# Physics 1 - Mechanics

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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.

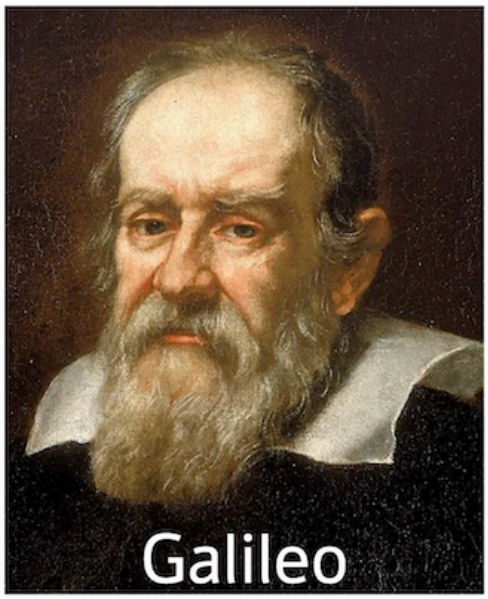
## goals

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.




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 edtion).
**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; rations, rates, proportions; equations, expressions, and inequalities; exponents, radicals, and scientific notation.

Khan Academy

## Algebra

Michel van Biezen

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# 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- | $\mu$ |
| $10^{-9}$ | 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

$$\left(b^m\right)\left(b^n\right) = b^{m+n}$$

4) Quotient Property of Exponent

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

5) Power of a Power Property of Exponent

$$\left(b^m\right)^n = b^{mn}$$

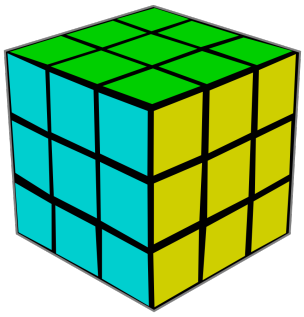
6) Power of a Product Property of Exponent

$$\left(ab\right)^m = a^m b^m$$

7) Power of a Quotient Property of Exponent

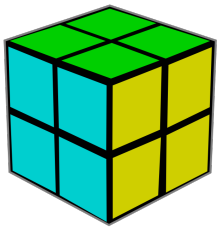
$$\left(\frac{a}{b}\right)^m = \frac{a^m}{b^m}$$

## volume and surface area



sides = 3
surface = $3^2$ x 6 = 54
volume = $3^3$ = 27

surface/volume = 2



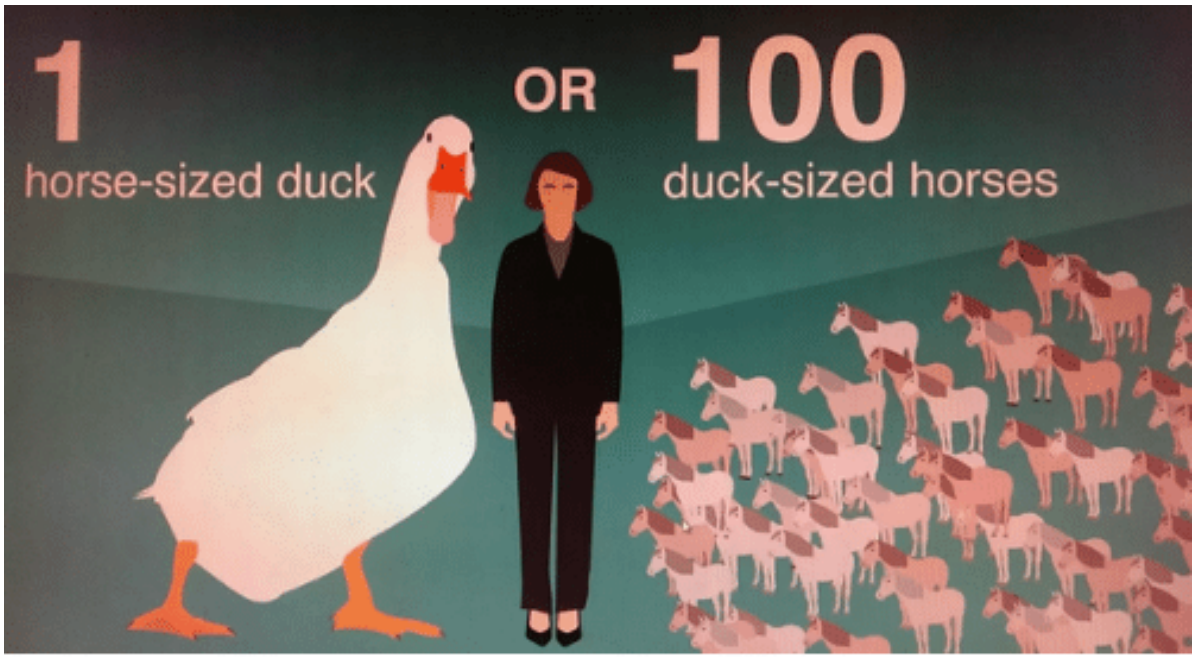
sides = 2
surface = $2^2$ x 6 = 24
volume = $2^3$ = 3

surface/volume = 3

sides = 1
surface = $1^2$ x 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

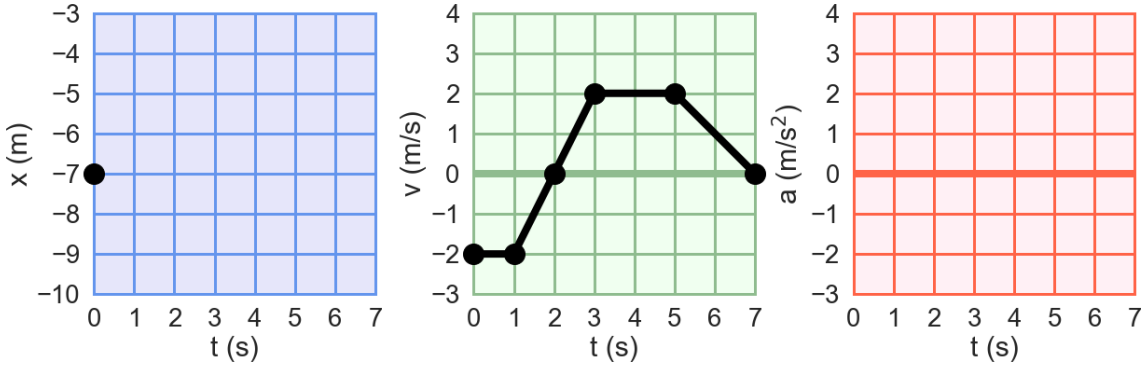
This is an *excellent* interactive website, with lots of useful exercises:
Distance vs. Displacement, Acceleration, Name That Motion, Motion Diagrams, Graph That Motion, Match That Graph, Position-Time Graphs - Conceptual Analysis, Position-Time Graphs - Numerical Analysis, Dots and Graphs, Which One 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

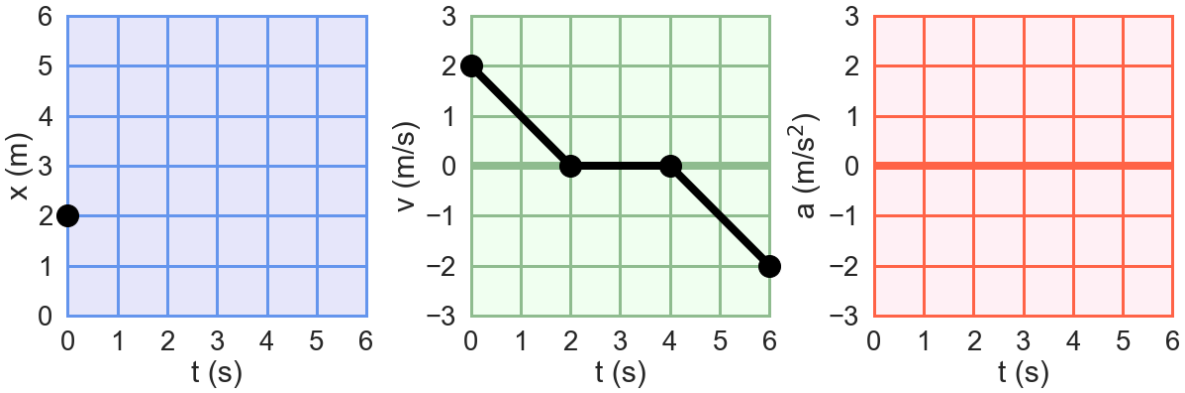
## $x$, $v$, $a$ graphs

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**

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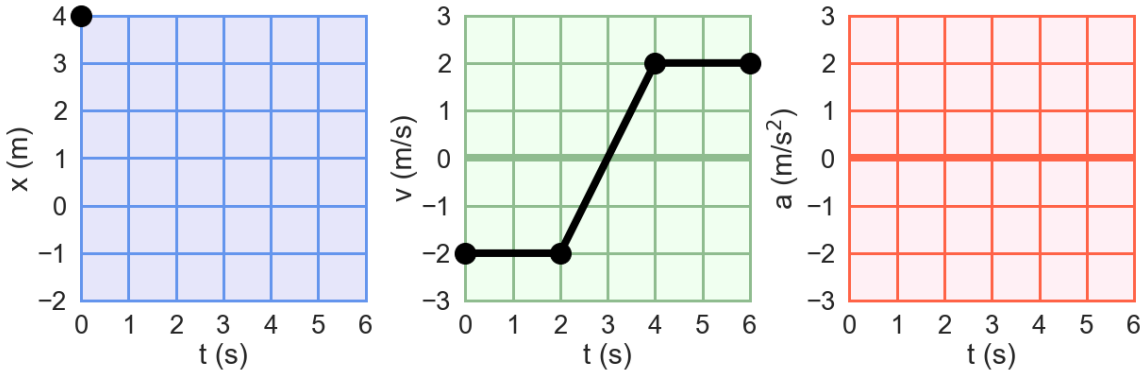


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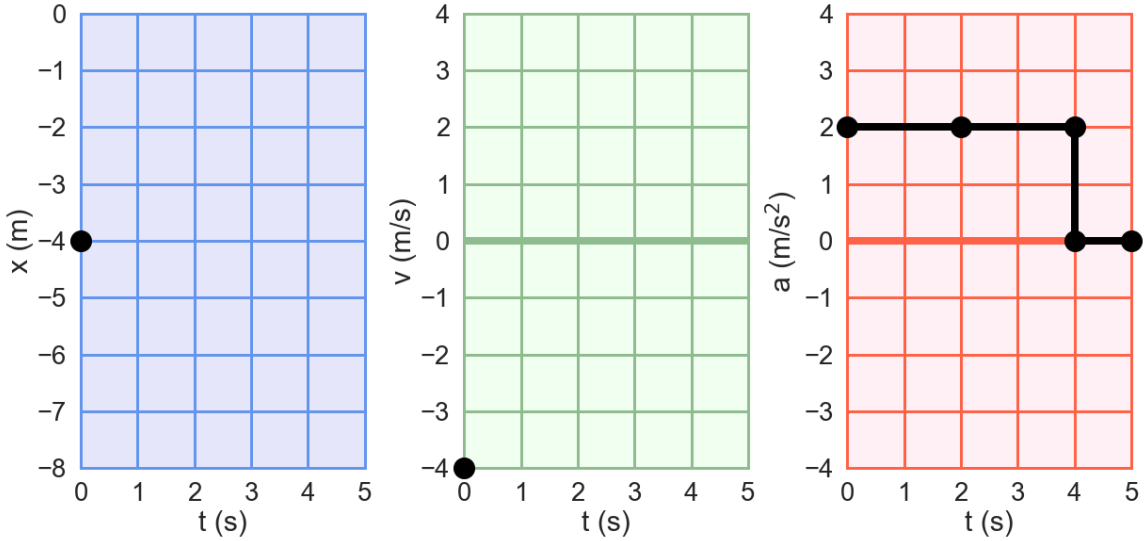

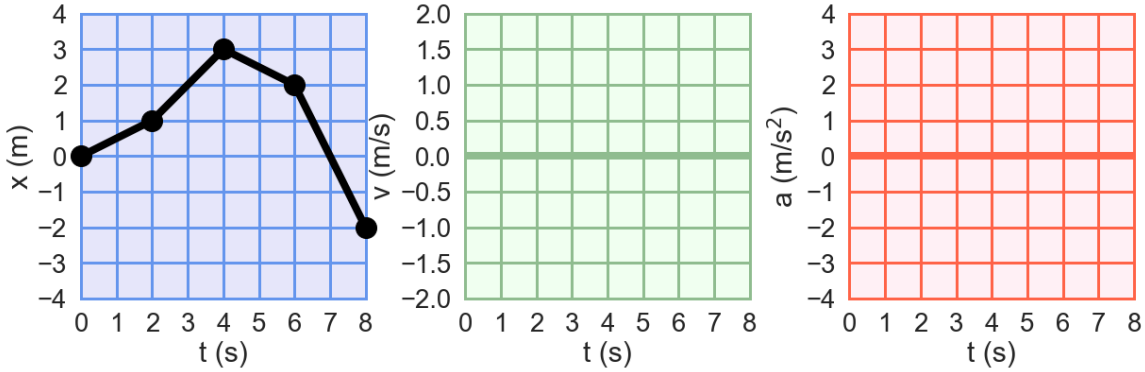


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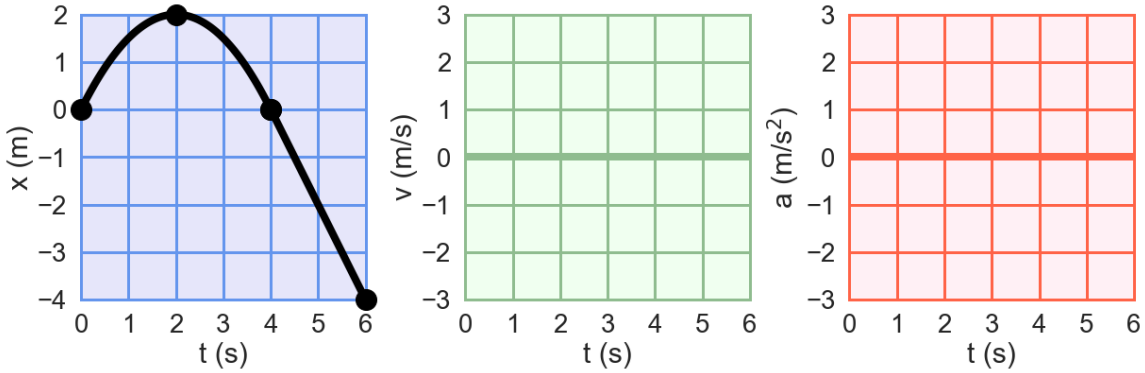
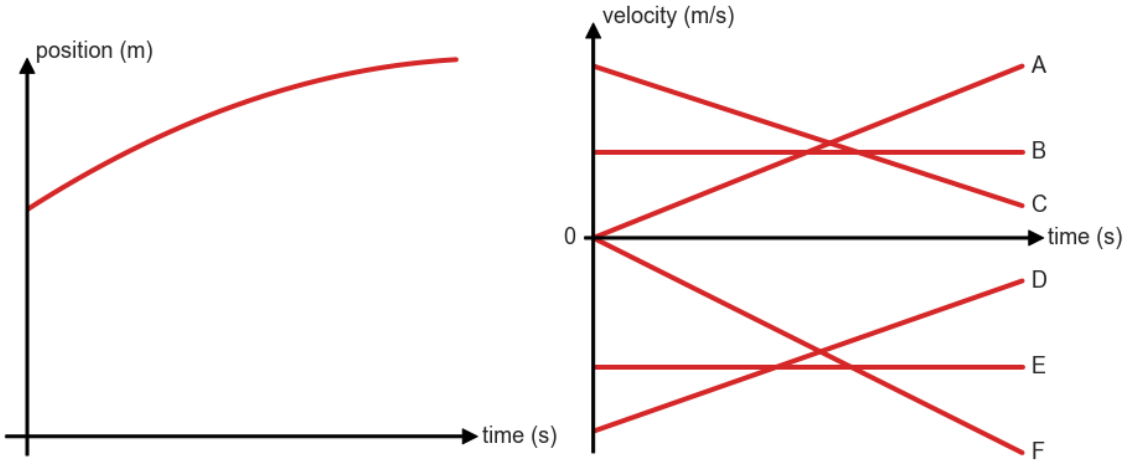



**Exercise 6**

## Match the graphs, $x$ and $v$

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

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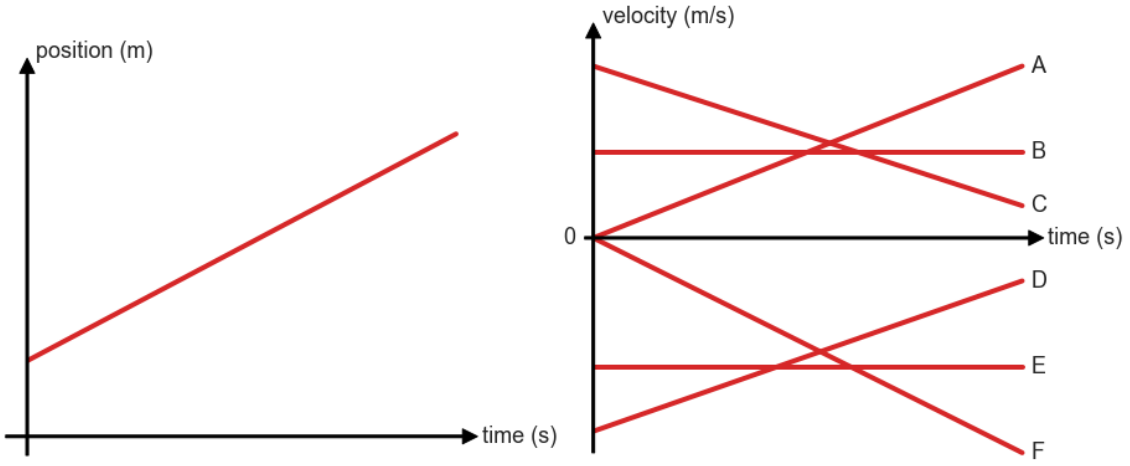


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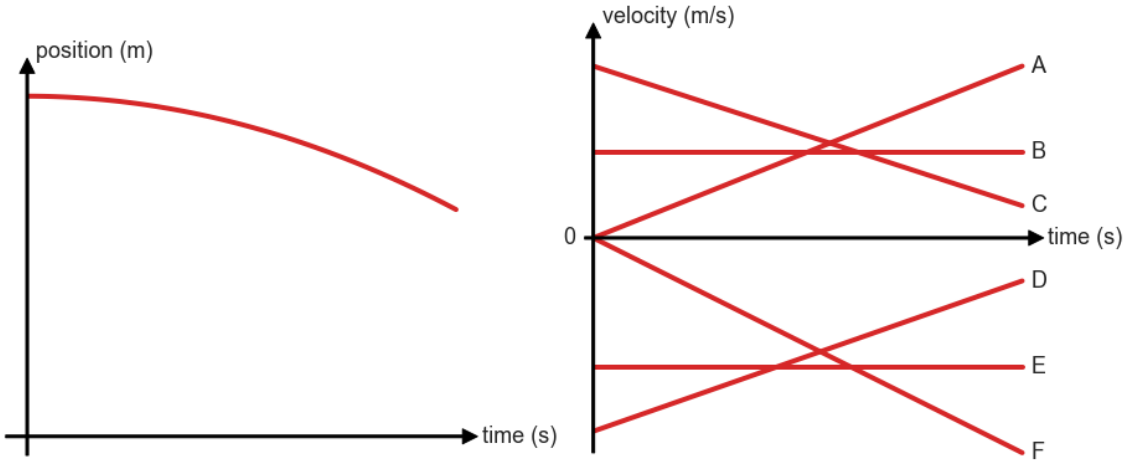


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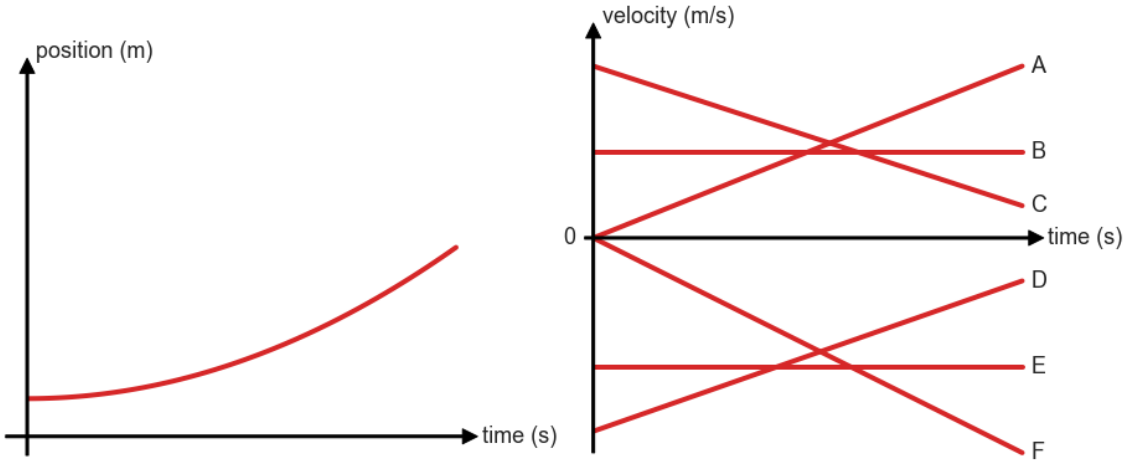


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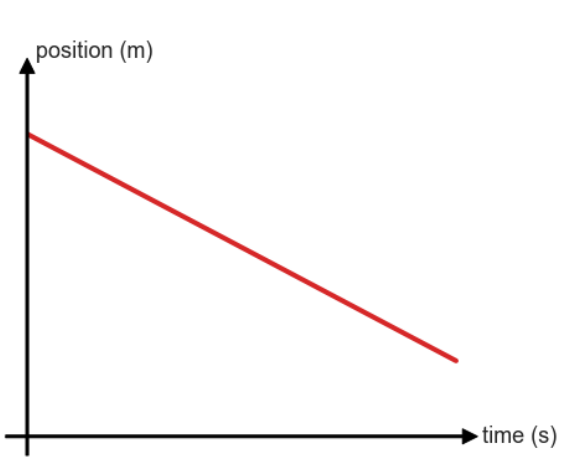


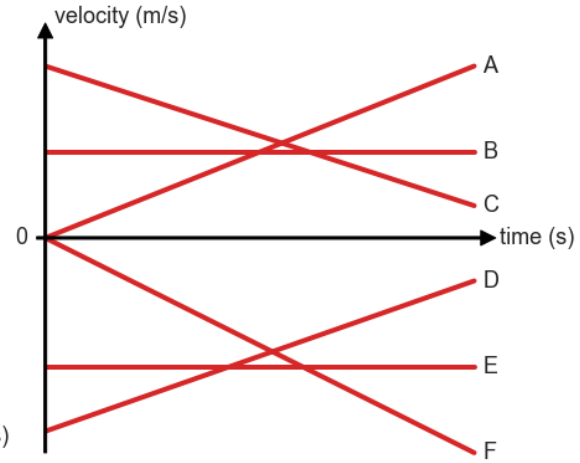


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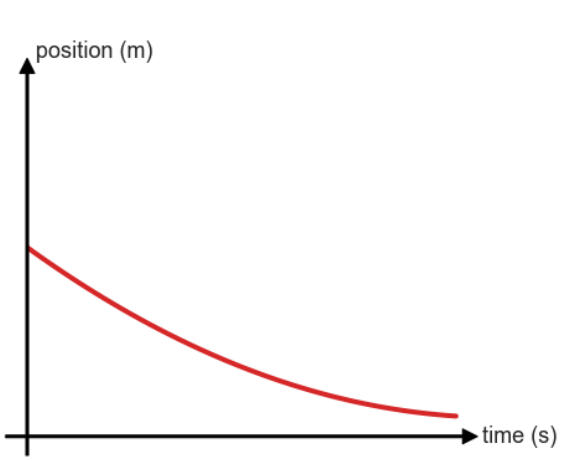


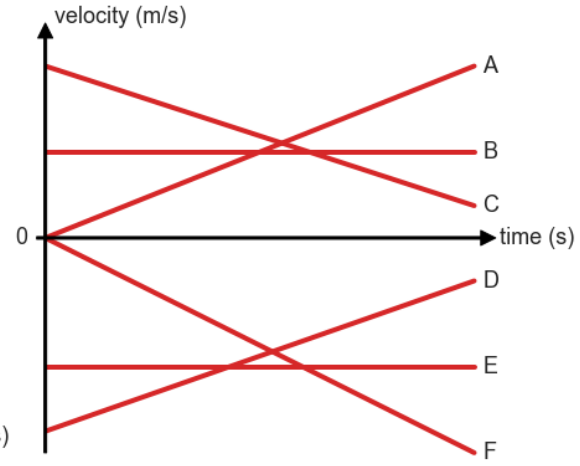


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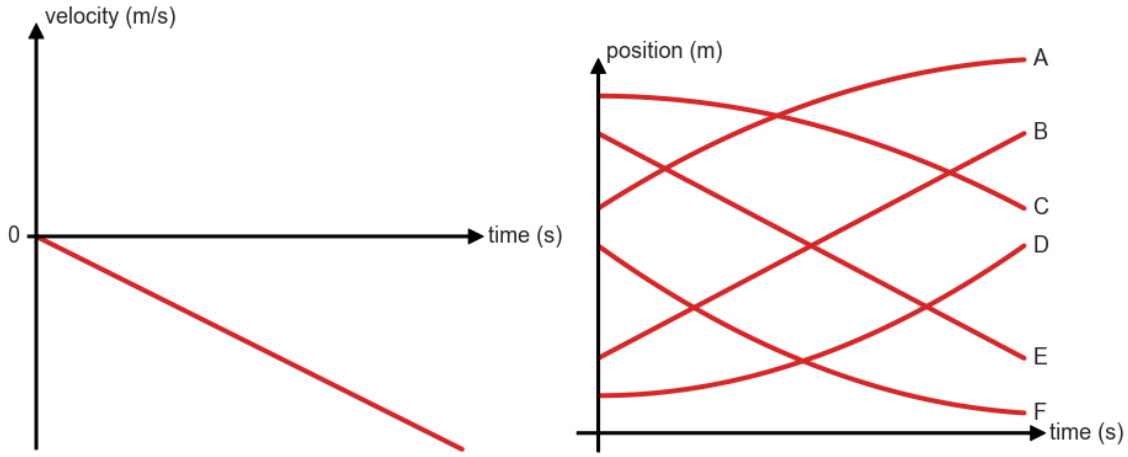


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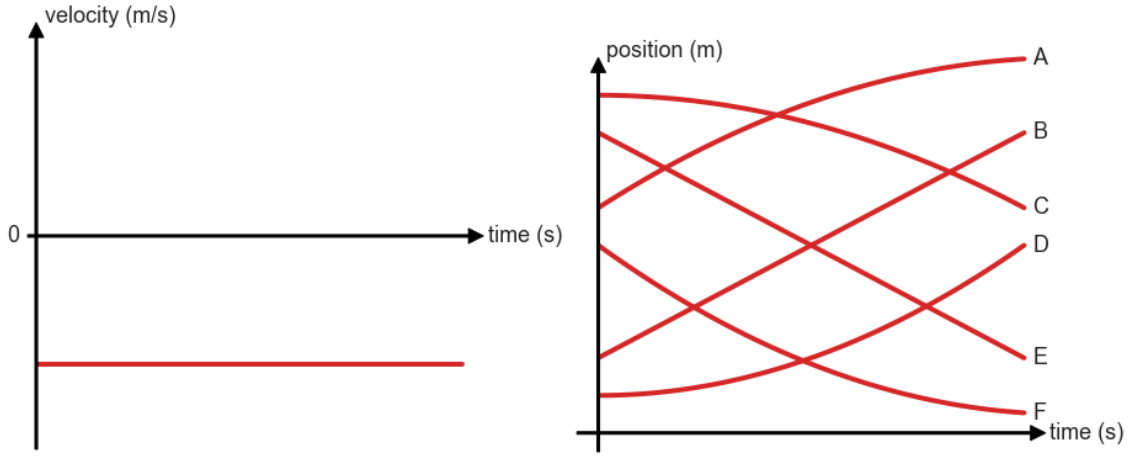


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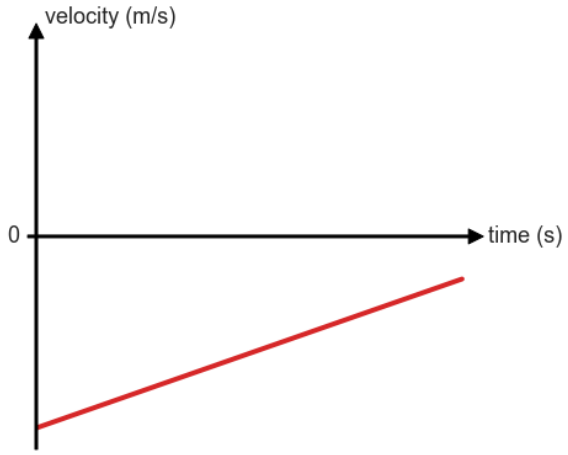


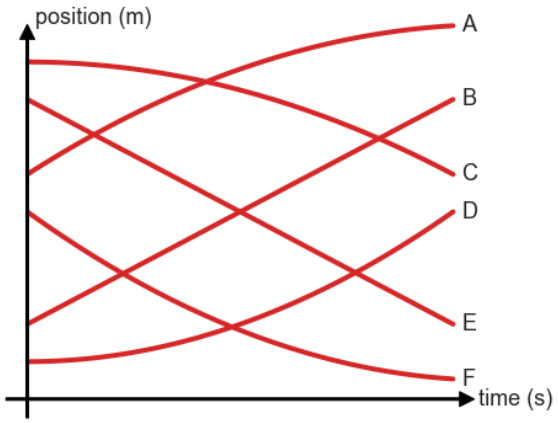


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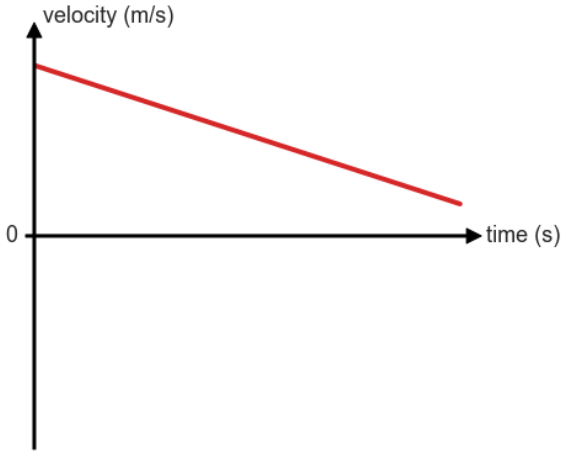


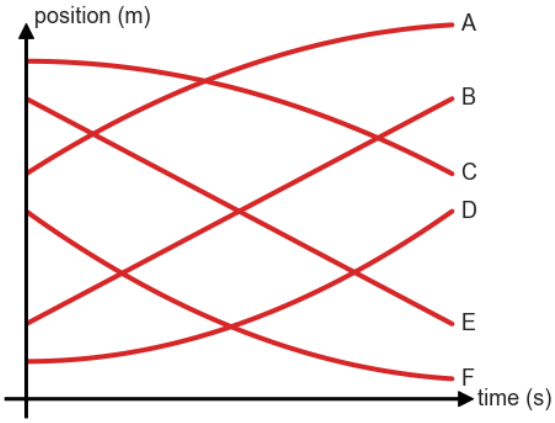


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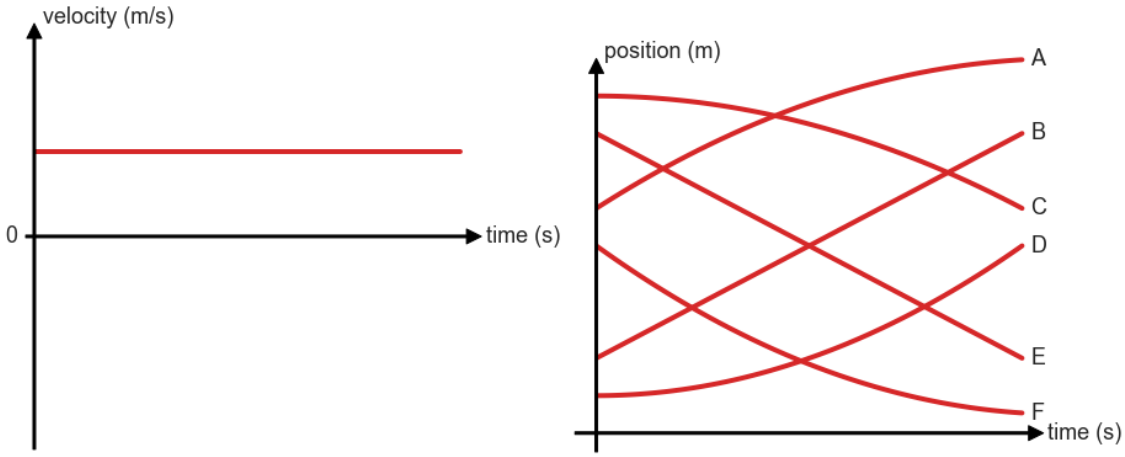


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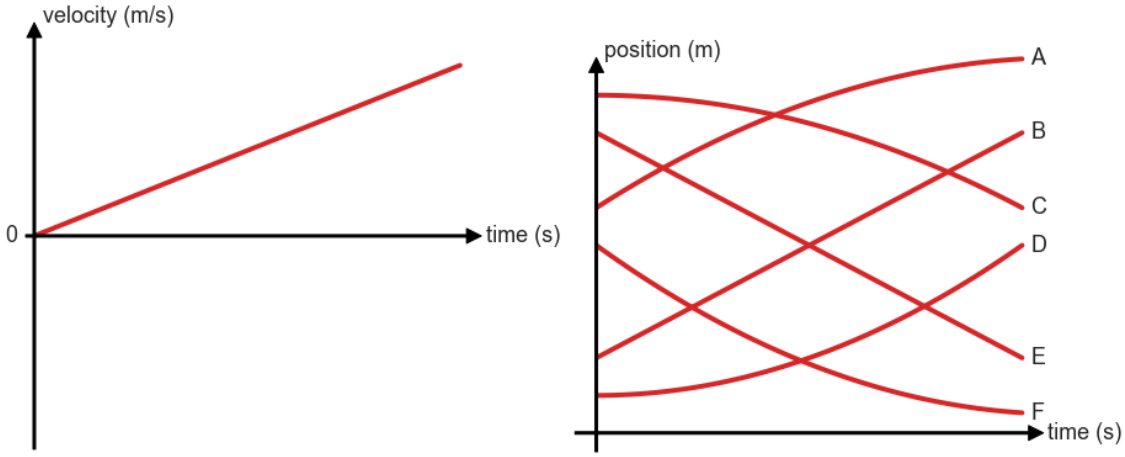
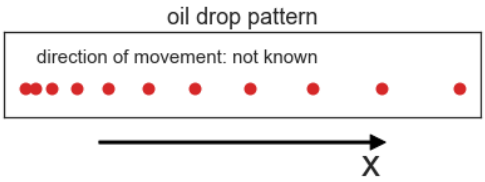
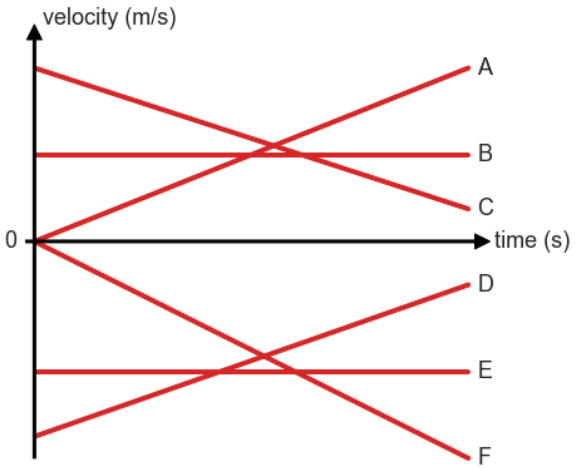



**Exercise 12**

## 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!

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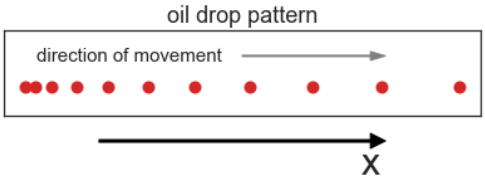


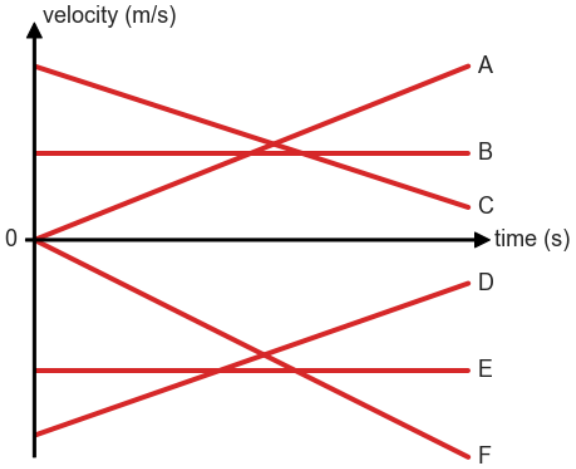


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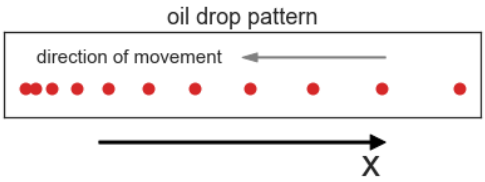


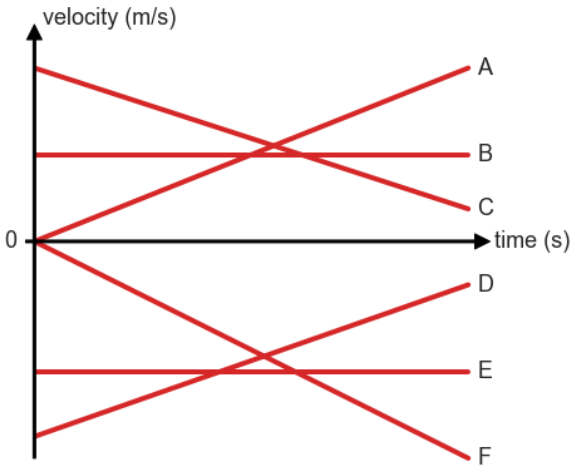


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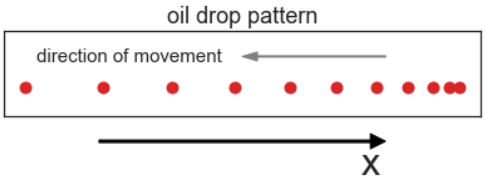


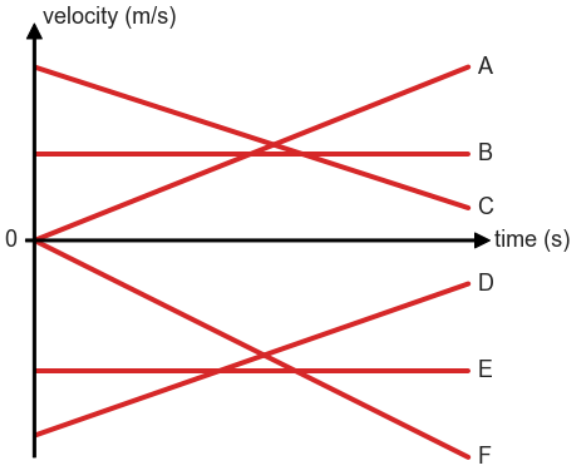


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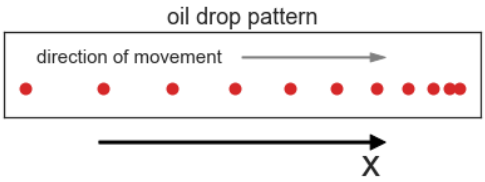


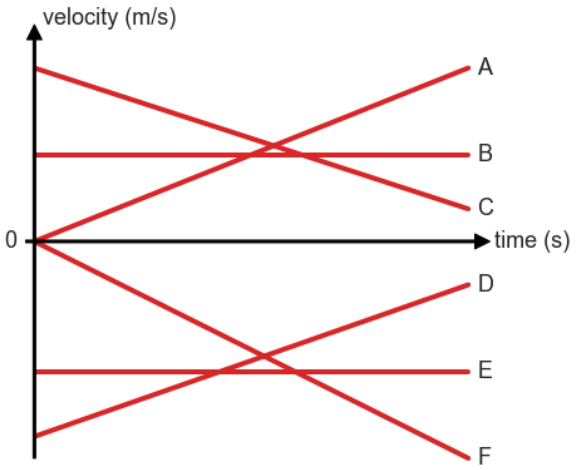


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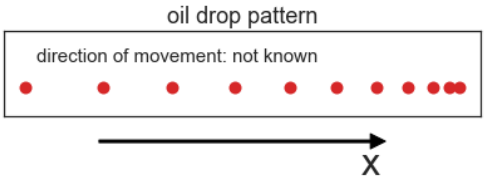


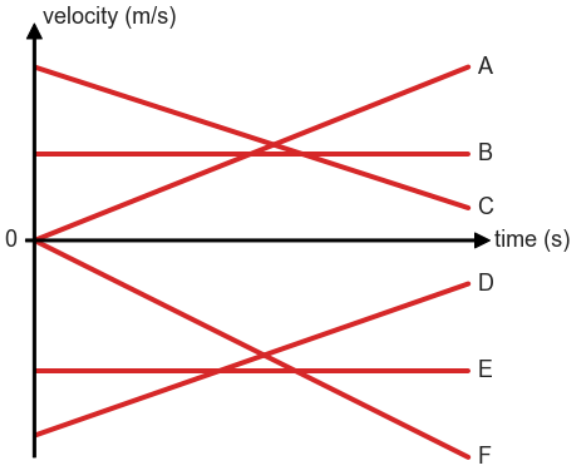


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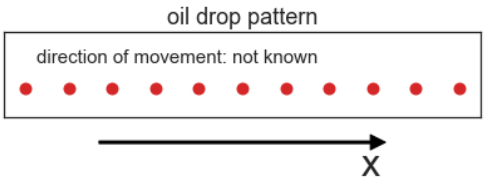
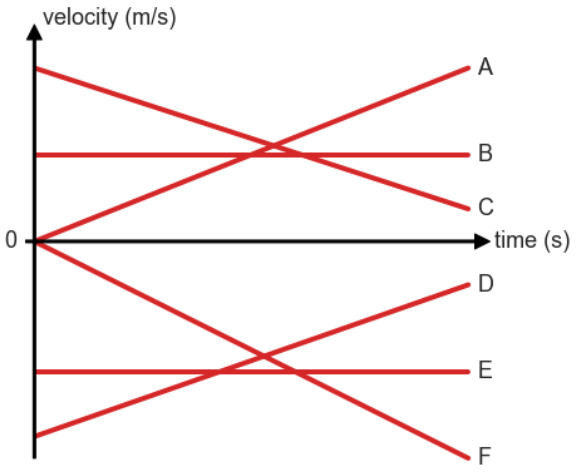
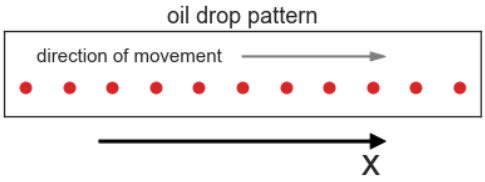
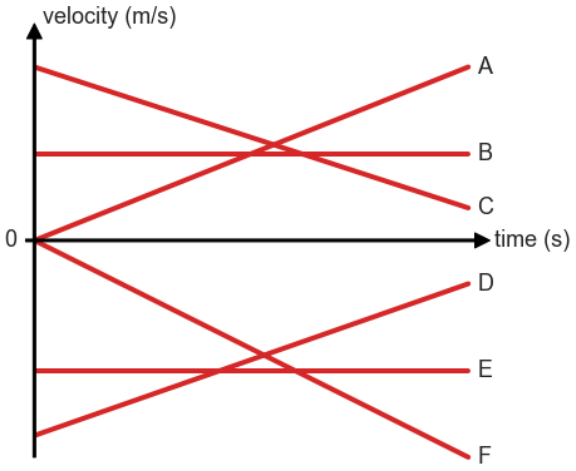


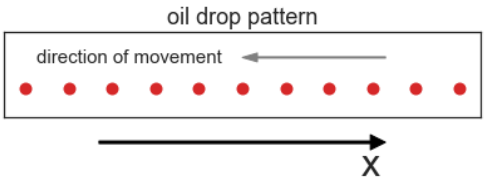



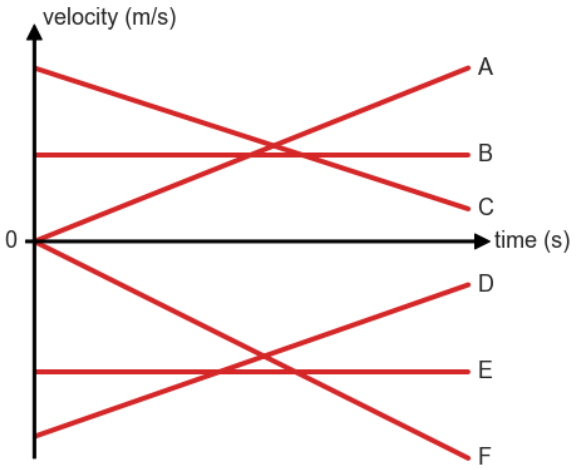

**Exercise 7**




**Exercise 8**

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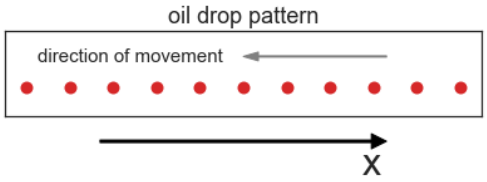
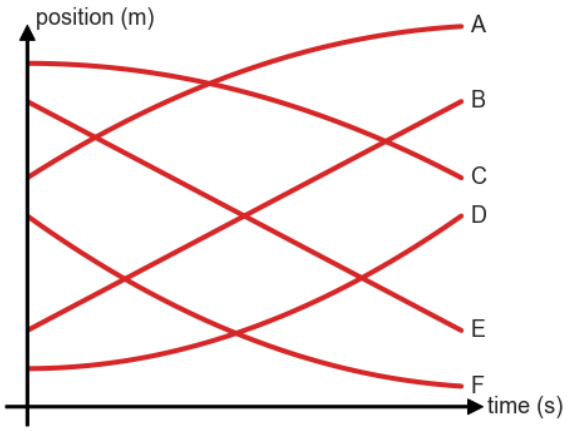
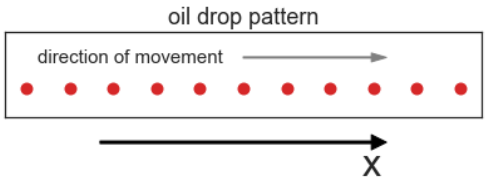
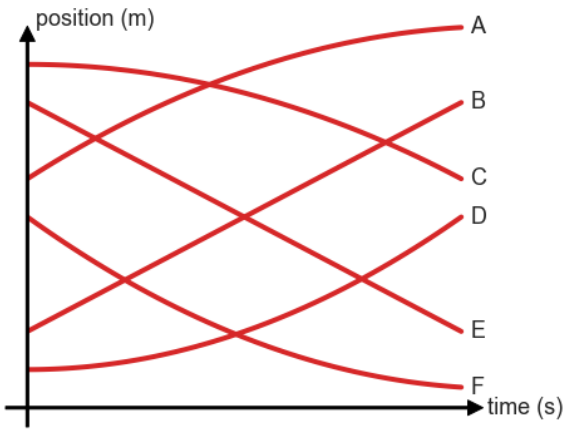


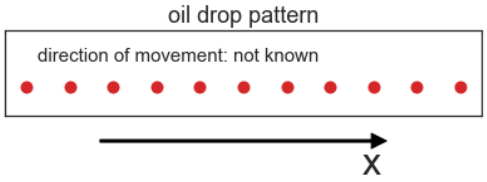



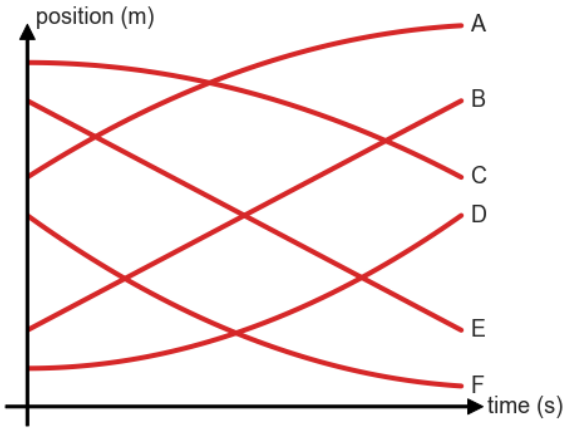

**Exercise 10**




**Exercise 11**

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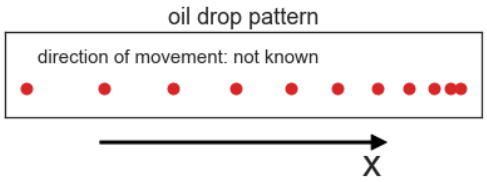
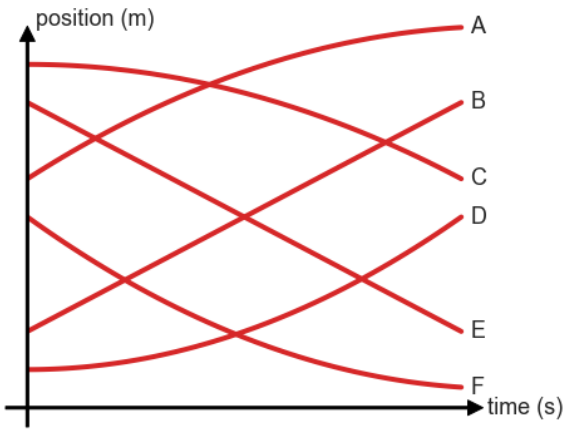
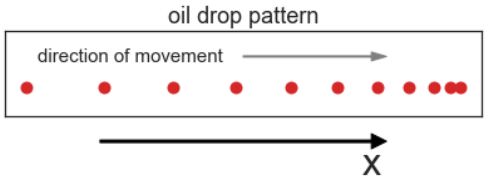
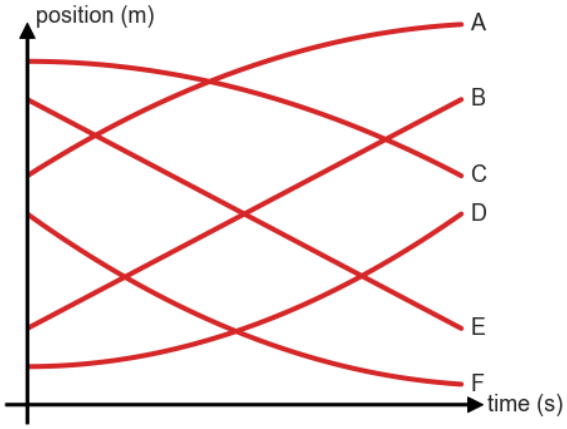


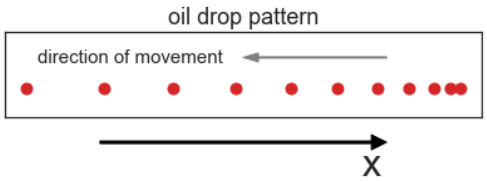



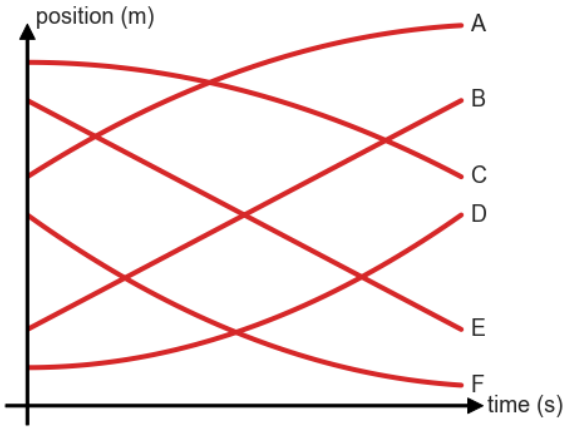

**Exercise 13**




**Exercise 14**

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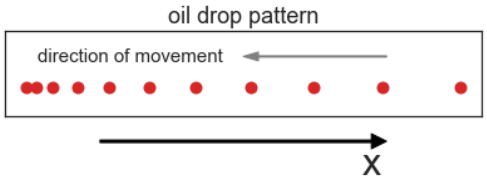
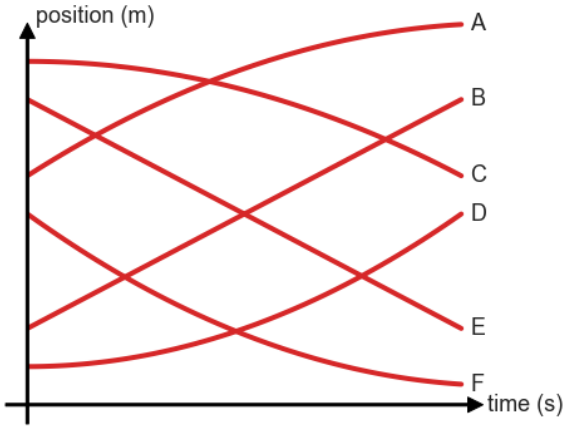
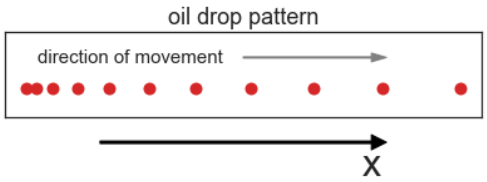
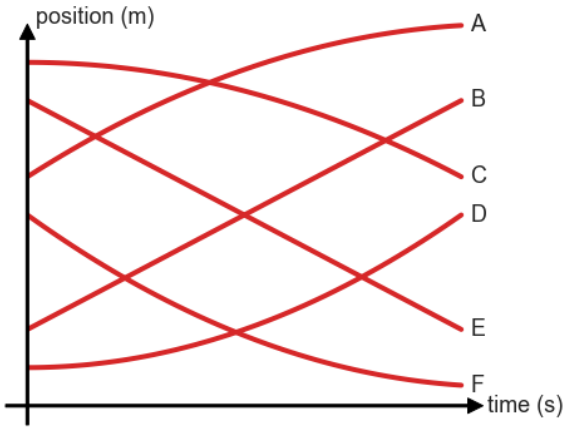


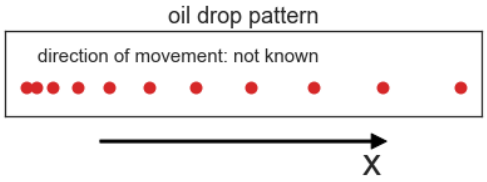



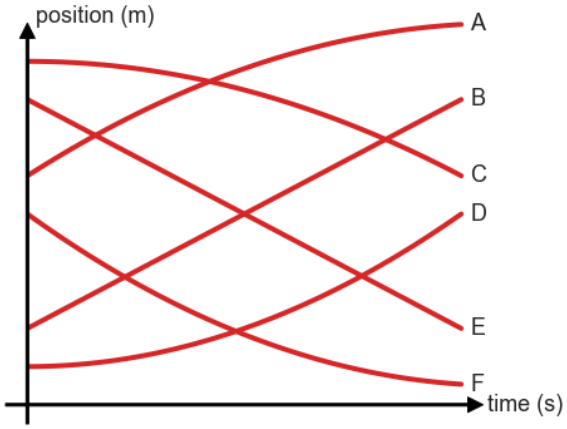

**Exercise 16**




**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)

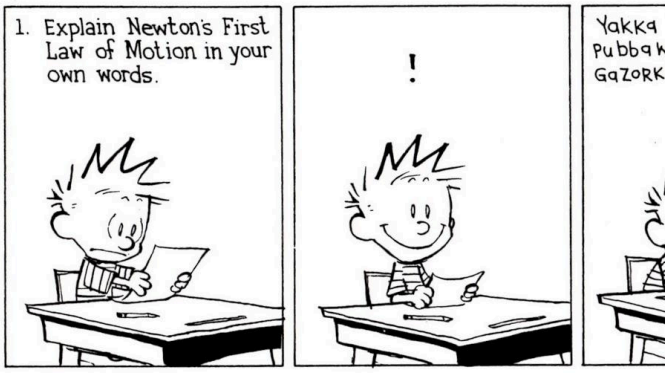
## Momentum, Lecture 3

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

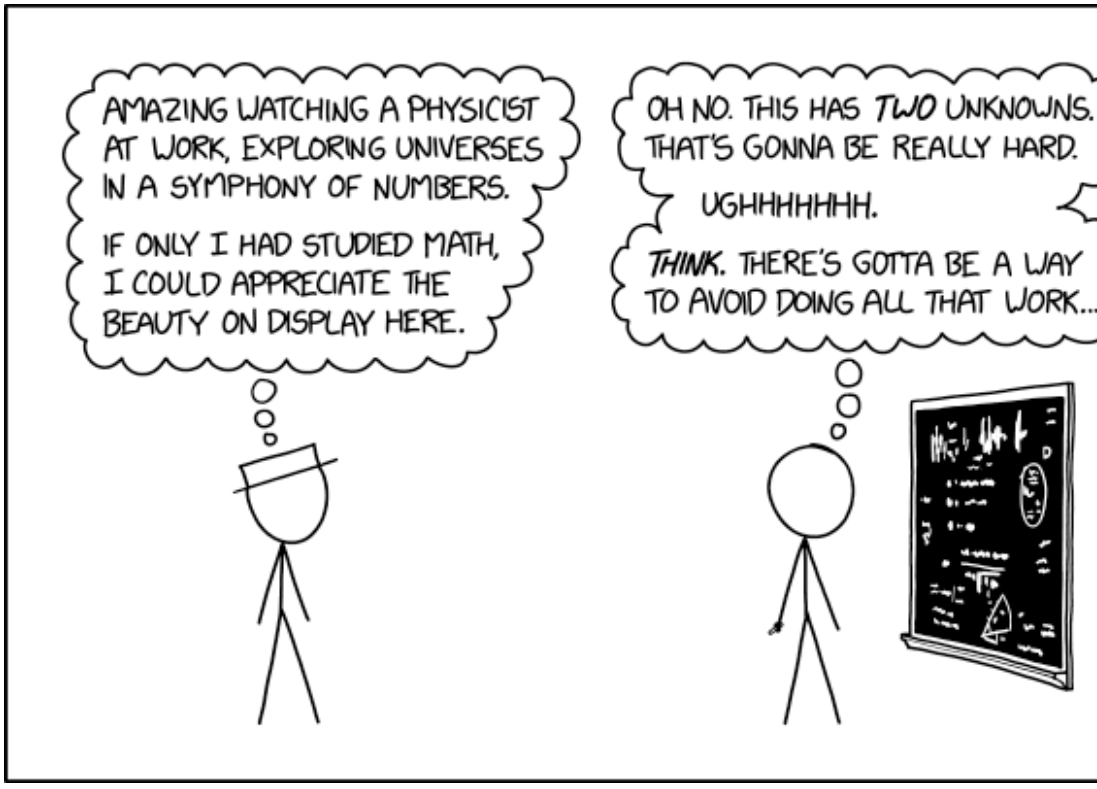
# Part II

# the good stuff

# cartoons




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




https://xkcd.com/2207/

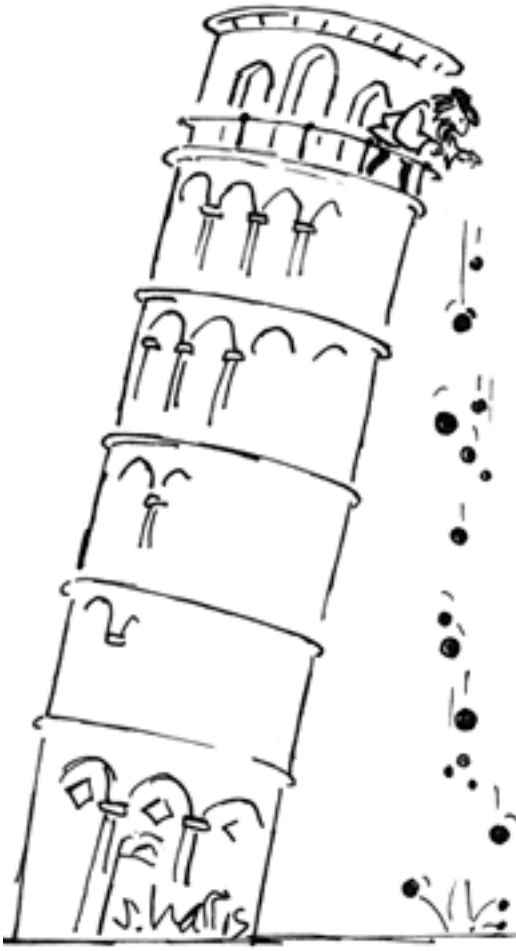

https://www.smbc-comics.com/comic/2013-06-16

# 1 PHYSIC

## 1.1 History

Aristotle said a bunch of stuff t
Galileo and Newton fixed things
stein broke everything again. Now
ly got it all worked out, except fo
stuff, hot stuff, cold stuff, fast st
dark stuff, turbulence, and the co

Science: Abridged Beyond the Point of Usefulness

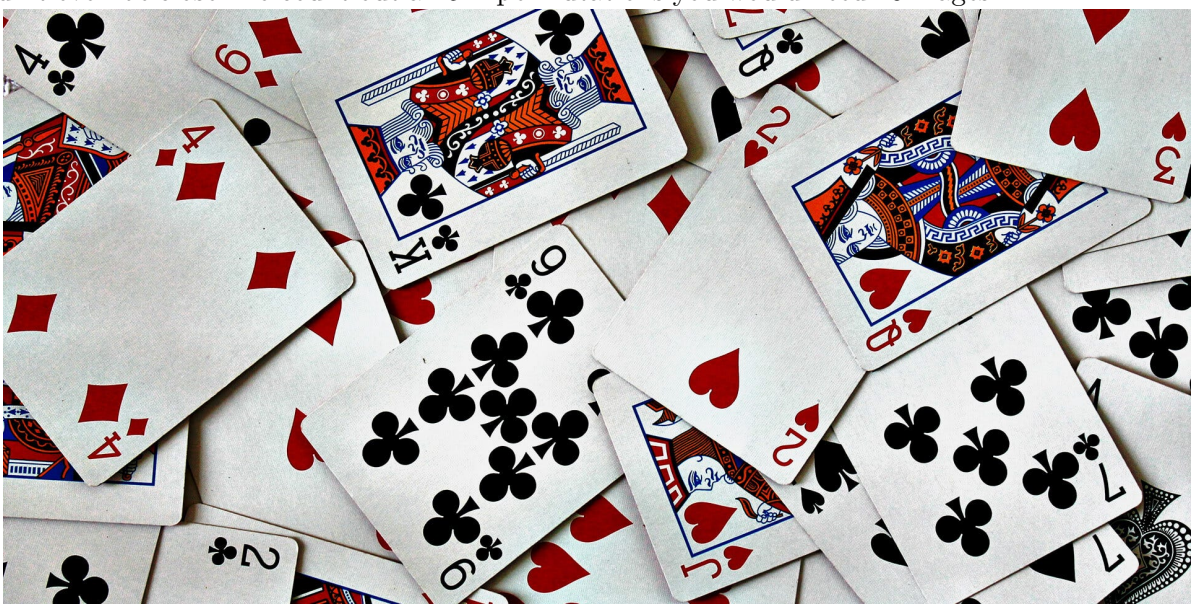



http://www.sciencecartoonsplus.com/gallery/physics/galphys2j.php#

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/xqcbyUNJWs

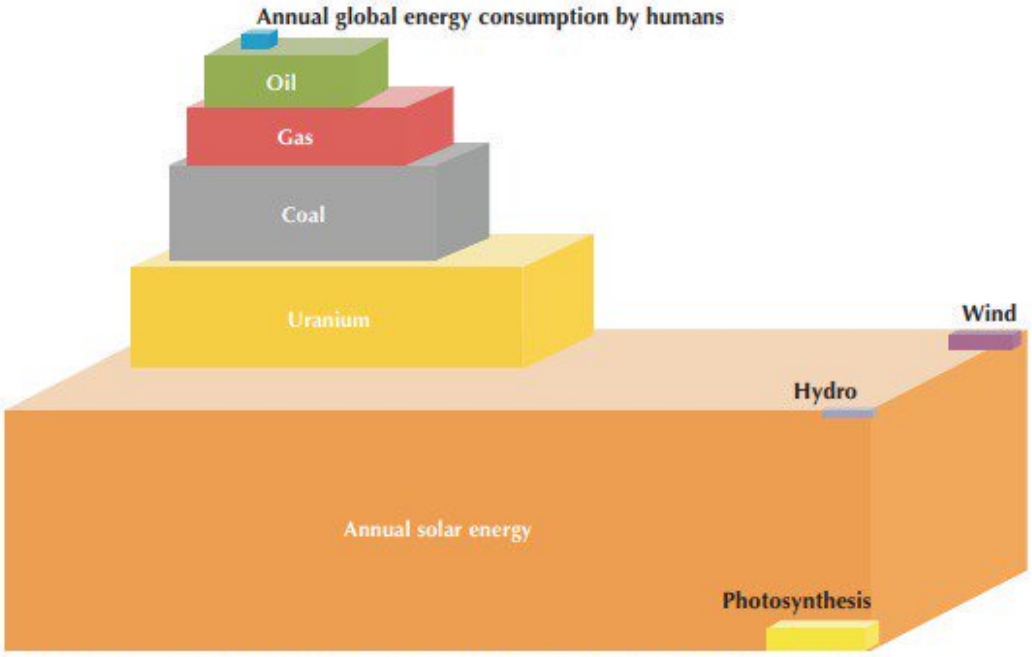
— Massimo (@Rainmaker1973) September 8, 2018

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

$$\left(b^m\right)\left(b^n\right) = b^{m+n}$$

4) Quotient Property of Exponent

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

5) Power of a Power Property of Exponent

$$\left(b^m\right)^n = b^{mn}$$

6) Power of a Product Property of Exponent

$$\left(ab\right)^m = a^m b^m$$

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

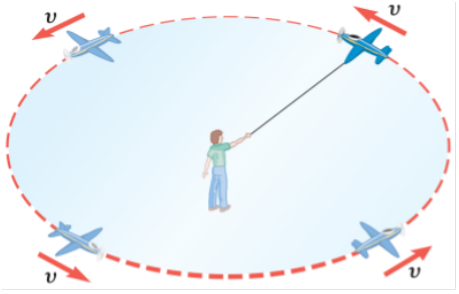
### Ball in a pie pan: Testing Experiment

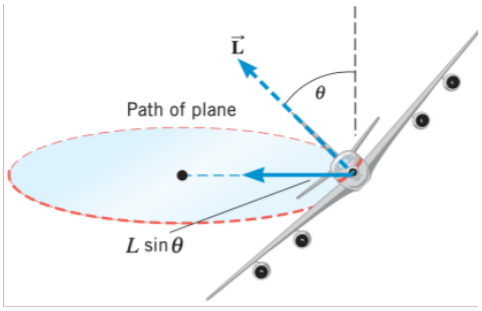
### Beer flipping

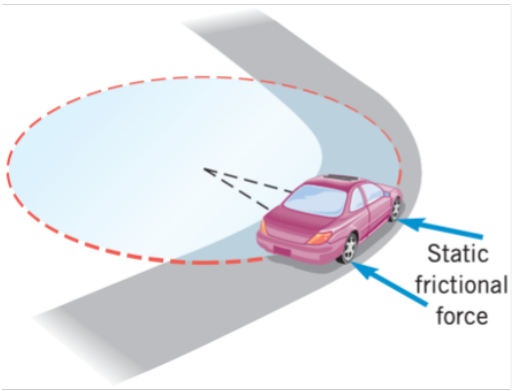
### 2001: A Space Odyssey

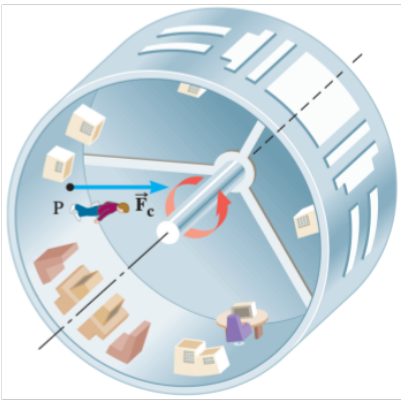
### Centripetal force

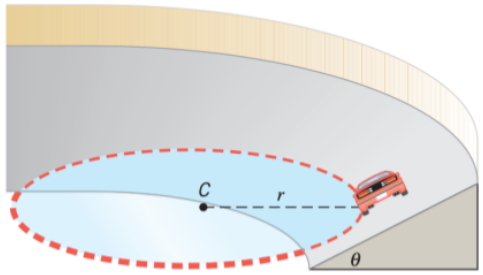
Many forces can take the role of the centripetal force.

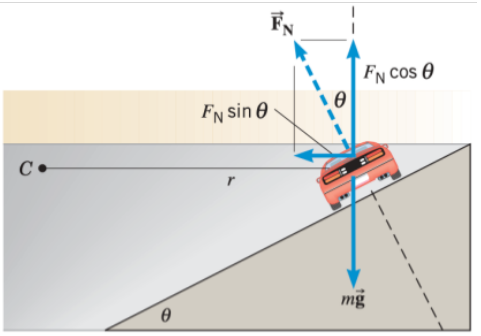

v
v
v
v

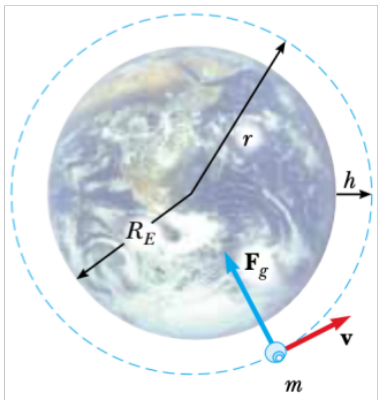

L
θ
Path of plane
L sin θ

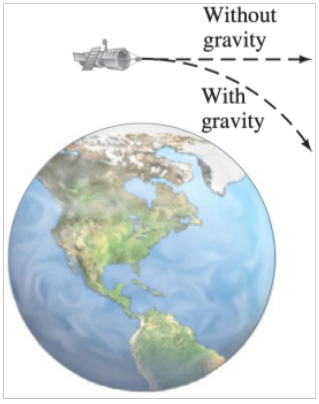

Static
frictional
force


P
F_c


C
r
θ


F_N
F_N cos θ
θ
F_N sin θ
C
r
mg
θ


r
h
R_E
F_g
v
m


Without
gravity
With
gravity

# Newton's laws

## Newton's first law

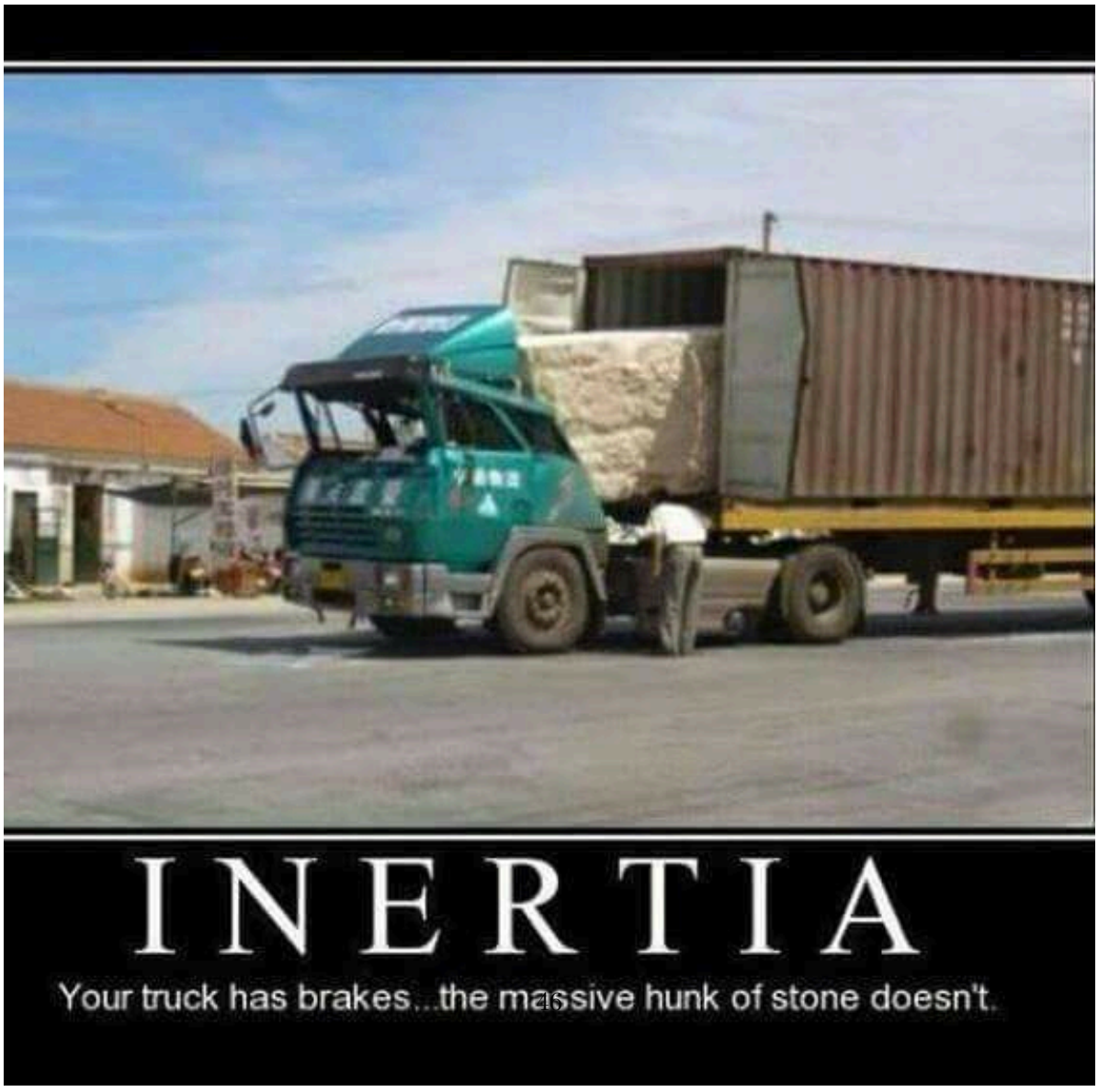
**The fall of the dinosaurs**

**Trampoline with leaves**

**At the Kibo ISS module**

**Rollerblades on a moving table**

**What is Inertia?**



## 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**

### Motorcycle kicks car

## Friction

### Static friction

### Static vs. kinetic friction

### No friction on inclined plane

### Cat fails to jump, not enough friction

### Spidergirl