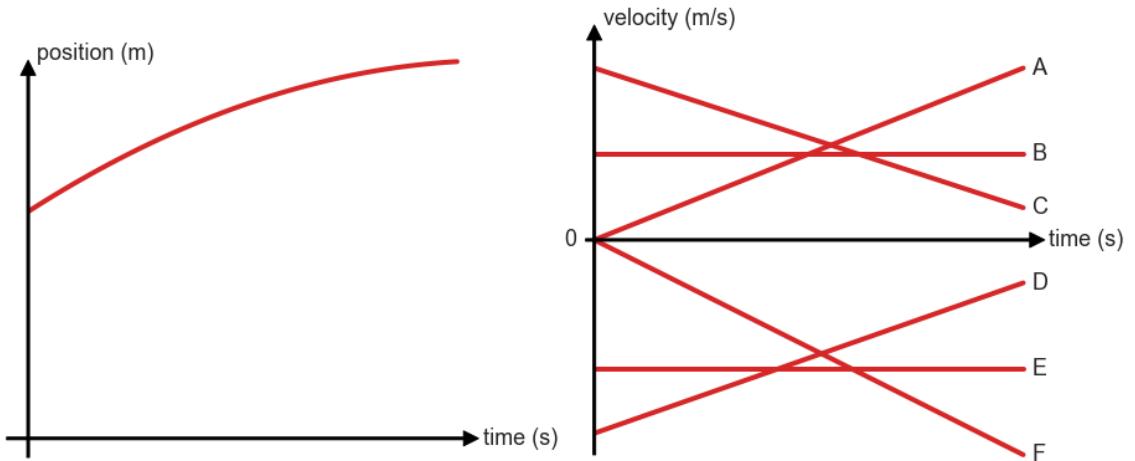
Exercise 5



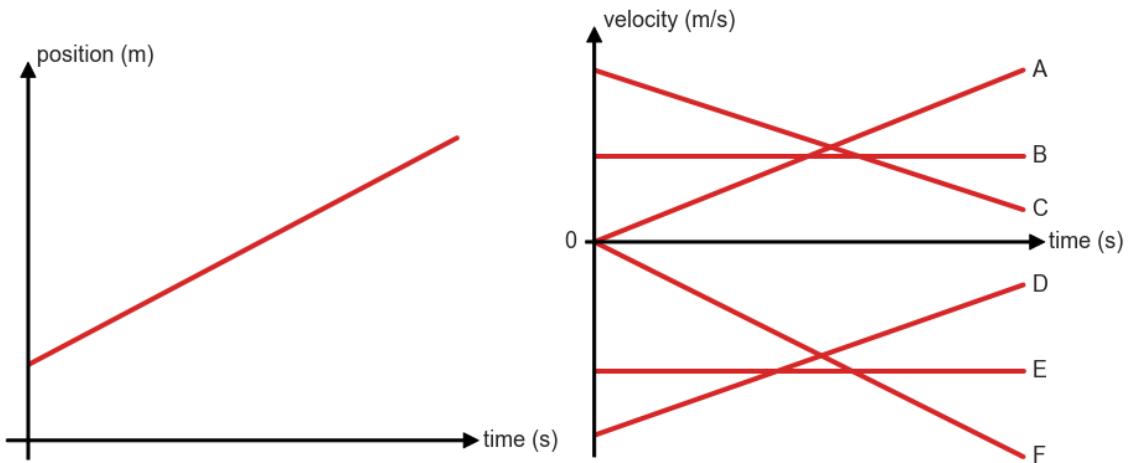
Exercise 6

Match the graphs, x and v

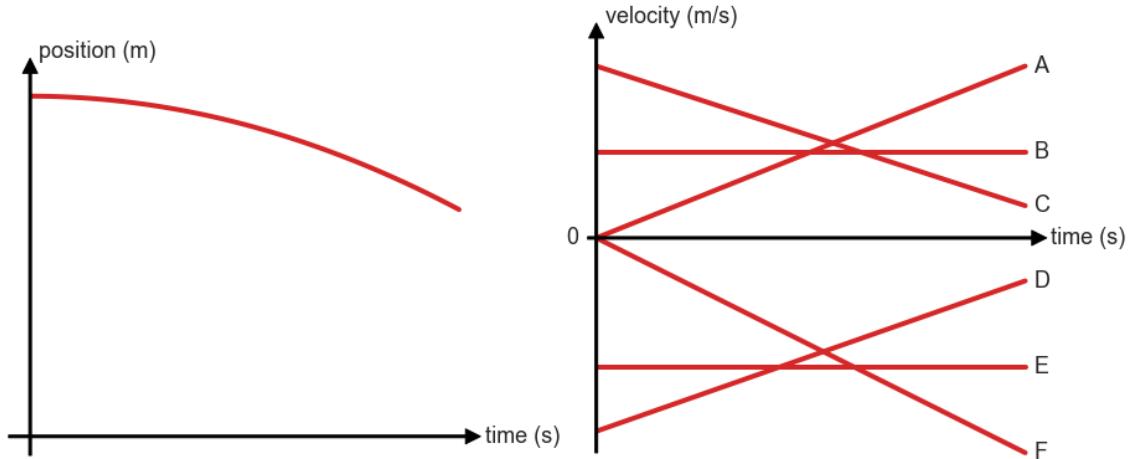
Match the curve on the left with one of the curves on the right.



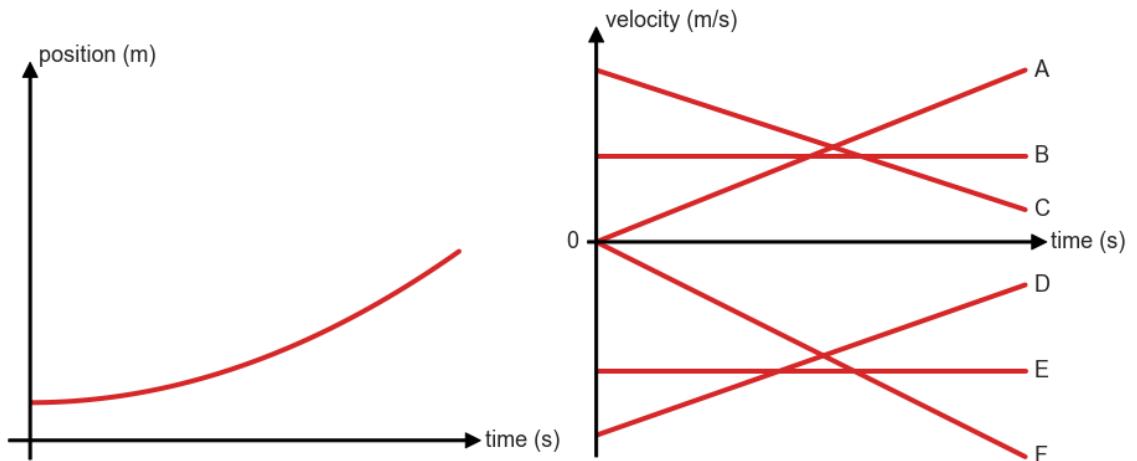
Exercise 1



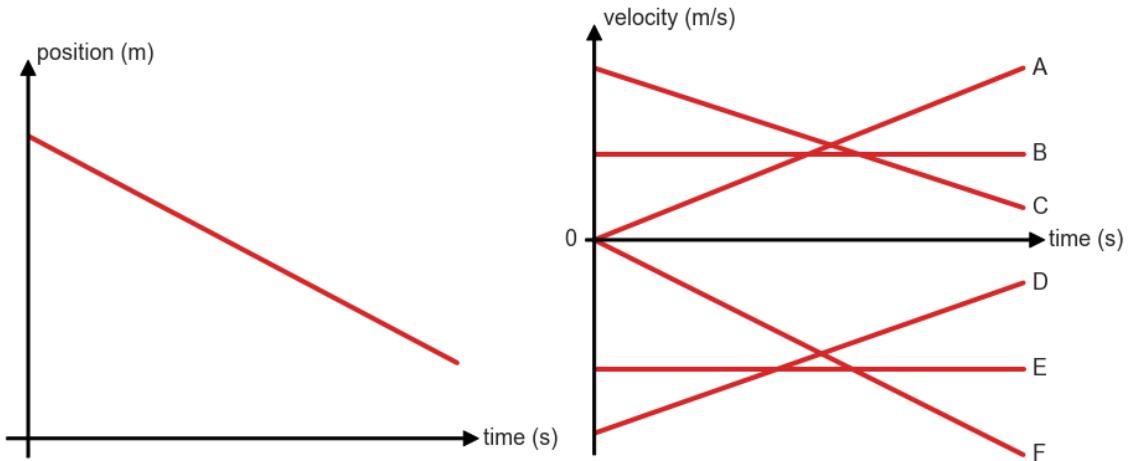
Exercise 2



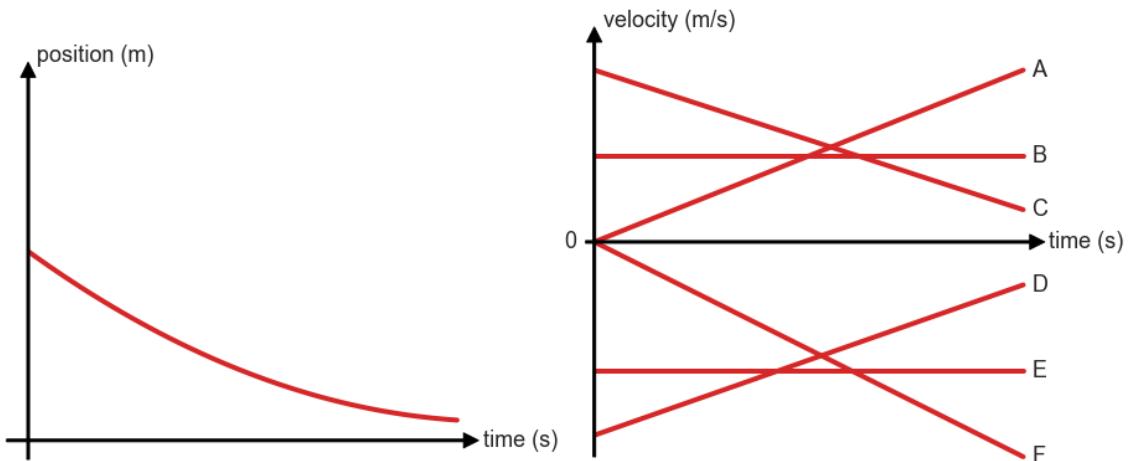
Exercise 3



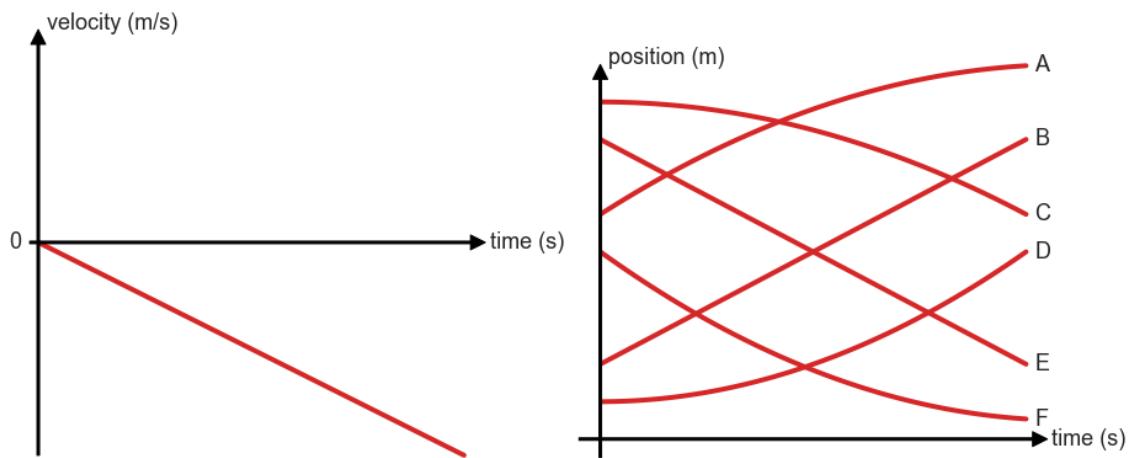
Exercise 4



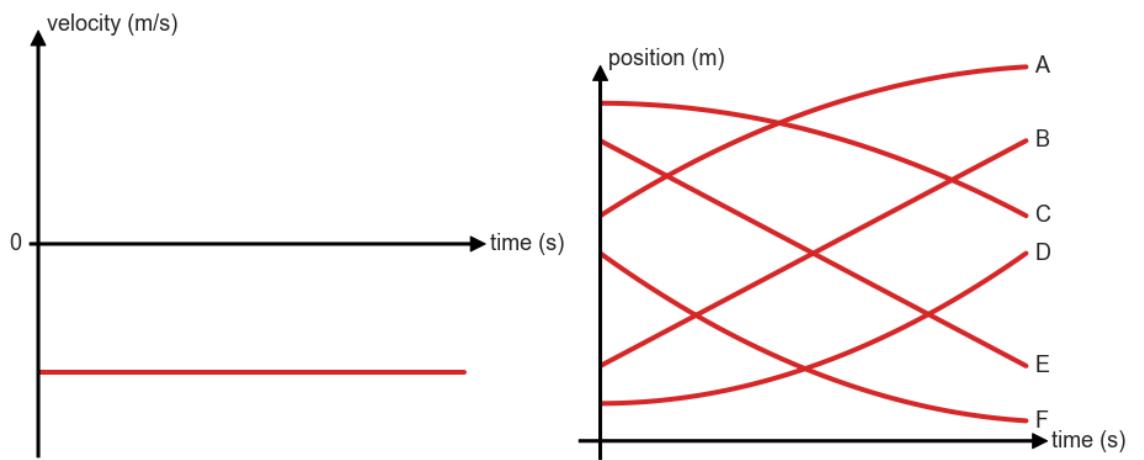
Exercise 5



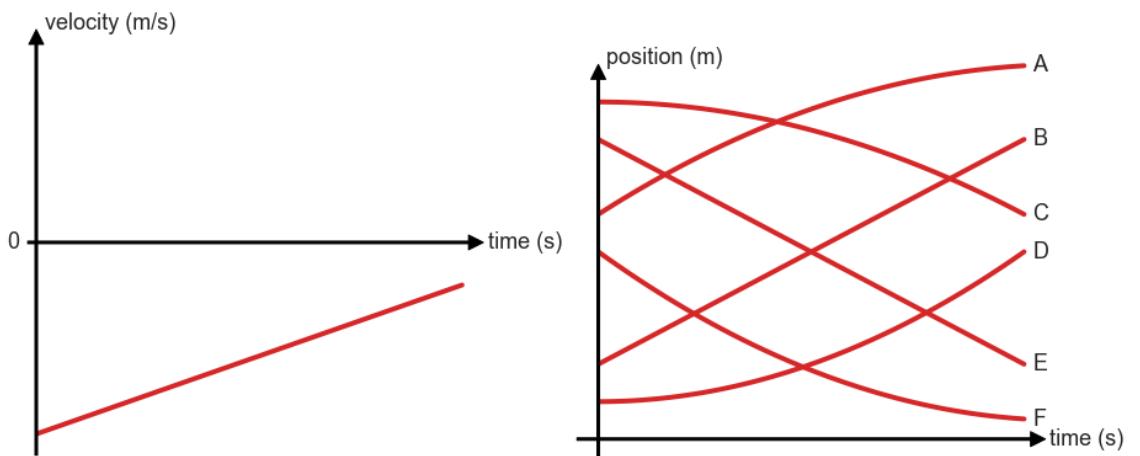
Exercise 6



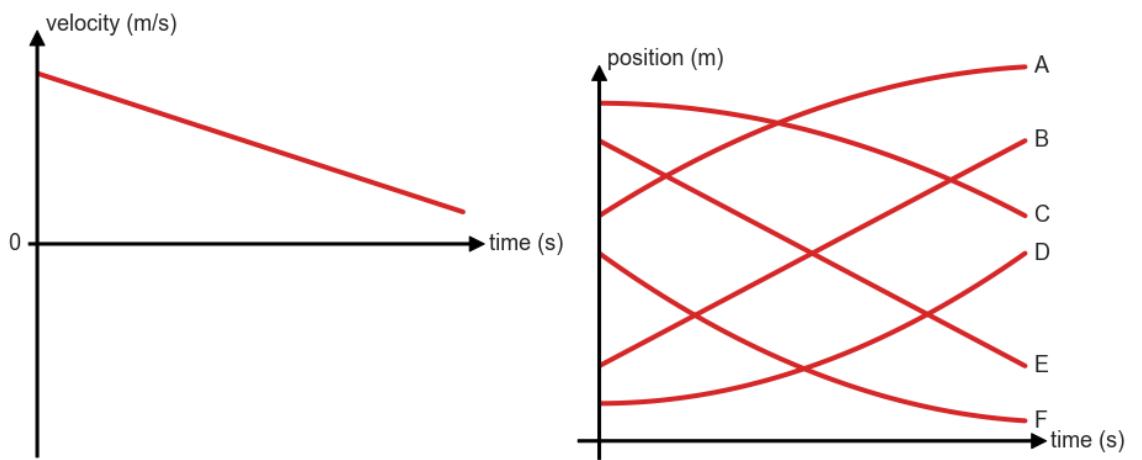
Exercise 7



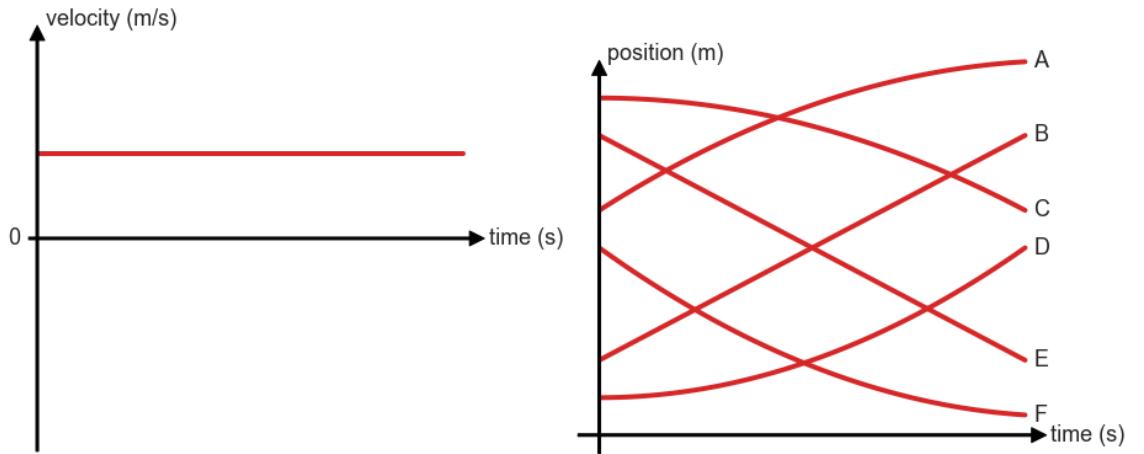
Exercise 8



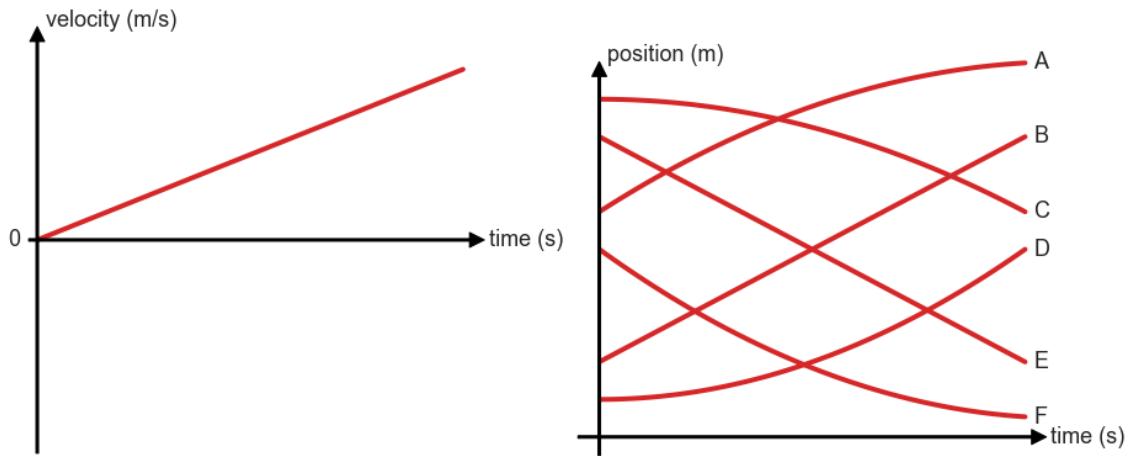
Exercise 9



Exercise 10



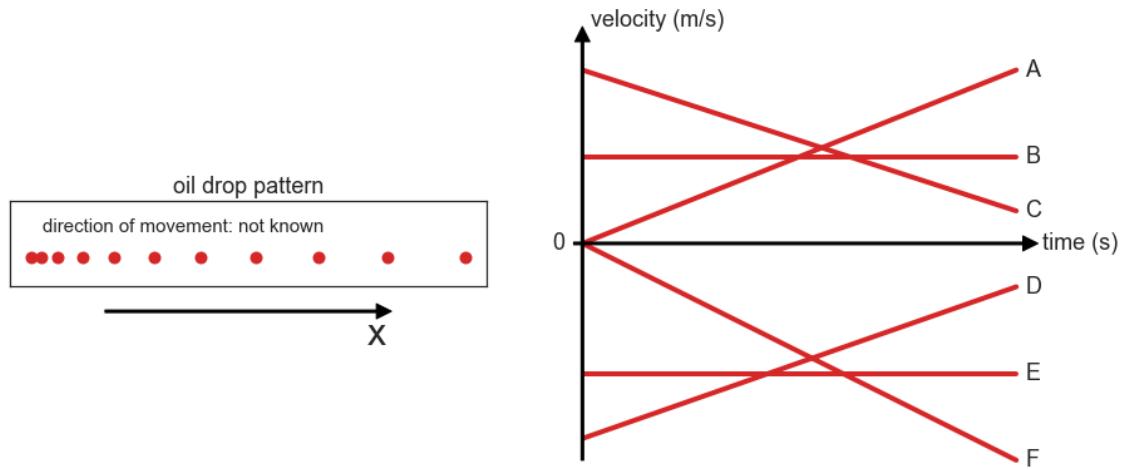
Exercise 11



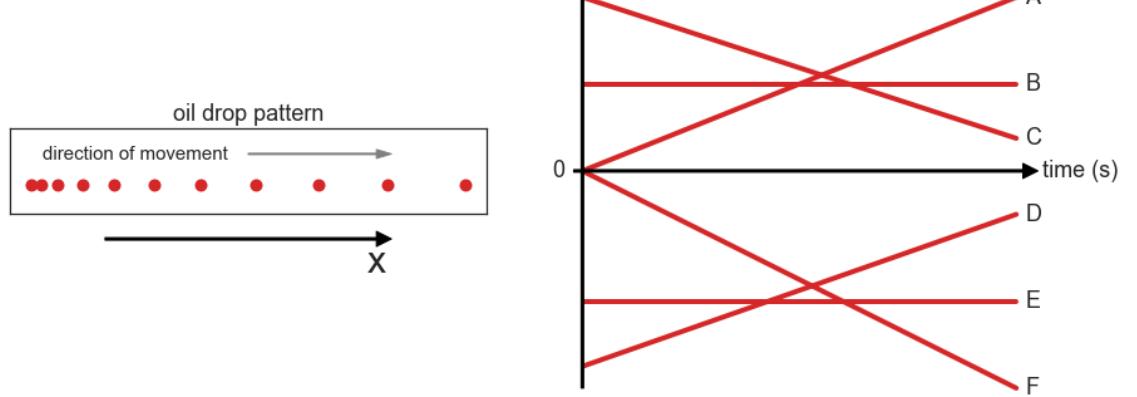
Exercise 12

Oil drop patterns

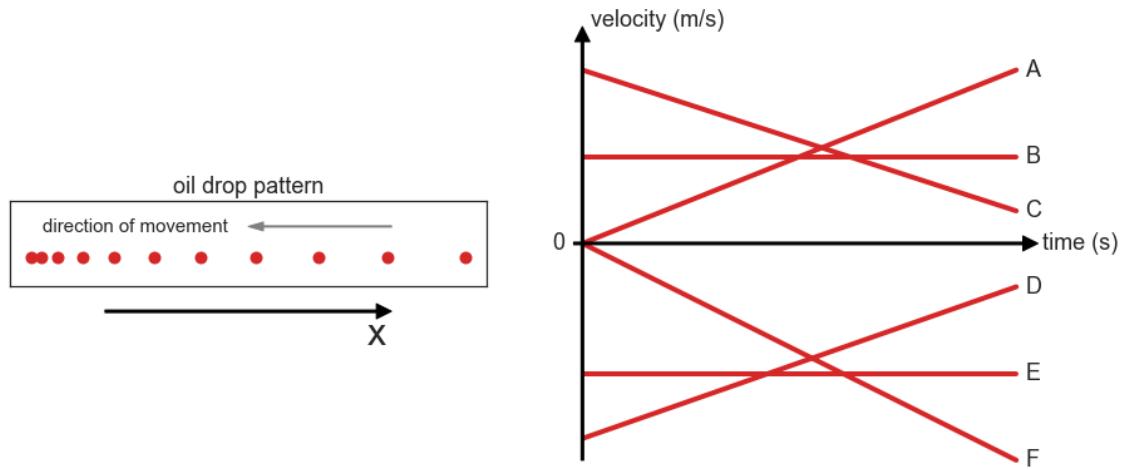
Oil drips from a car *at fixed time intervals*. Match the oil drop pattern the car leaves on the road with the curves on the right. Attention: there might be more than one solution!



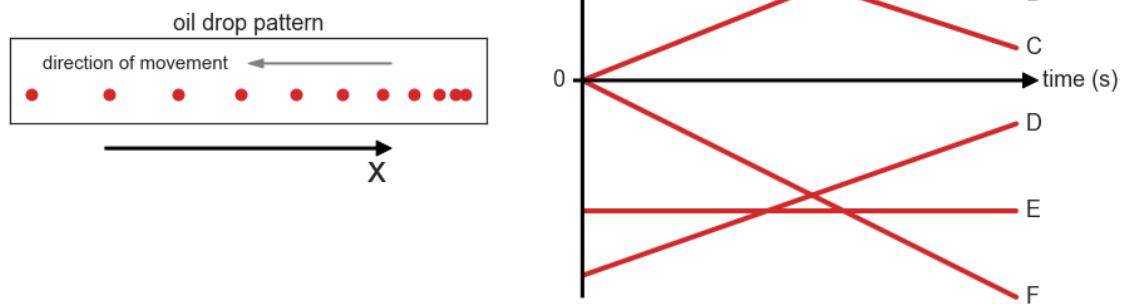
Exercise 1



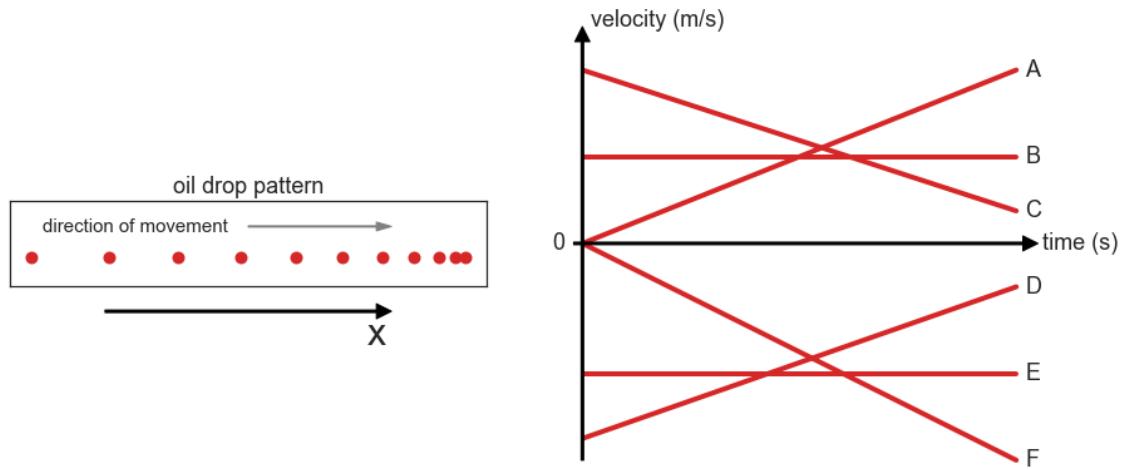
Exercise 2



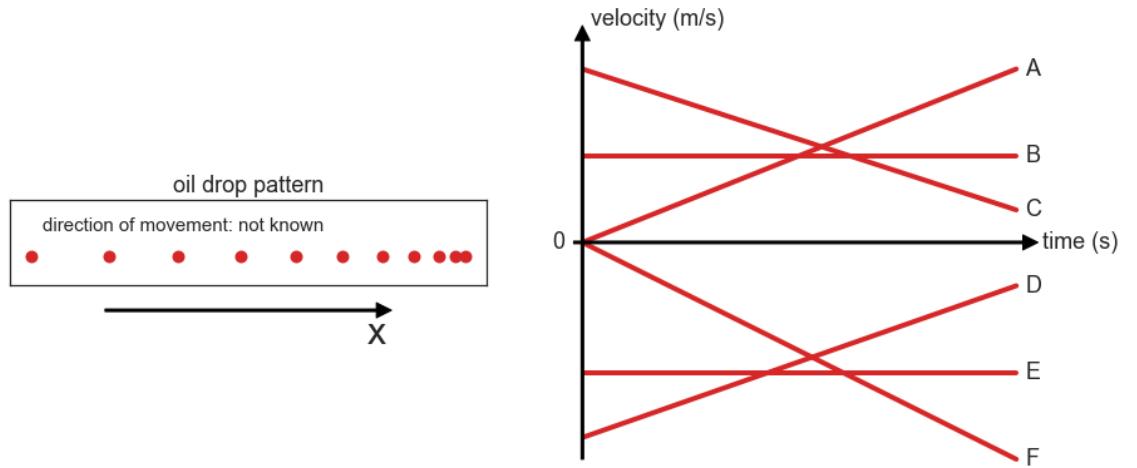
Exercise 3



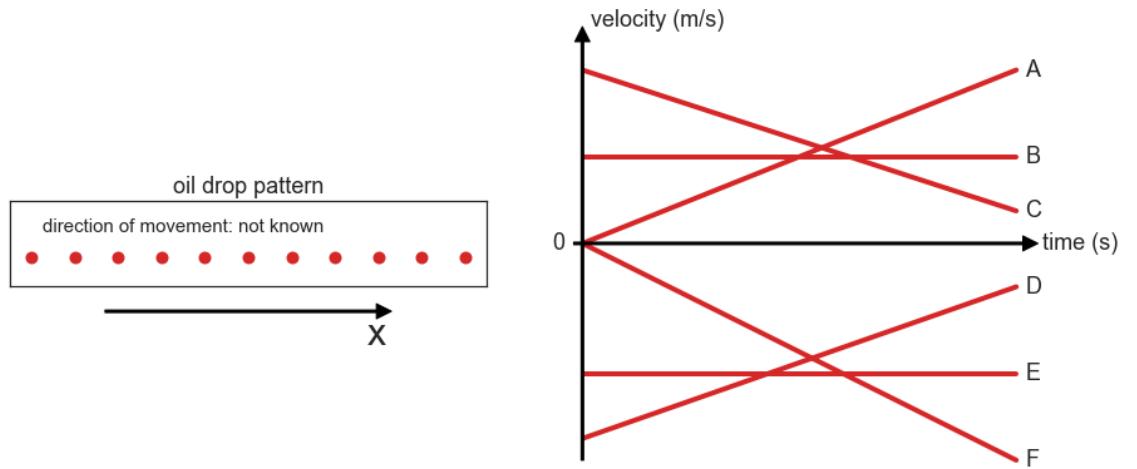
Exercise 4



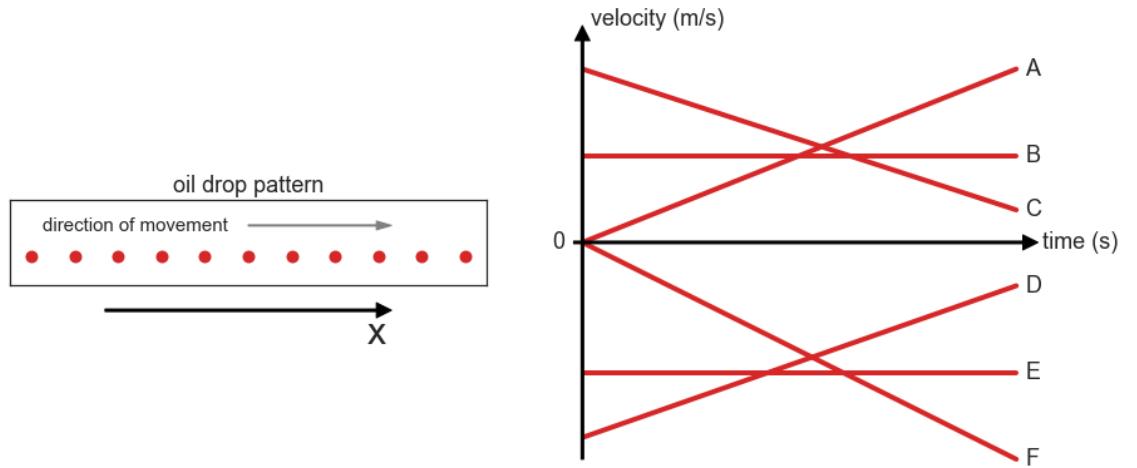
Exercise 5



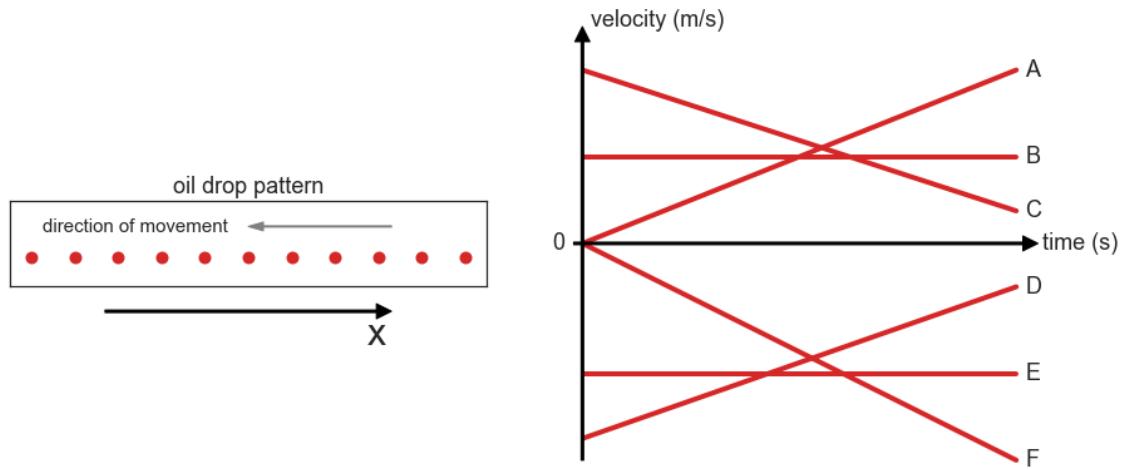
Exercise 6



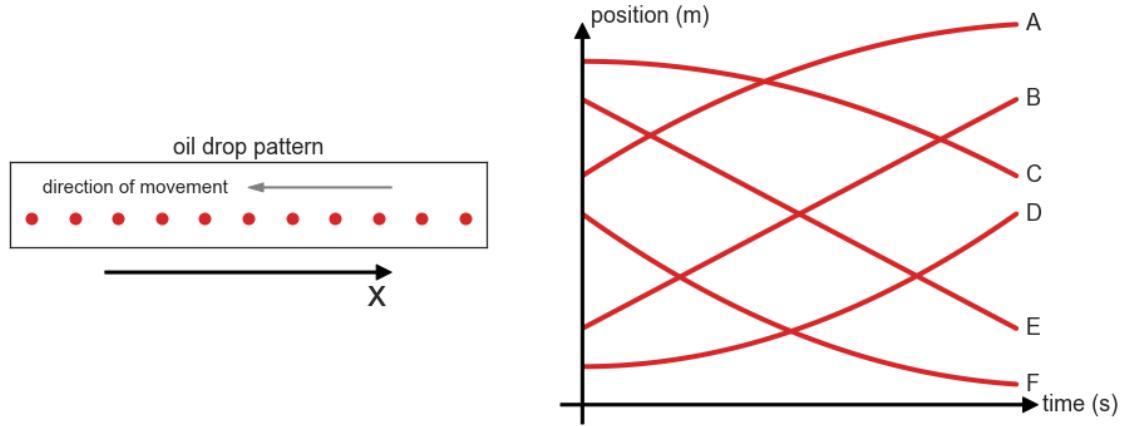
Exercise 7



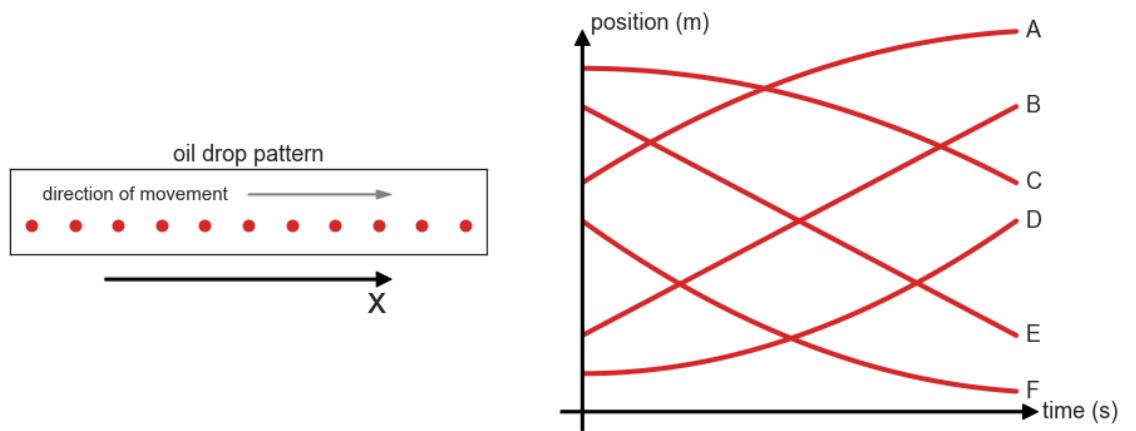
Exercise 8



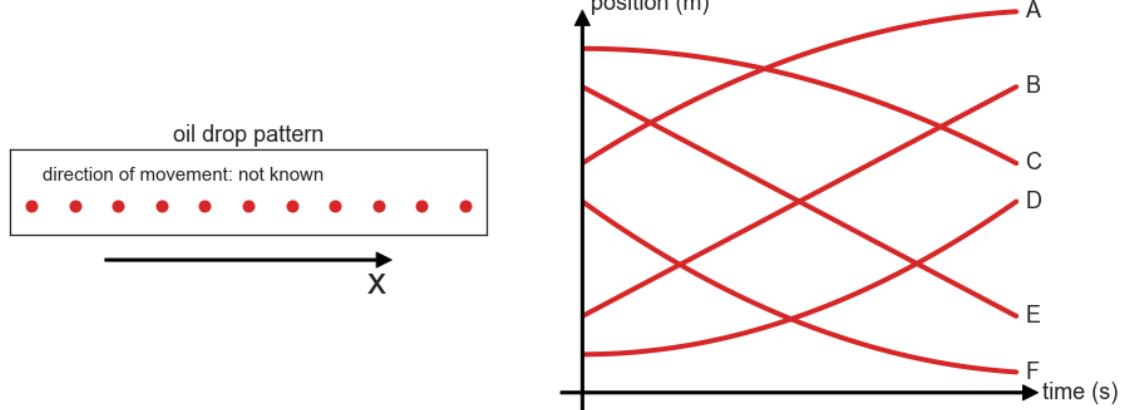
Exercise 9



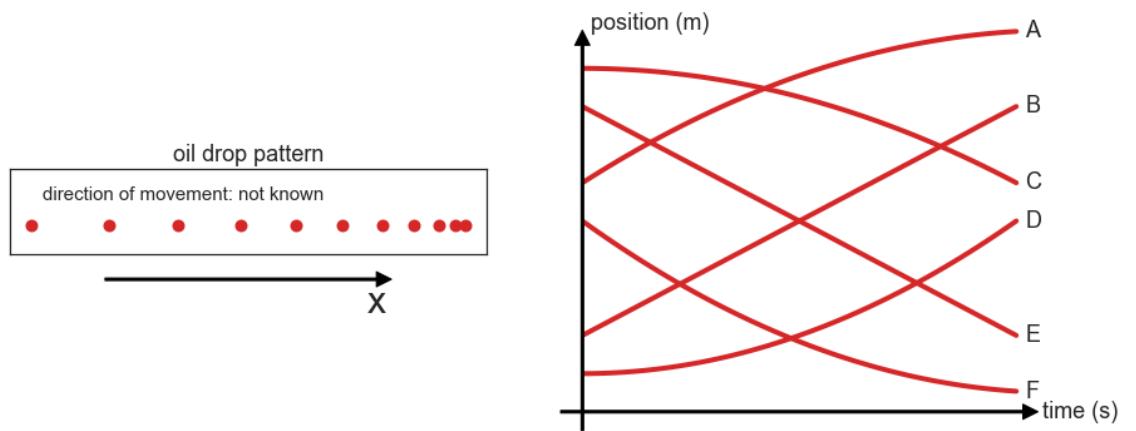
Exercise 10



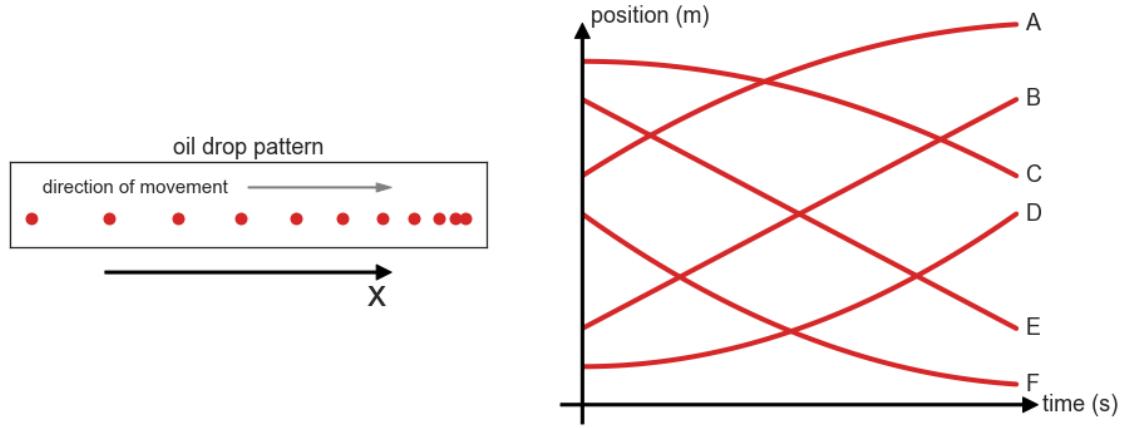
Exercise 11



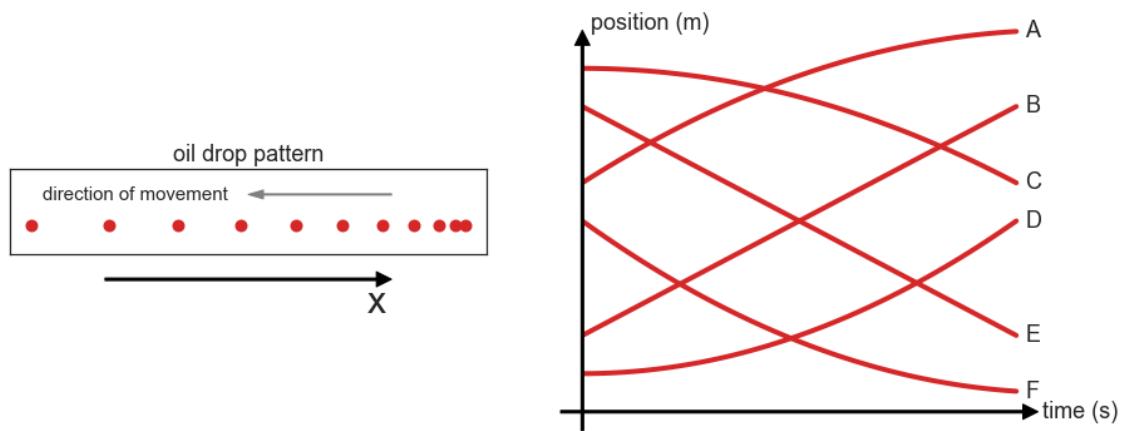
Exercise 12



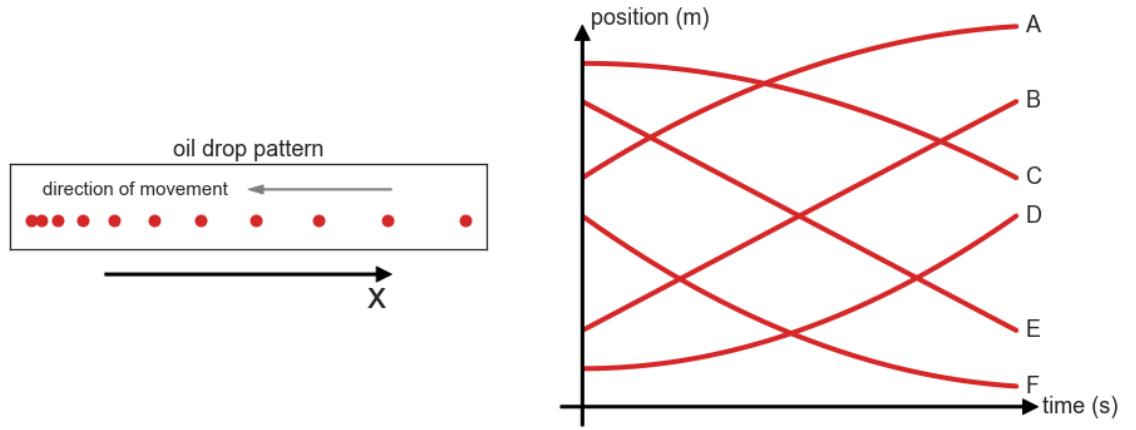
Exercise 13



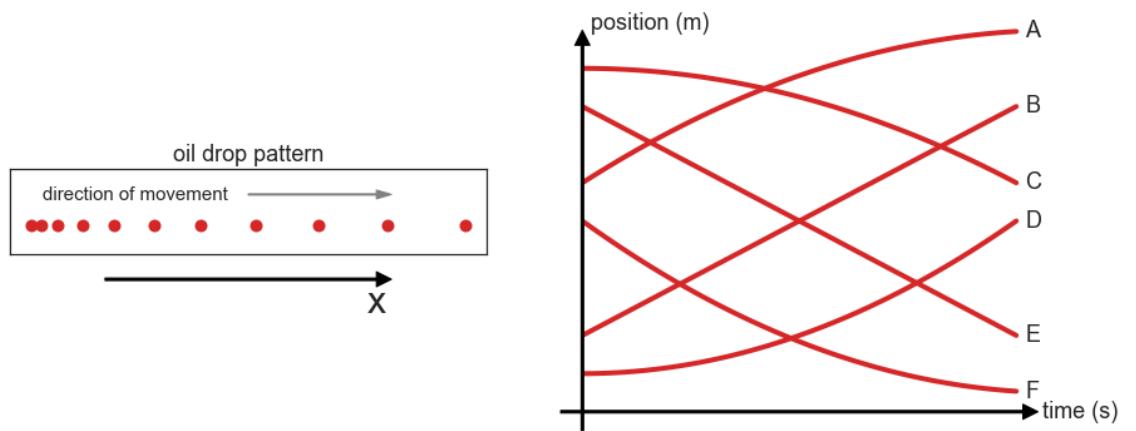
Exercise 14



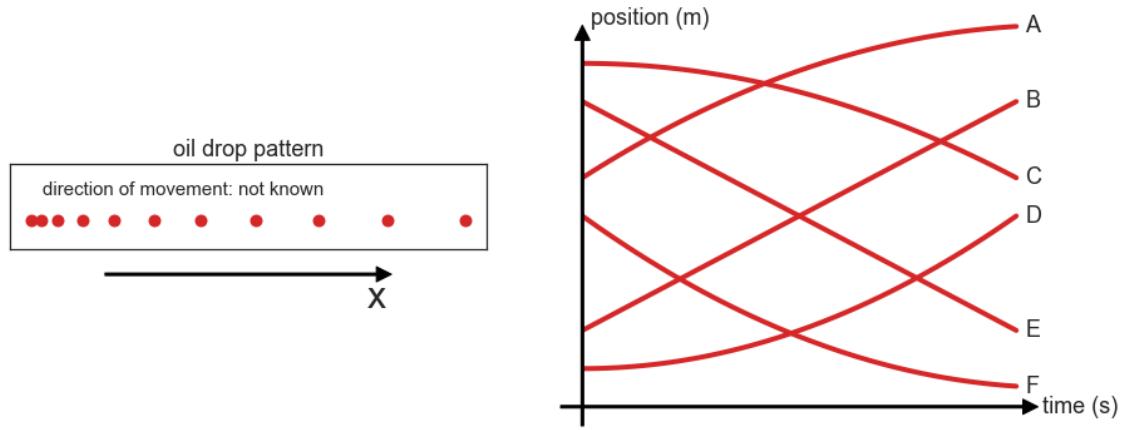
Exercise 15



Exercise 16



Exercise 17



Exercise 18

extra: momentum

Momentum, Lecture 1

Momentum, Lecture 2

Videos of people flying backwards after being shot:
* [Bruce Willis](#) (watch the few first seconds)
* [Uma Thurman](#) * [Morgan Freeman](#) (watch from 1:10)

Momentum, Lecture 3

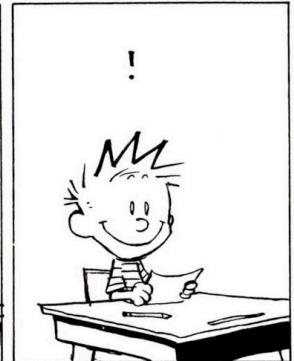
Videos of a Newton's Cradle
* [Newton's Cradle with a High-Speed Video Camera](#) * [Amazing Demonstration Of A Giant Newton's Cradle!](#)

Part II

the good stuff

cartoons

1. Explain Newton's First Law of Motion in your own words.



Yakka
Pubba
Gazork

<https://www.gocomics.com/calvinandhobbes/2015/01/12>

AMAZING WATCHING A PHYSICIST AT WORK, EXPLORING UNIVERSES IN A SYMPHONY OF NUMBERS.
IF ONLY I HAD STUDIED MATH, I COULD APPRECIATE THE BEAUTY ON DISPLAY HERE.



OH NO. THIS HAS TWO UNKNOWNS. THAT'S GONNA BE REALLY HARD.
UGHHHHHHHH.
THINK. THERE'S GOTTA BE A WAY TO AVOID DOING ALL THAT WORK...



<https://xkcd.com/2207/>



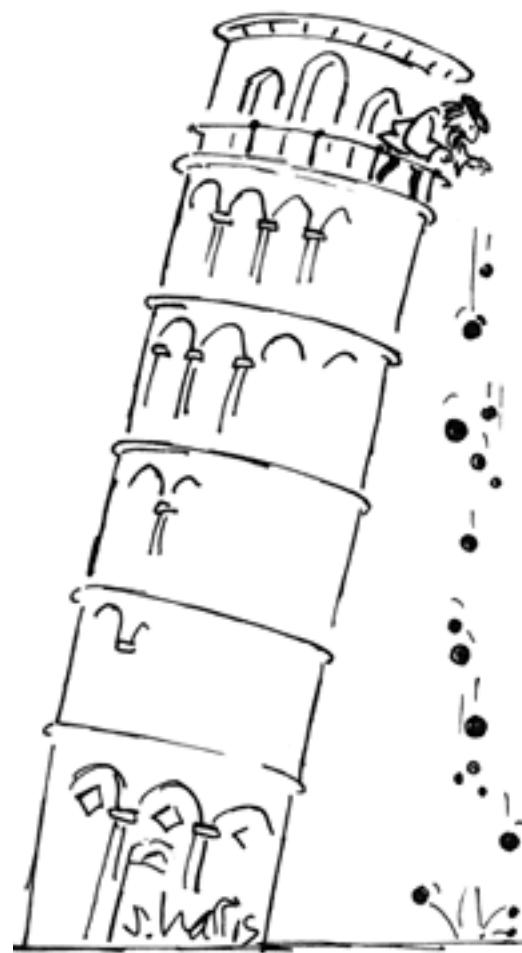
<https://www.smbc-comics.com/comic/2013-06-16>

1 PHYSIC

1.1 History

Aristotle said a bunch of stuff that was wrong.
Galileo and Newton fixed things.
Einstein broke everything again. Now we finally got it all worked out, except for dark matter, dark energy, hot stuff, cold stuff, fast stuff, slow stuff, dark stuff, turbulence, and the cold dark matter.

Science: Abridged Beyond the Point of Usefulness



<http://www.sciencecartoonsplus.com/gallery/physics/galphys2j.php#>



Why science teachers
should not be given
playground duty.

units

Any time you pick up a well shuffled deck, you are almost certainly holding an arrangement of cards that has never before existed and will likely never exist again. $52! \approx 10^{68}$. Suppose a new permutation of 52 cards was drawn every second starting from The Big Bang (13.8 billion years ago). You wouldn't even be close. To count out all $52!$ permutations you would need 10^{51} ages

of the universe.



Any time you pick up a well shuffled deck, you are almost certainly holding an arrangement of cards that has never before existed and will likely never exist again. - Yannay Khaikin
pic.twitter.com/afOpu0y7qA

— Berger | Dillon (@InertialObservr) September 18, 2019

If you worked every single day, making \$5000/day, from the time Columbus sailed to America, to the time you are reading this tweet, you would still not be a billionaire.

How much larger/heavier/longer was the Megalodon compared with a great white?



This is the mass damper of the Taipei 101 skyscraper: it has a mass of 728 tons and a diameter of 5.4 meters. It helps stabilize the building in high winds and this is the record movement realized during typhoon Soudelor with 160 km/h winds **what is the mass density of this ball?**

This is the mass damper of the Taipei 101 skyscraper: it has a mass of 728 tons and a diameter of 5.4 meters. It helps stabilize the building in high winds and this is the record movement realized during typhoon Soudelor with 160 km/h winds <https://t.co/e0MxA0iOG5>

pic.twitter.com/xqcbUNJWs

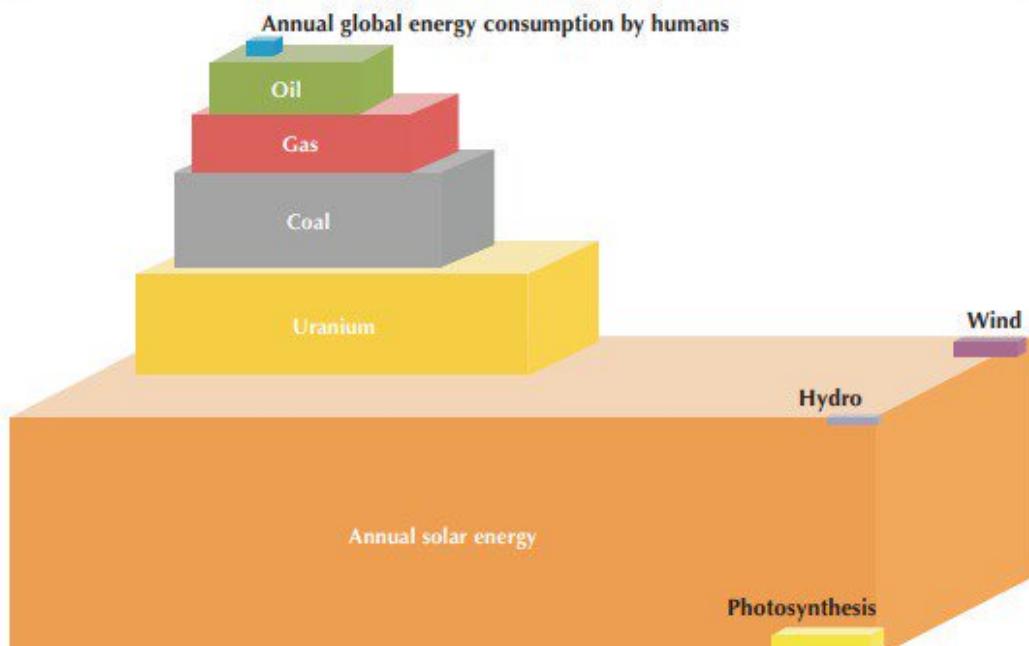
— Massimo (@Rainmaker1973) September 8, 2018

<https://www.youtube.com/watch?v=xqELmBNyWfU>

orders of magnitude, from

<https://twitter.com/Rainmaker1973/status/1125710475378012161>

Figure 2.1 Total energy resources



Source: National Petroleum Council, 2007, after Craig, Cunningham and Saigo (republished from IEA, 2008b).

Exponent Rules

Assume that a and b are nonzero real numbers, and m and n are any integers.

1) Zero Property of Exponent

$$b^0 = 1$$

2) Negative Property of Exponent

$$b^{-n} = \frac{1}{b^n} \quad \text{OR} \quad \frac{1}{b^{-n}} = b^n$$

3) Product Property of Exponent

$$(b^m)(b^n) = b^{m+n}$$

4) Quotient Property of Exponent

$$\frac{b^m}{b^n} = b^{m-n}$$

5) Power of a Power Property of Exponent

$$(b^m)^n = b^{mn}$$

6) Power of a Product Property of Exponent

$$(ab)^m = a^m b^m$$

7) Power of a Quotient Property of Exponent

$$\left(\frac{a}{b}\right)^m = \frac{a^m}{b^m}$$

kinematics

Motivation for studying kinematics

firefighting airplanes in action, dogs jumping into a car, woman walking the wrong way

X and Y movements are independent

#PhysicsFactlet (179)The rate of change of position is velocity.The rate of change of velocity is acceleration.The rate of change of acceleration is jerk.The rate of change of jerk is jounce.The rate of change of jounce is crackle.The rate of change of crackle is pop.

— Jacopo Bertolotti (@j_bertolotti) October 8, 2019

2d kinematics

Harlem Globetrotter Makes Incredible Trick Shot From Plane Flying 70 MPH

jumping goats

Kevin failed Physics

Yes, Kevin failed physics and math, but he knew how to build a helluva ramp!
pic.twitter.com/8rPrtRmCYy

— Hold My Beer (@HldMyBeer) August 31, 2021

Galilean relativity

swimming against the current

Mythbusters - Soccer Ball Shot from Truck

<https://youtu.be/BLuI118nhzc>

Circular motion

Hamster, from

<https://twitter.com/SJSchauer/status/1186484325451227136?s=09>

Human Loop the Loop with Damien Walters

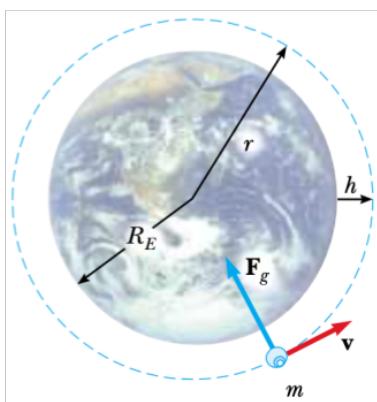
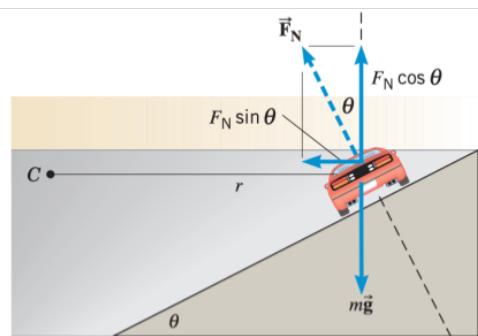
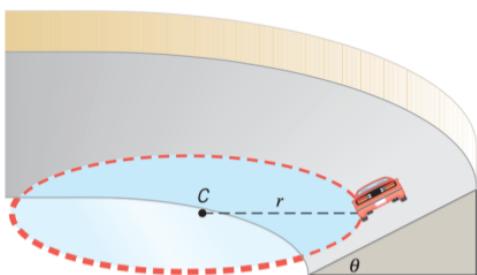
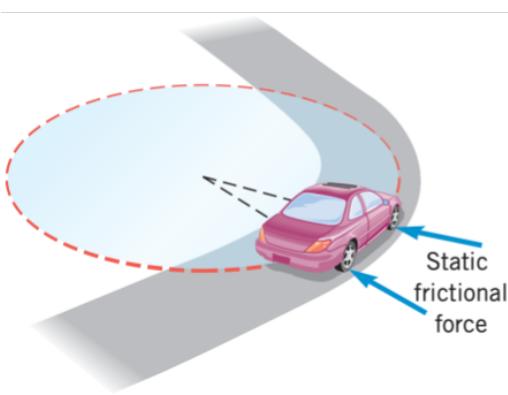
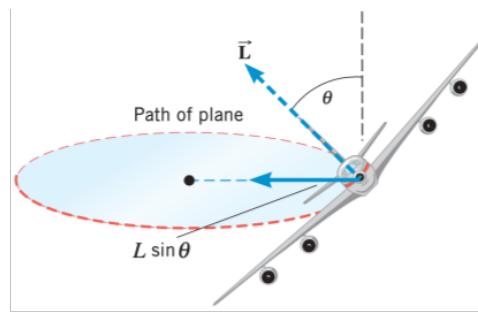
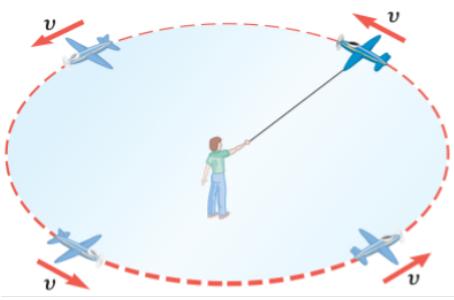
Ball in a pie pan: Testing Experiment

Beer flipping

2001: A Space Odyssey

Centripetal force

Many forces can take the role of the centripetal force.



Newton's laws

Newton's first law

The fall of the dinosaurs

Trampoline with leaves

At the Kibo ISS module

[Rollerblades on a moving table](#)

What is Inertia?



I N E R T I A

Your truck has brakes...the massive hunk of stone doesn't.

Newton's second law

Man with superhuman strength

Inside the ISS

Whack-a-Stack

Apollo 15 hammer-feather drop

Newton's third law

Newton cartoon

Isaac Newton: *slaps roof of car*

Car: *slaps Isaac Newton*



Motorcycle kicks car

Friction

Static friction

Static vs. kinetic friction

No friction on inclined plane

Cat fails to jump, not enough friction

Spidergirl

linear momentum & center of mass

Collisions

brain during collision

golf ball

Football to the Face 1000x Slower - The Slow Mo Guys

Elastic collisions

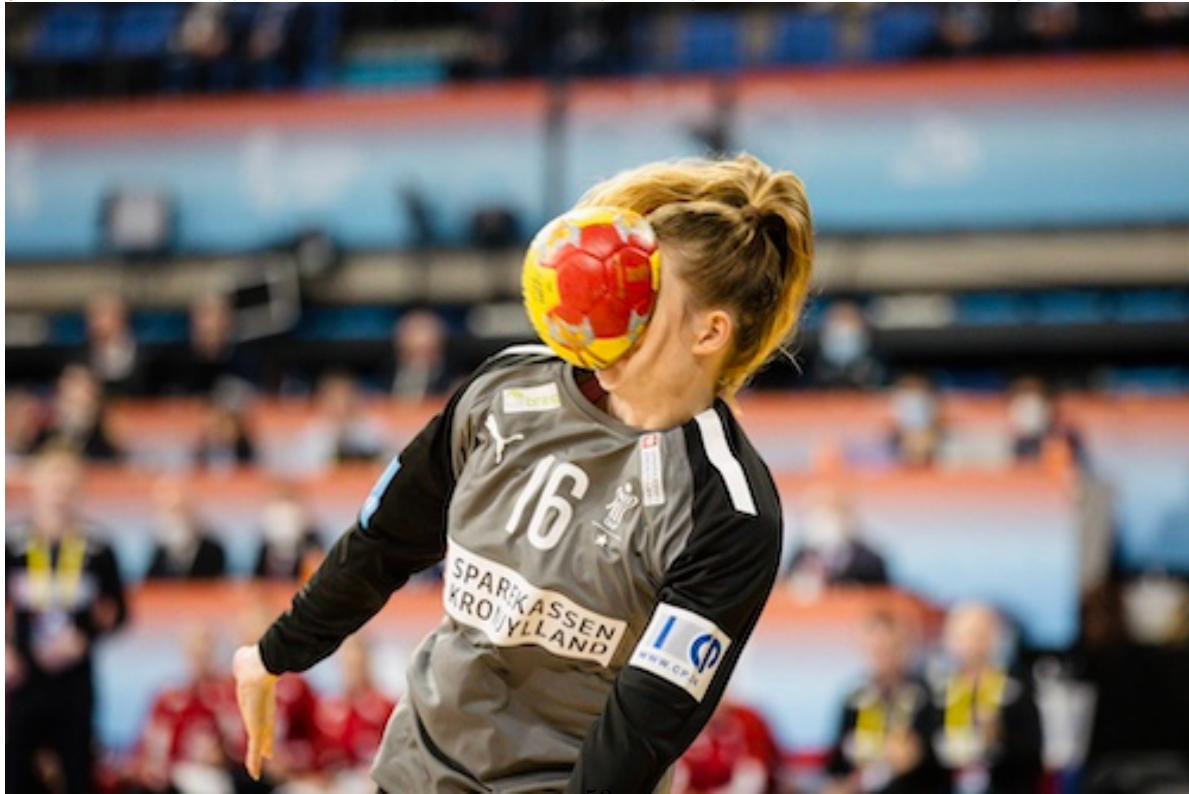
failed collision

bullets ricochet off water

periodic billiard collision

Althea Reinhardt's face save

{% twitter https://twitter.com/BeardedGenius/status/1472221793595310084 %}



Inelastic collisions

Apple collision at 90 km/h.

Center of mass

center of mass parabolic trajectory

Josh Imatorbhebhe vertical jump

Internal vs external forces

How to push your pickup truck

energy

Elastic energy

The First Hold & Release Bungee Jump | Damien Walters

<https://youtu.be/iN1beukMJc>

Potential and Kinetic Energy

Visualization of conservation of energy

High road low road track race, potential-kinetic energy tracks

https://youtu.be/_GJuJClGYJQ

Mondo Duplantis 2018, play at 0.25 speed

150 Ton Hydraulic Guillotine Vs Deck of Cards

fluids

How a 50 kg iron working anvil floats on liquid mercury From <https://twitter.com/Rainmaker1973/status/119421>

Hydrostatic pressure

Pressure change during diving

{% twitter <https://twitter.com/physicsastronomy/status/1464007031367602181?s=12> %}

Fish tower

The Hydrostatic Paradox - Explained!

Pascal's Blaizing Barrel - Exploding Glass Barrel with Water Pressure

The Pressure Paradox #VeritasiumContest #GrandPrizeWinner

Surface tension

from <https://twitter.com/Rainmaker1973/status/1191329332926570497?s=09>

WOW

rope swing record

does the period of a pendulum depend on its mass?

Time-Lapse: Lose Yourself in the Night Sky

fastest response time

The kangaroo rat's escape response to a snake attack is less than 70 milliseconds and the quickest mammalian startle response.

Selected solar system objects to scale in size, rotation speed and axial tilt

Milky Way and Earth

Milky Way spinning around Earth

Milky Way fixed, earth spinning round

The Milky Way Fly Out

Stefan Payne-Wardenaar

Least action, path of bowling ball minimizes action

A free-falling frame of reference cancels gravity

{% twitter <https://twitter.com/sfera314/status/1173284029900173315> %}

Mesmerising Mass Sheep Herding

Solar eclipse from space

150 Ton Hydraulic Guillotine Vs Deck of Cards

exams

Some past exams (in hebrew):

Year	Midterm	Moed A	Moed B	Moed C
2021-2022				
2020-2021				
2019-2020				
2018-2019				
2017-2018				

more stuff

Physics cartoons

Great online Physics resources:

- [Khan Academy - English](#)
- [Khan Academy -](#)
- [Michel van Biezen](#)
- [Walter Lewin's 8.01x - MIT Physics I: Classical Mechanics](#)
- [PhET: fun, free, interactive, research-based science and mathematics simulations](#)